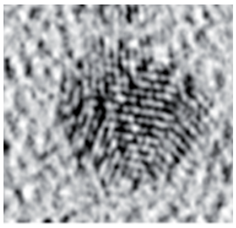
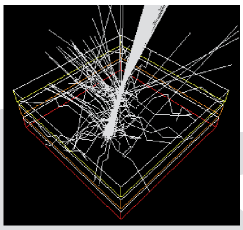
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

CISBAT

2 - 3 September 2009
International Scientific **Conference**

RENEWABLES IN A CHANGING CLIMATE
From Nano to Urban Scale


PROCEEDINGS

LESO-PB
LABORATOIRE D'ENERGIE SOLAIRE
PHYSIQUE DU BÂTIMENT

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CISBAT 2009

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Organisation :
Solar Energy and Building Physics Laboratory (LESO-PB)
Ecole Polytechnique Fédérale de Lausanne (EPFL)
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In association with
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PREFACE

Centred on research and development in solar energy applications to the built environment, the international conference CISBAT 2009 highlighted a large number of interesting technological innovations. The discoveries and developments presented by scientists from five continents are all part of the effort to mitigate greenhouse gas emissions generated by buildings.

Renewables are expected to play a very important role against the global threat of a changing climate, even more so as 2009 will hopefully see a new “Post-Kyoto” era in their favour to be initiated at the COP15 United National Climate Change Conference to be held in Copenhagen (Denmark)[1].

“Anti-crisis” programmes, which have been launched by several countries in favour of job creation within the framework of a “Green New Deal” will also contribute to sustain the solar momentum.

The organisers of the CISBAT Conference, financially supported by the Swiss Federal Office of Energy (SFOE), therefore had no problem convincing their academic partners - Cambridge University (CU) and the Massachusetts Institute of Technology (MIT) - to collaborate in the organisation of this event on the EPFL campus. More than 200 participants from 30 different countries were present during the two conference days and we are confident that they will be even more numerous at the next edition, as feedback from attendees encourages the organisers to increase the size and the duration of the CISBAT conference.

Prof. Dr. Jean-Louis Scartezzini
Director of the Solar Energy and Building
Physics Laboratory
EPF Lausanne

[1] www.cop15.dk, United Nations Climate Conference, Copenhagen, Dec 7-Dec 18 2009

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KEYNOTES

PROSPECTS OF RENEWABLE ENERGY IN THE GLOBAL ENERGY SYSTEM

Summary of Keynote Presentation by D. Yogi Goswami, Ph.D., PE

Co-Director, Clean Energy Research Center
University of South Florida, Tampa, FL 33620

Global energy consumption in the last half century has rapidly increased and is expected to continue to grow over the next 50 years, however, with significant differences. The past increase was stimulated by relatively “cheap” fossil fuels and increased rates of industrialization in North America, Europe and Japan; yet while energy consumption in these countries continues to increase, additional factors make the picture for the next 50 years more complex.

These additional factors include China and India’s rapid increase in energy use as they represent about a third of the world’s population; the expected depletion of oil resources in the near future; and, the effect of human activities on global climate change. Oil production will peak in the near future and will start declining thereafter. Since oil comprises the largest share of world energy consumption, a reduction in availability of oil will cause a major disruption unless other resources can fill the gap.

Natural gas and coal production may be increased to fill the gap, with the natural gas supply increasing more rapidly than coal. However, that will hasten the time when natural gas production also peaks. Additionally, any increase in coal consumption will worsen the global climate change situation.

Presently, there is a resurgence of interest in nuclear power. However, it is doubtful that nuclear power alone will be able to fill the gap. Forecasts from the International Atomic Energy Agency show that nuclear power around the world will grow at a rate of only 0.5% to 2.2% over the next 25 years.

Based on this information it seems logical that the RE technologies of solar, wind and biomass will not only be essential but will hopefully be able to fill the gap and provide a clean and sustainable energy future. Fortunately the solar, biomass and wind technologies are finally showing signs of maturity. Wind and photovoltaic power have grown at rates of over 30% - 35% per year over the last few years. It seems that Solar Thermal Power technologies are at the verge of such rapid growth. There are many differing views on the future energy mix. However, it is becoming evident that as much as 50% of the world’s primary energy in 2050 will have to come from Renewable Energy. To achieve that level of renewable energy use by 2050 will require a worldwide commitment and an unprecedented global effort.

ADVANCED NANOSTRUCTURED COATINGS FOR SOLAR ENERGY CONVERSION: LARGE OPPORTUNITIES FOR SMALL STRUCTURES

Keynote by Dr. Andreas Schüler, Extended Abstract

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1. INTRODUCTION

Due to their fascinating optical and electronical properties, nanometer-scaled structures play an important role in solar energy conversion [1]. Nanocomposite coatings consist typically of dielectric, semiconducting or metallic nanocrystals embedded in a host matrix. In this presentation, we describe how such nanostructures can result in interesting new material properties which can be exploited in solar energy conversion. We try to give an overview on the large variety of solar energy applications of nanostructured thin films including antireflection coatings on solar collector glazing, colored coatings with high solar transmittance for novel glazing of solar thermal facades, photoluminescent quantum dot solar concentrators for photovoltaic energy conversion, nanostructured photovoltaic cells, and optical selective absorber coatings for thermal solar collectors.

2. THEORY

Effective medium theories such as the Bruggeman and the Ping Sheng theories are used to model the dielectric function of nanocomposite materials [2] (see Fig.1). In many cases, the nanometric dimensions of the film structures give rise to quantum confinement, the latter implying modifications of the electronic and optical properties of the thin films [3]. Revolutionary new types of electronic band structures have been predicted for nanostructured semiconductors which could create possibilities of novel electronic transitions in photovoltaic cell materials [4].

3. EXAMPLES FOR SOLAR ENERGY APPLICATIONS OF NANOTECHNOLOGY

Dielectric nanostructured films are used as coatings on solar collector glazing. Nanoporous silicon dioxide films exhibit a low refractive index suitable for broad band anti-reflection, and such coatings enter the market now. Novel nanocomposite quaternary Mg-F-Si-O films exhibit also a low refractive index in the desired range (see Fig.2), and might be more resistant regarding gradual pore-filling by hydrocarbons [5]. Nanocomposite Ti-Si-O films are used in novel multilayered coatings on glazing of solar thermal facade collectors [6,7] (see Fig.3). Such coatings combine a colored reflection with a high solar transmittance and open new possibilities for the architectural integration of solar collectors in building facades [8-10]. The optical performance of the multilayered interference filters is optimized by computer simulations of thin film interference [11]. Such thin film interference calculations are also used in order to design novel sun protection coatings with a better overheating protection at a comparable level of daylighting [12]. This novel glazing, developed by the research group of Prof. P. Oelhafen at the University of Basel, offers the possibility of tremendous energy savings due to the reduction of cooling needs in hot summers.

One promising application of semiconductor nanocrystal containing composite films might be planar photoluminescent concentrators for photovoltaic solar energy conversion (see Fig.4). Quantum dot containing nanocomposite thin films have been synthesized by a low cost sol-gel process and characterised by photoluminescence spectroscopy [13]. A tool for ray tracing simulations has been developed on the basis of Monte-Carlo methods that are applied to polarization-dependent reflection/transmission at the involved interfaces, photon absorption by the semiconductor nanocrystals and photoluminescent reemission [14]. Such simulations allow estimating the efficiency of the envisaged devices.

Periodic nanostructuring of semiconductors could result in revolutionary new types of electronic structures where special intermediate bands occur [4]. Such intermediate bands would give rise to additional electronic transitions boosting the efficiency of next-generation photovoltaic cells.

Embedded nanometer-sized metal clusters play an important role for selective absorber coatings for solar thermal collectors [15]. Metal doped amorphous hydrogenated silicon-carbon films (a-$Si_{1-x}C_x$:H/Me) can be deposited by a combined physical vapor deposition/plasma enhanced chemical vapor deposition process (PVD/PECVD) [16]. Multilayered solar absorber coatings have been developed on the basis of this promising material. The PVD/PECVD process has been upscaled successfully from the laboratory to industrial production [1]. The highly durable coatings are extremely stable at elevated temperatures in air [17], and service lifetimes above 25 years are expected.

Recently, a CTI (Swiss Innovation Promotion Agency) project on the development of a low cost sol gel process for the deposition of nanocomposite selective solar absorber coatings has started. Our industrial partner, ENERGIE SOLAIRE SA, still uses the traditional electroplating process for the production of selective solar absorber coatings. The process is based on highly toxic Cr(VI) compounds, and is accused to heavily pollute the environment. We propose a novel low-cost sol-gel process which will be pollution-free. The novel coatings shall be more corrosion resistant, and exhibit superior aging stability at elevated temperatures.

4. Outlook and Conclusions

Nanotechnology is a rapidly evolving field, and a large research community is working on novel nanostructures and their applications. We believe that future progress will have considerable impact on the field of solar energy conversion. Future work within our group will include among other topics novel inorganic thermochromic coatings for overheating protection of solar thermal systems (new SFOE project). Such smart absorber coatings shall prevent the solar collector and the solar system from the extreme temperatures occurring during stagnation in hot summer periods.

At EPFL's Solar Energy Laboratory LESO, a new laboratory for plasma-assisted deposition of nanocomposite solar coatings, thin film analysis and optical characterization shall be installed in fall 2009. The novel experimental infrastructure will help us to set up a competence center for cutting-edge research in nanostructured solar coatings. Our group will support the upscaling and commercialization of the novel coatings being developed in our laboratory, and will accompany actively the development of the building integration of the new solar systems.

Figures

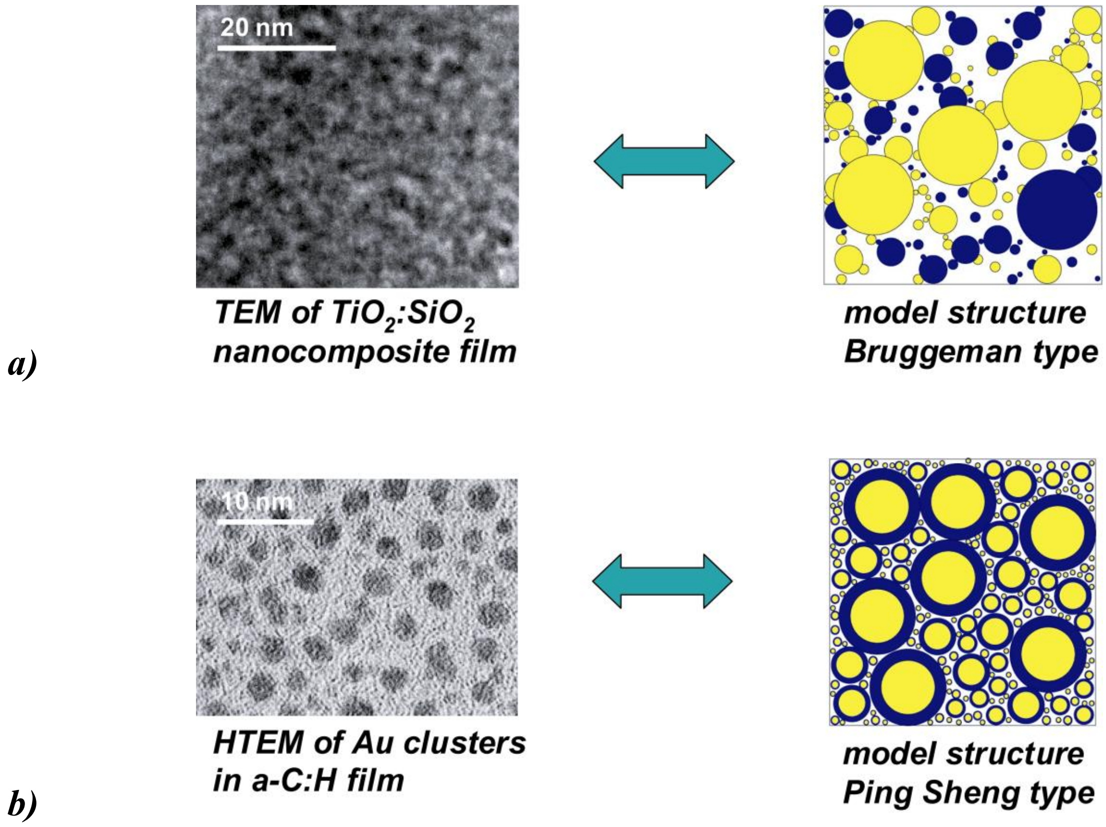


Fig.1: Transmission electron microscopy of nanostructured coatings and model structures used in effective medium theories.
a) For TiO_2:SiO_2 nanocomposites (coatings on solar façade glazing), a Bruggeman model can be used for the prediction of the optical properties.
b) For metal cluster containing a-C:H films (selective absorber coatings for thermal solar collectors) the effects of the internal interfaces become important. Here, a coated sphere model has to be used for the calculus of the optical properties.

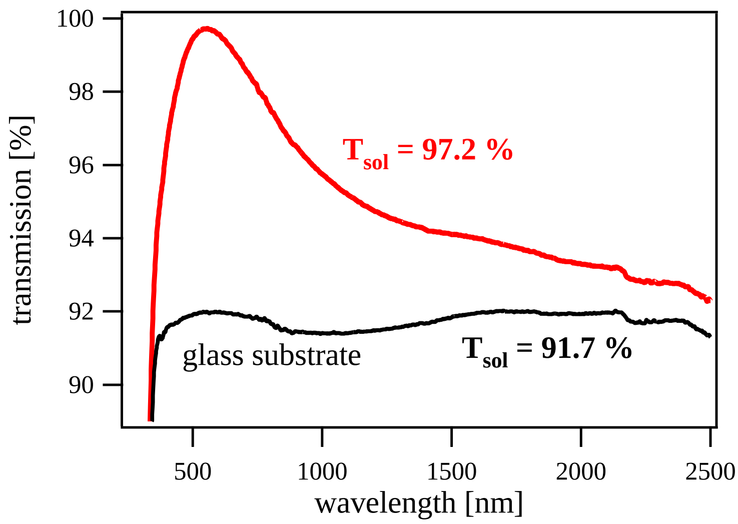


Fig.2: Broad band antireflection of solar collector glazing by novel quaternary Mg-F-Si-O coatings developed at LESO-PB. The solar transmittance can be raised from 91.7% for the uncoated white solar glass to 97.2% for the coated glass. In order to achieve antireflection in the full solar range (UV-VIS-NIR), a low refractive index around 1.22 is necessary. This has been achieved previously only by nanoporous SiO_2 films, and such coatings are entering the market now. The novel Mg-F-Si-O films might be more resistant towards gradual pore filling by hydrocarbons.

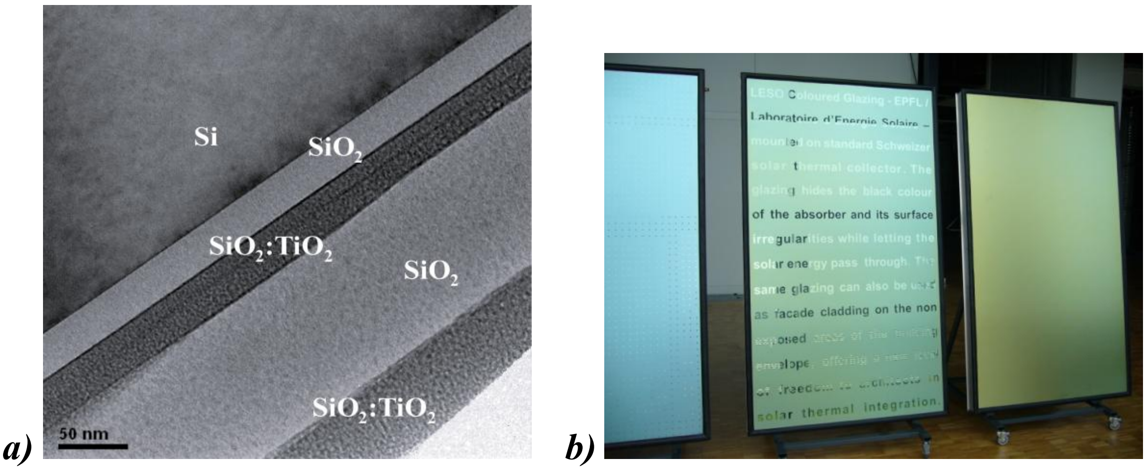
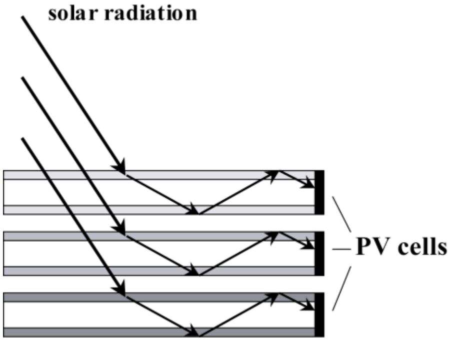


Fig.3: Coatings for colored solar thermal facades, developed at LESO-PB. The energy losses due to the coloration can be kept below 5%.
a) Transmission electron microscopy of the multilayered coating comprising granular nanocomposite and homogenous SiO_2 layers.
b) Novel facade collectors in different color shades, exposed at LESO-PB.



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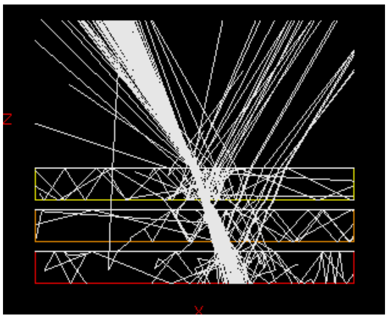

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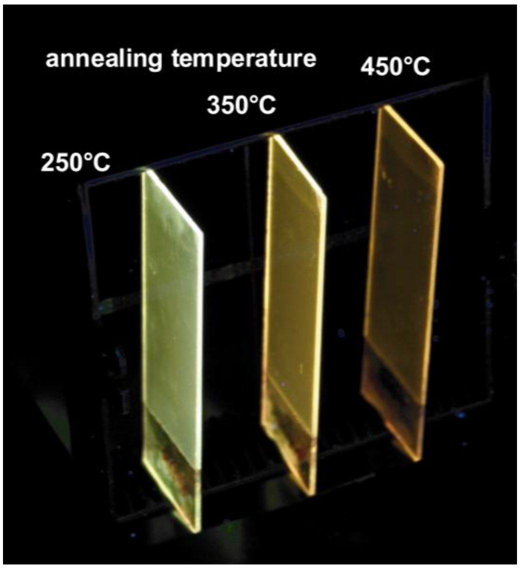

c)

Fig.4: Quantum dot containing nanocomposite coatings used in photoluminescent planar solar concentrators for photovoltaics.
a) Sketch of the principle of photoluminescent solar concentrators. The incoming solar radiation is absorbed by the fluorescent material in the coatings. A large part of the emitted radiation is captured by total internal reflection and concentrated within the coated panes. At the edges only a small area of photovoltaic cells is needed in order to convert the radiation into electricity. The PV cells are spectrally matched to the emission wavelengths.
b) Monte Carlo ray tracing simulation performed with LESO's computer code PHOTONSIM. The program takes into account the fluorescent properties of the used quantum dots, and polarisation dependent reflection and transmission at the interfaces.
c) Fluorescent quantum dot containing coatings, produced at LESO using a sol-gel dip-coating process. The main advantage is that large areas might be coated at very low cost. The inorganic nanocomposite coatings are expected to be highly durable.

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CLIMATE CHANGE – FACTS AND CHALLENGES

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ProClim- Forum for Climate and Global Change
Swiss Academy of Sciences

The recent IPCC report 2007 is very clear in its statement that human activities and especially the emissions from burning fossil fuel are the major cause of the observed climate change [1]. While the climate change projections are much improved and now allow an assessment of uncertainties and of regional patterns, the overall picture published in the IPCC reports 1995 and 2001 still hold. New observations not yet included in the new IPCC 2007 report on the other hand show accelerated emissions and climate change indicators. In addition the vulnerability of the ecosystems and of our society to climate change is higher than assumed especially when global average temperatures rise above 2ºC. Many countries have thus adopted a 2ºC stabilization target. The combined reduction plans of these countries, however, fall way short of fulfilling this stabilization target, even if all promises were fulfilled.

Carbon-based fuels account for more than 80% of energy supplies worldwide. Because of the long life of CO_2 in the atmosphere it is the most critical of the main greenhouse gases and need special attention. Within the last 50 years the global temperature has risen by 0.6ºC. To stop human induced climate change would require the greenhouse gas emissions to drop well below 10 G tons of CO_2 per year or about one ton of CO_2 per person per year assuming a population of 8 - 9 billion people by 2050 (Figure 1)[2]. One ton of CO2 amounts to about 400 liters of burned oil per person per year including production and transport. It means essentially a carbon emission free world. The faster we reach this target, the less CO_2 is accumulated in the atmosphere and the lower will be the stabilization temperature.

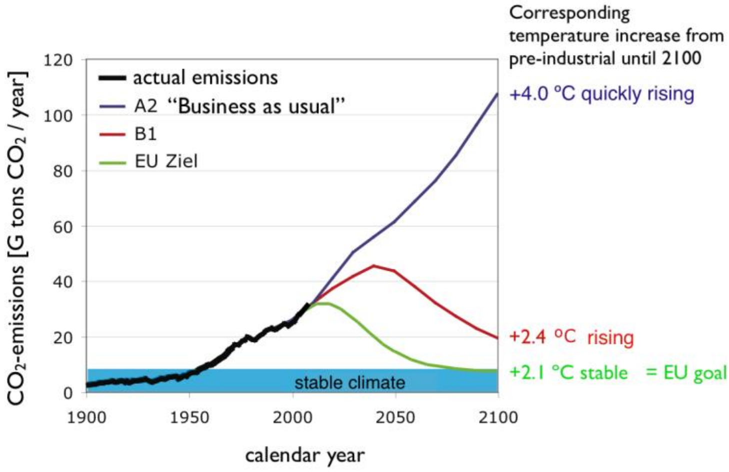

Figure 1:
Actual emissions (solid line) increase faster than assumed in the IPCC business as usual scenario, mainly due to the lower energy efficiency in the developing countries. To stabilize the climate requires the global emissions to fall well below 10 G tons of CO_2 . The more carbon we emit into the atmosphere until we reach this goal, the higher will be the corresponding temperature and climate change. [2]

These per capita emissions are very unevenly distributed in the world (Figure 2). The inland emissions of Switzerland today amount to 6 t CO_2 per person per year with nearly the same amount of 'grey' emissions caused by imported goods from other countries. The USA emits about 18 t and China already over 3 t of CO_2 per person per year with fast rising trend. The longer we wait until we reach the one ton goal the higher will be the accumulated CO_2 in the atmosphere and thus the climatic change. For Switzerland to reach the 1 ton of CO_2 target by 2100 would require an annual reduction of the emissions by at least 2%.

To stabilize the temperature at 2°C with respect to pre-industrial levels would require the world emissions to fall to half of today's level within the next 30 years despite the fast economic growth especially in China and India. In great contrast to the 2°C goal the recent observations indicate that the greenhouse gas emissions are changing faster than assumed even in the most pessimistic IPCC scenarios [3].

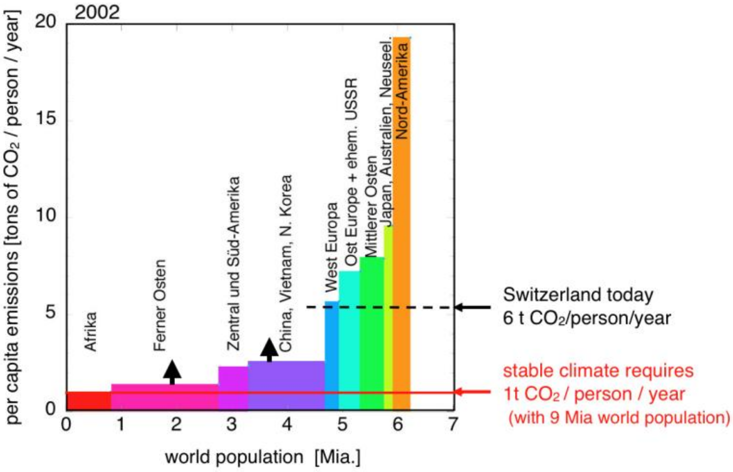

Figure 2:
Per capita emissions are very different depending on the continent we look at. With a population approaching 9 Mia persons by 2050 the emissions must fall below about 1 ton of CO_2 per person per year to reach a stable climate. [2]

The rapidly growing emissions and the observed warming have impacts which exceed the anticipated change, as is shown by newly available high precision observations: The sea level rise since 1990 (Figure 3) is substantially faster than the IPCC business as usual projections. The loss of ice mass of Greenland has accelerated by a factor of five between 2003 and 2008 and contributes about .5 mm per year to the sea level rise. In addition the extent of the arctic sea ice in September has declined faster than anticipated by the models. As a consequence the arctic see may be ice free in the fall already within one to three decades. The loss of sea ice may also influence the atmospheric circulation patterns.

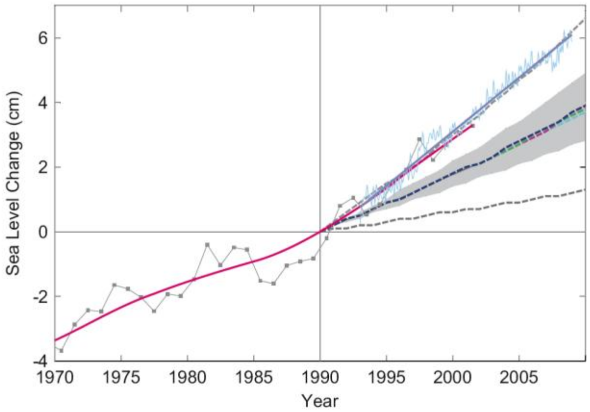

Figure 3:
The observed change of the sea level between 1970 and 2008 (solid line) is much faster than the IPCC 2007 projections (dashed lines represent a business as usual and a low emission scenario respectively). The shaded area indicates the uncertainity of the projections for one scenario. [3]

Recent studies indicate that not only climate change is faster than anticipated in the worst case business as usual scenario but also that societies and ecosystems are more sensitive to climate change than previously recognized. Figure 4 illustrates qualitatively the risk for different threats with increasing temperature. The figure shows that the threats become critical (red) at lower temperature change (say 2ºC) today than estimated in the IPCC report 2001. The poorest countries and societies will be most vulnerable because of their much weaker adaptive capacities.

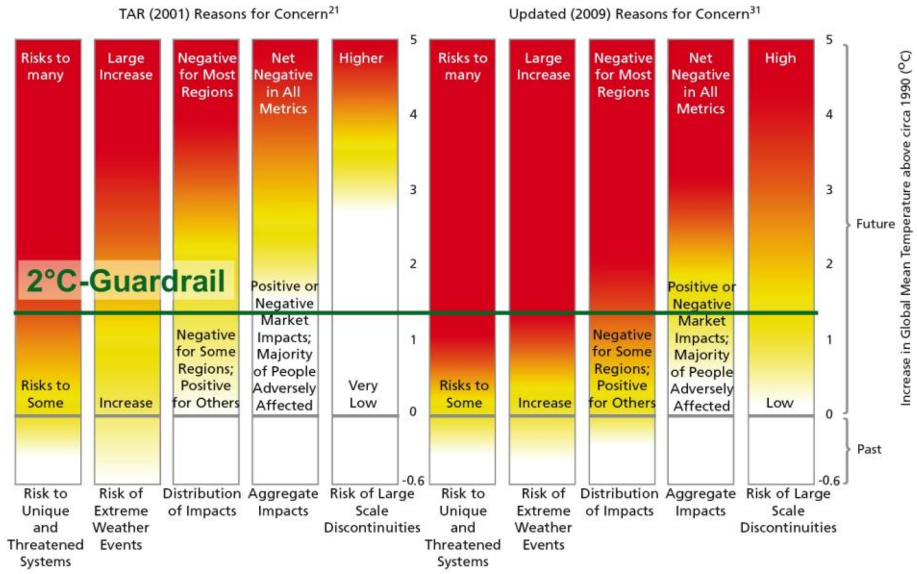

Figure 4: The impact of climate change and thus the reasons for concern are considered higher today as valued by the expert in 2001 in the IPCC Third Assessment Report TAR. Increasing risks are symbolized by the red color for different threats. [4]

With the present knowledge about the climate system, the focus of research shifts from the detection and attribution of climate change towards measures to cope with the unavoidable climate change and to means to slow down future change. To successfully meet these challenges will require radical innovations and new corporate solutions: improving the efficiency of energy conversion; reducing energy demand through improved and alternative processes; increasing recycling and improving efficiency in the use of energy-intensive materials; replacing materials and substances with less energy-intensive alternatives. Many options to reduce greenhouse gas emissions are relatively cheap or come even at cost savings, as has been compiled by McKinsey [5] for the world (Figure 5) and more specifically for many countries. Many of the proposed mitigation options require an investment up front, however. The new emphasis will thus also rely on societal transformation to reduce the inertia of societies and of the economic system to change.

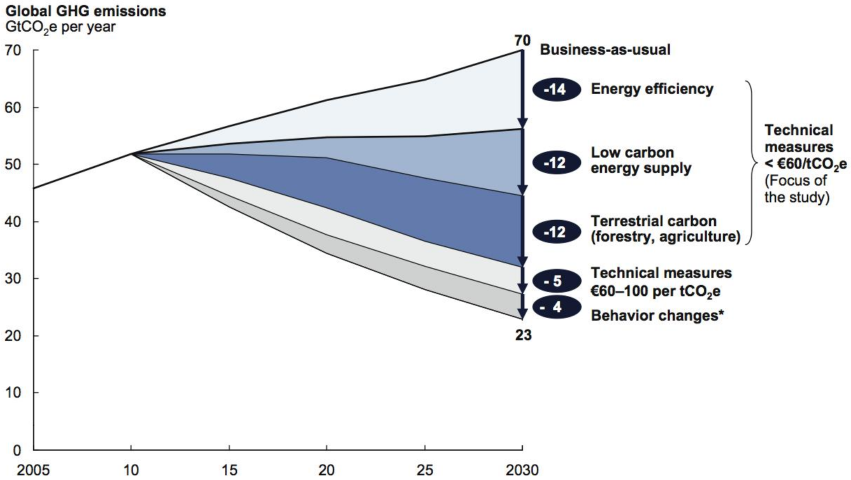

Figure 5: With costs of less than 60€ per ton of $CO_{2\,eq}$ more than half of the worldwide greenhouse gas emissions (38 Gt of 70 Gt $CO_{2\,eq}$) may be reduced through technical measures by 2030 [5]. The oil price is assumed to be 60$/barrel. The contribution of behavior changes is small because many are already included in the above mentioned measures.

The energy and climate issues will demonstrate to what extent our social system based on a free-market economy is capable of correcting self-induced aberrations in resource use by changing the background conditions. Given the global nature of the problem actions must be quickly implemented on a global, regional and local level. Furthermore the changes cannot be limited to climate alone but must encompass a more sustainable use of all resources.

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RENEWABLES AND THE FUTURE OF SUSTAINABLE URBAN DEVELOPMENT

Keynote by Professor David Fisk

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SUMMARY

The challenges of the 21st century will be solved in an urban context for most of the world. Focussing on just one, man-made climate change, shows that the sustainable city of the future will look substantially different from its 20th century counter-part. Many of the new solutions will be deploying renewable energy and passive design. However it is important not to miss interactions with other urban development constraints because cities seem likely to be much more integrated in how they use energy in future. Some possible changes like the electrification of transport actually reinforce the renewable energy case. Others like resilience suggest there is much research to do down stream to ensure the integration is seamless. Forty years is a feasible time to realise a decarbonised city but only just.

INTRODUCTION

The world's great cities have demonstrated by their longevity, their ability to develop sustainably with time. The 21st century is often presented as one of immense challenges to the human race (Rees 2004). It will also be the century in which most of the world will be urbanized. Consequently, those challenges will be faced by largely urban populations in an urban context. Up until the late 18th century the great cities of the world ran on renewable energy. Indeed Adam Smith might be marked as the last solar powered economist. The function of the city in the preceding centuries had continually changed. At various times cities were places of refuge, a place for consumption, a place for exchange and at times for production. Cities are clearly able to manage change. Resource shortages often presented themselves but were most frequently solved by developments in transport technology, exporting problems and importing solutions. It was transport technology that opened the way to burn coal in cities and so commenced two centuries of non-renewable lifestyle.

Almost immediately it became apparent that while there was no shortage of coal there was a severe shortage of environmental absorptive capacity. The 19th century urban environment was characterised by very high levels of air and water pollution. That problem was tackled by moving industry away from urban centres and building taller stacks, but then oil and gas arrived introducing new pollutants. New power and heat distribution systems enabled the sky scrapper skyline just as much as the structural engineer. But an even more profound effect was wrought by transportation. Cities are in some ways time machines, juggling distance and speeds to facilitate collective arrivals and departures within social norms. Faster travel does not save time so much as increase distance travelled (Metz 2008) and facilitates economies of scale through agglomeration (Graham 2007). Unfortunately this has meant that cities have spread in a way that makes them critically dependent on transport fuels. While oil looks as if it were just another expensive fuel in a national portfolio of primary energy, it is the strategic lifeblood of the modern city. That critical dependence is now replicated throughout the capital cities of the world.

SUSTAINABLE CITIES AND CLIMATE CHANGE

The idea of a 'sustainable city' has emerged during the 1990's as recognition that the pattern of development reached by the end of the 20th century is not well suited to the challenges ahead. A short paper can hardly cover such a wide economic, social and environmental agenda even if limited to issues bearing on the use of renewable energy. But one challenge, man made climate change serves to make many of the points. In July the G8 agreed the aim of an 80% reduction in greenhouse gas emissions by 2050. Allowing for the first calls on the remaining 20% of emissions, that means, to all intents and purposes, that no fossil fuels will be delivered in cities by the middle of this century. This is of course challenging. But we need to bear in mind that many of the other challenges, such as energy security, that need to be mastered over the same period often have shared solutions.

THE ALL ELECTRIC CITY?

An engineer's first reaction might be to follow the model of the mid-20th century and move primary fuel handling outside the boundary of the city altogether. One might imagine large nuclear – presumably with a fuel cycle better suited to civilian use – and fossil fuelled power stations with carbon capture and storage feeding electricity into cities from afar via high voltage lines, with cities reassuringly carrying on as before. While that is a technically feasible solution, and possibly an economic solution for 24/7/52 industrial base loads, it is otherwise very expensive indeed. While both technologies can in principle load follow they are very costly to do so, with for example shortened life of expensive plant from thermal stresses. So the first real area of contention is the diurnal and inter-seasonal variation in energy demand.

If we are to understand the competition for non-base load and especially the competition for low-grade energy uses like space heating then it may be time to be semantic. For most of the twentieth century it was common to make a distinction between fuel and power. Fuel was stored energy, and power, which meant principally electricity, was energy 'on the lose'. The fashion after the first Oil Crisis to merge fuel and power into energy has generally been unhelpful for a clear public discourse (Patterson 2007). For example whereas it was once normal to associate photovoltaic technology with electrical storage it has become more common to talk of 'selling back to the grid' as if amateur gardeners were selling cabbages at a public market. The original purpose of the electricity network was to connect the efficiency of the power generator directly to the local electric motor. The synchronous grid had an elegance and stability that is not shared with a network trying to supply and sell over the same copper.

Using electricity transmission network to collect energy from disparate local sources is not an ideal role for electricity. Proponents of a hydrogen economy are quick to argue that hydrogen as an energy vector is a fuel and not power and so is much better for this task. Indeed they would probably question whether all of the out of town base load generation need be devoted to electricity. Electricity could be left to hydrogen fuel cells at the final point of use. This is an attractive idea, especially to providers of energy from precocious renewable resources (Bossel 2006, Press el al 2009). But cities when innovating often make use of the systems they already have so hydrogen may be a fall back if local electricity distribution technology fails to deliver. Innovation theory would suggest that we would look for the first signs of a hydrogen energy vector in industry (Fisk 2009) but there are no signs as yet.

STORAGE

If we are to stay with the all-electric scenario then the sustainable city is certainly looking for electricity storage. If it is looking for storage, which is always expensive, and at current technologies it is about as expensive to store as to generate (Poonpun et al 2008), then it is probably deploying in parallel much more sophisticated tariffs then are widely used in Europe at the moment to negotiate with the consumer when to take power. For example refrigeration loads, whether industrial or domestic, offer storage options that are unexplored by adjusting refrigeration timing. While pumping fresh water is often the largest single electricity customer in a city, water companies often pay a simple commercial tariff despite significant opportunities to manage load. Information technology which has played a large part in improving 20th century transmission could play a similar role with final consumers, especially commercial consumers whose loads are already computer controlled. But the greatest unexplored area is the deployment of electric vehicles.

ELECTRIC VEHICLES

Electric vehicles whether powered by batteries or fuel cells (which the thermodynamics expert will spot are different versions of the same thing) in part address the energy security problem by diversifying energy sources. In the all-electric scenario they offer a substantial energy storage capability. This it should be emphasised is 'potential' rather than real. We need to bear in mind that the rate of energy transfer to the petrol tank using the nozzle at a conventional petrol pump is around 10MW, rather more than the power rating of a high speed express train. Trickle charging is the norm for good battery life and so while trips to the filling station are avoided charging times need to be managed. In defence private motor vehicles have very low load factors (King 2007).

But electric vehicles have more to offer than just the smoothing of renewable energy sources over the day. While natural ventilation has much to commend it, mechanical ventilation is capturing market share across the developed world because of the intrusiveness of traffic noise when windows are open. Much of this low speed noise is associated with engine transmission in the stop start conditions of urban traffic. Electric vehicle traffic is typically 10 – 20 dB quieter and would mean that most roads would be comfortably below 50dB. Indeed this synergy has been exploited by Arup's in their exploratory studies of the Dongtan 'eco-city' outside of Shanghai (Head 2008). There natural ventilation was reinstated by reducing traffic noise by using electric vehicles, powered in this case by bio-fuels derived from local agricultural waste.

The synergies between passive design and electric vehicles go further. Urban planners have only coarse policy instruments to apply to deliver sustainable cities. Density is one control that is frequently applied in zoning rulings. Data collected from real cities (Newman et al 1999) has suggested that low density cities are energy intensive. The complicating factor is that high density cities are frequently very poor and low density cities relatively rich so the results have often been contested. The difficulty for renewable energy is that high density cities offer fewer if any opportunities for passive solar technologies because of building shading. Thermal and photovoltaic solar opportunities remain fixed while the demand increases with density. There is clearly something wrong here because pioneering 'zero-carbon' residential and commercial buildings are frequently stand alone. An application of life cycle optimisation to both low and high density cities layouts reveals the problem. It is possible to find zero-carbon solutions for the stationary demand of both low and medium density city layouts but the technologies switch (Shah 2009). In essence a city has a carbon footprint and it is a matter of choice of technology whether it clusters in the centre of the footprint or spreads itself over it. The real distinction is transport consumption which increases roughly as the inverse square root of density as one would expect on scaling grounds. So it is that transport militates against the lower densities favourable to many passive solar technologies. Here again the electric car (may be hydrogen fuel cell) comes to the rescue by taking most of transport emissions out of the equation if not out of the wallet.

OPTIMISED RESILIENCE

Lower density cities have the opportunity for local resilience using many of the techniques developed for renewable energy and buildings. Higher density cities need to exploit the opportunities of proximity. Until recently services were provided to buildings individually optimised but without any cross-optimisation. Bio-mimicry alone might suggest that cities could do better. Indeed an exergy analysis of the London Energy data (Demartial 2009) hints at the low exergy efficiency of around 10%. Heat recovery technology plays a significant part in improving this figure. The heat pump thus can paly a role in both low density and higher density solutions. It is probably a matter of taste whether this is treated as ‘heat recovery’ or exploiting ‘ambient energy’. So for example many cities are likely to employ desalination plants to handle predicted water shortages. Desalination is an energy intensive process but provides opportunities to exploit the considerable exergy traditionally thrown away. Similarly energy security considerations suggest that many cities will be importing liquefied natural gas (presumably ending up in CCS applications!). But apart from the intrinsic calorific value of the fuel liquefied gas offers substantial exergy that is traditionally lost rather than converted to power. Water pumping spends energy forcing water through pressure reducing valves that could have been replaced by micro-turbines. This kind of energy integration is already common in process engineering where it reaped very large savings in the 1970’s and seems likely to be common in cities of the future with one caveat.

Cities, like natural systems, place a high premium on resilience. Road networks and metro-networks have resilience as an emergent property (e.g. Angeloudis 2006). This is why many buildings like hospitals have standby capacity and why the grid networks carry substantial spinning reserves. Here the modest rise, passively ventilated, naturally lit building has extraordinary advantages. The reason why downtown Lagos does not have the high rise buildings characteristic of many oil rich states is that its electricity supply is so reliable. But the reliability of 20th century building services has led to a dangerous downgrading of the this dimension of passive operation. The challenge for the distributed generation networks implied by many renewable technologies is not just load balancing but dynamic stability. Issues are not improved by the characteristics of information technology loads which can easily present 10% of the electricity consumption. Renewable energy is often a by-word for energy security

‘POWERED BY BIOFUELS’

This paper has been rather coy about the role of biofuels in a sustainable city meeting the 80% reduction. As observed earlier cities were once totally biofuel dependent. In those times biofuels were locally produced and prices largely reflected the physical realities. The transportation of coal became economic because prices began to signal biofuel (i.e. wood) scarcity. Now with globalisation of food production and widespread farm subsidies the situation for any particular biofuel is far more complex (Royal Society 2008). Second generation biofuels would certainly be on the market by 2020 but as part of a global market (JRC 2008). Lack of success so far in containing illegal logging, itself a significant emitter of greenhouse gas, is not encouraging that sourcing and supply in any quantity will be trouble free. Nor would it seem wise to destroy biodiversity in order to reduce greenhouse gases when part of the reason for the reduction was to preserve it! Biofuels then have some question marks for city energy use in the way that safe handling of nuclear waste and secure carbon sequestration leave areas to be informed by more research.

Assuming that human ingenuity wins again then ‘sustainable biofuels’ can be pasted into much of the picture drawn in this paper. Bio-methane could for example be used in natural gas grids that would have gone to waste in the all-electric future. Sustainable bio-fuels make a strong case at least as a transition stage in weaning urban settlements off of oil and natural gas. In scenarios in which the world brings greenhouse gases to a tolerable equilibrium biofuel technology is easily envisaged as an equilibrium solution, assuming that land take for food has similarly stabilised around 2050. Interestingly, if the world overshoots then burning as opposed to growing biofuels still presents an issue, as indeed would the burning of urban waste. Heat from renewables is not necessarily carbon free! If the cost of emissions is taken as around the \$100/tC implied by carbon sequestration (Gibbins et al 2004) then biofuels incur that penalty against solar, wind and tidal power.

CONCLUSIONS

The least probable urban future is business as usual. All the world’s problems are going to be solved in cities and many of those solutions will be deploying renewable energy and passive design. Climate change will be one amongst many. However it is important not to miss interactions with other urban development constraints. Some like the electrification of transport actually reinforce the renewable energy case. Others like resilience suggest there is much research to do down stream to ensure the integration is seamless. Forty years is a feasible time to realise a decarbonised city but only just.

ACKNOWLEDGEMENTS

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Nanostructured materials
for solar energy conversion

OPTICAL SELECTIVE COATING FOR SOLAR ABSORBERS

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ABSTRACT

Solar thermal energy is generally accepted as very energy efficient in providing space heating and cooling, desalination of sea water or solar thermal electricity generation. For all these applications, one of the key elements is the optical selective coating for solar absorbers.

The process that we developed to produce such multilayered coating for solar thermal absorbers is sol-gel dip-coating; this chrome-free and low-cost process works at atmospheric pressure and temperature. The optical properties of the thin films have been characterized by spectrophotometry and ellipsometry.

Coatings deposited on stainless steel substrate exhibit more than 94% of solar absorptance and 11% of thermal emittance at 100°C. These results are particularly interesting since the samples show a very promising durability.

INTRODUCTION

Solar thermal energy conversion is accepted as very energy efficient in providing space heating, domestic hot water generation, industrial process heating, or desalination of sea water. One key element of all these applications is the optical selective coating on the solar absorber, which should absorb a maximum of the incoming solar radiation (black body) but avoid energy loses by infrared radiation (infrared mirror). Today, standard selective coatings absorb more than 95% of the incoming energy and have a thermal emittance of only 5%. Two main types of solar absorbers are available on the market, glazed and unglazed solar absorbers. Figure 1 illustrates the scheme of the radiative transfer for each type.

Selective thermal absorber coatings available commercially today are either produced by traditional electrodeposition of black chrome [1-2], as selective paint [3], or by vacuum deposition processes such as reactive evaporation or magnetron sputtering [4-6]. In the electroplating process, toxic Cr6+ ions occur, and care has to be taken to avoid environmental pollution. This product is very durable but is suffering more and more from the bad image of the production process. In vacuum deposition, processes initial investment costs related to the expensive vacuum equipment are high and can be out of reach in certain situations.

This explains the interest in developing a sol-gel process for the production of nanocomposite selective solar absorber coatings. Indeed, a sol-gel dip-coating process does not require expensive vacuum equipment and we intend to avoid completely the use of chrome. Using a sol-gel process, L.Kaluza demonstrated that it was possible to reach 86% of solar absorptance and 11% of thermal emissivity with only one individual layer [7]. By sol-gel spin-coating T.Boström obtained fascinating properties for multilayered coatings with a nitrogen annealing: solar absorptance 97% and thermal emittance 5% [8]. Recently, R.Bayón obtained results with ternary oxide that shows good solar absorptance (94%) and thermal emittance (6%) on aluminium substrate [9]. A novel low-cost sol-gel coating process for solar absorbers is developed in our institute. We propose a new tandem absorber composed of a nanocomposite absorbing material on stainless steel substrate.

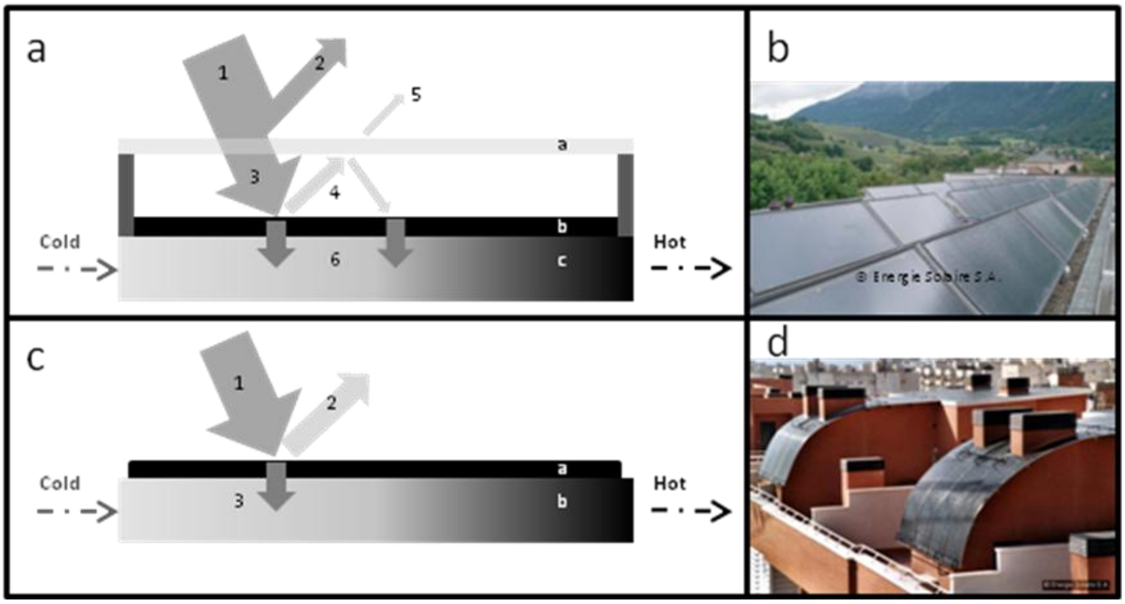

Figure 1: a) schematic diagram of radiative energy transfer in a glazed solar panel b) picture of glazed solar panels installed on the roof of a building c) schematic diagram of radiative energy transfer in an unglazed solar panel d) picture of unglazed solar roof.

Method

In order to develop complex nanostructured materials, an iterative process is followed (figure 2). After the deposition of a coating we characterise the thin film with two groups of method. Spectrophotometry, ellipsometry and durability measurements allow us to know the properties of the new layer such as spectral reflectance, refractive index, thicknesses and durability. From scanning and transmission electron microscopy (SEM and TEM), X-ray diffraction (XRD) and X-Ray photoemission spectrometry (XPS), a structural model is derived, which allows us to improve the film properties of the next iteration.

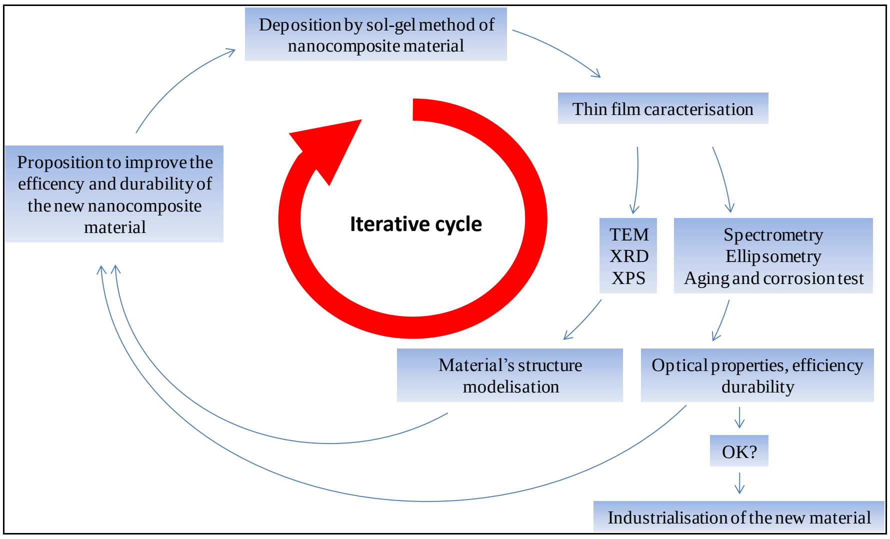

Figure 2: Iterative cycle for the development of novel nanocomposite coatings.

Samples preparation

The sol-gel coatings are deposited on stainless steel as well as on glass or silicon wafer substrates. The stainless steel that we use is specular reflecting and has 10% of thermal emittance at 100°C. For the development in the laboratory, the typical size of the substrate is 7 cm by 6 cm.

The method we use to deposit the layer is a dip-coating process. Metal alcoxides are obtained by dissolution of metallic salt in pure ethanol. A surfactant is added in order to improve the wettability (in order to protect our industrial partner, the compounds of the solutions are not described in this paper). This technique permits to deposit coatings in ambient air, at room temperature. Figure 3 illustrates the dip-coating process and the three main steps: 1-dipping of the substrate in the solution, 2-withdrawal at constant speed and formation of a liquid film at the surface, 3-evaporation of the solvent and formation of a xerogel. By means of a thermal annealing between 400°C and 500°C in air during 90 minutes, the films are hardened and oxidized. With this technique we are able to control with accuracy the thickness of the layer as a function of the withdrawal speed and the viscosity of the used solution.

Characterisation techniques

The thickness of the layers is determined by spectroscopic ellipsometry. A Sopra GESP5 ellipsometer is used to measure the ellipsometer angles Ψ and Δ between 300nm and 2000nm at various angles of reflection. The ellipsometric data are analysed by applying a point-by-point fitting algorithm elaborated by our team. This non-destructive method allows us to determine the thickness with an accuracy of ±2.5nm and the complex refractive index, n and k, of the material.

Spectrophotometry in the visible and near infrared wavelength range up to 2500nm was carried out in order to determine the optical performance of our nanostructured material on stainless steel. In the visible range, the spectral reflectance is measured by a spectrograph (Oriel MultiSpec 125^{TM} 1/8m with Instaspec II^{TM} Photodiode Array Detector with an integrating sphere). For the near infrared range an Optronic Laboratories Monochromator OL 750-M-S is associated with a NIR-sensitive PbS detector (OL 730). A LabVIEW routine has been programmed allowing the control of the various components for acquisition of the optical data. For selected samples, measurement of the spectral reflectance is controlled by an UV-VIS-NIR Cary 5 spectrophotometer equipped with an integrating sphere.

The spectrophotometric measurements allow us to measure the spectral reflectance $R(\lambda)$ and to calculate the solar absorptance α_{sol} (Equ 1) by weighting the spectral absorbance $\alpha(\lambda)=1-R(\lambda)$ with the solar energy distribution I_{sol} (reference spectrum AM1.5 global).

$$\alpha_{sol} = \frac{\int_{300}^{2500} I_{sol}(\lambda)(1-R(\lambda))d\lambda}{\int_{300}^{2500} I_{sol}(\lambda)d\lambda} \qquad (1)$$

The thermal emittance at 100°C, $\varepsilon_{th,}$ is measured by means of an emissiometer Inglas TIR100. In this method, the surface is exposed to the thermal radiation of a black hemisphere heated to 100°C. The infrared radiation is reflected by the surface of the sample and detected by a sensor (thermopile). The showed emittance is then inferred from the IR reflectance.

A simple accelerated aging test is performed by thermal annealing in air. Two kinds of layers were tested together: a highly durable selective black chrome coating and a selective black coating made by sol-gel processing in the lab.

RESULTS AND DISCUSSION

Thicknesses of the layers

The novel black selective coating is composed of a multilayer stack, where interference phenomena are important. It is thus crucial to know the thickness of the deposited layers precisely. Figure 3 shows the thickness of deposited layers in function of the withdrawal speed. We calculated the thicknesses by ellipsometric measurement of layers on silicon wafer substrate.

In the range from 3 mm/sec to 7 mm/sec the thicknesses we obtained varied between 30nm and 80nm. The data can easily be fitted by a power law with the exponent of 2/3. Our results follow the Landau-Levich equation [10].

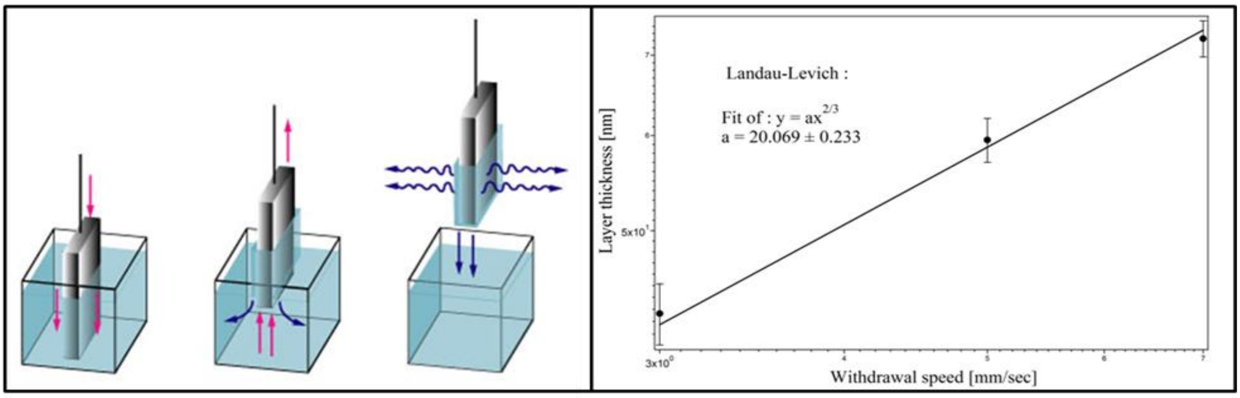

Figure 3: On the left: dip-coating process and the three main steps. On the right: measured thicknesses of the nanocomposite layer in a function of withdrawal speed. The data follow the exponential behaviour predicted by the Landau -Levich equation.

Optical performance

In order to optimize the global performance of a black selective coating for solar absorbers, we aim to maximize the solar absorptance α_{sol} and minimise the thermal emittance ε_{th}.

In a first step, the optical performance of an individual layer was optimized. As interference phenomena are important, an optimal thickness has to be found by adapting the withdrawal speed. The figure 4 shows the reflectance obtained by spectrophotometric measurement of one individual layer coating on stainless steel substrate. The associated solar absorptance leads to a value of α_{sol}=85.5% and the measured emittance to ε_{th}=11%.

In order to improve the solar absorptance, an anti-reflection layer was applied as top layer. The material we used is a quartz base material also deposited by sol-gel method. Optimisation of the thickness of this anti-reflection coating was made by simulation (Tfcalc) and led to values below 100nm. The figure 4 shows the reflectance of a double-layered coating (solid line). This top layer allows us to decrease the reflectance in the entire solar spectrum. The calculated optical properties are α_{sol}=94% and ε_{th}=11%. It is also interesting to note that, as the emittance measurement shows it, far infrared properties don't change when the anti-reflecting layer is added.

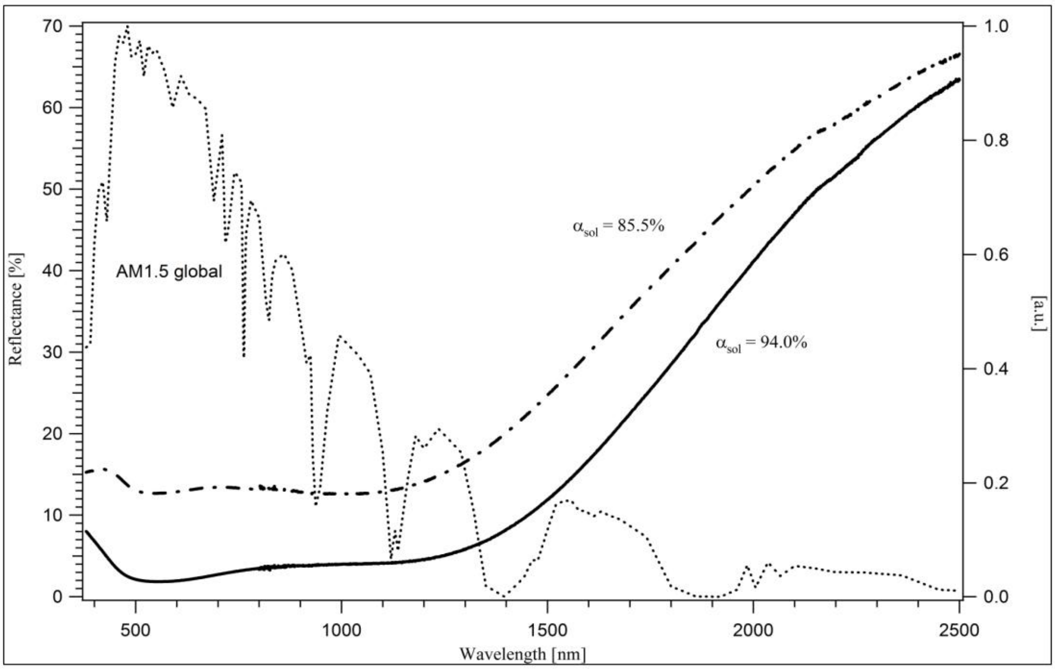

Figure 4: Visible and near infrared reflectance of the novel nanocomposite solar absorbing coating. The dotted line represents the reflectance of one individual layer coating on stainless steel. The solid line represents the reflectance of a double-layered coating on stainless steel (ε_{th}=11%). On the left, the spectrum of solar radiation is represented (scale on the right).

Coating durability

In terms of durability, the required properties of solar panel coating are very high. Comparative aging test was performed in our lab with our coating and a highly resistant black chrome coating. The duration of the aging steps were 4, 8 and 16 hours. After each step, we measured the solar absorptance α_{sol} and the thermal emittance ε_{th} of both samples. After 28 hours at 360°C, the black chrome coating is deteriorated and the optical properties decrease from α_{sol}=96.7% to α_{sol}=81.7% (Figure 5). In the same time, our coating didn't change his optical properties. The solar absorptance and the thermal emittance remain at α_{sol}=93.7% and ε_{th}=11%.

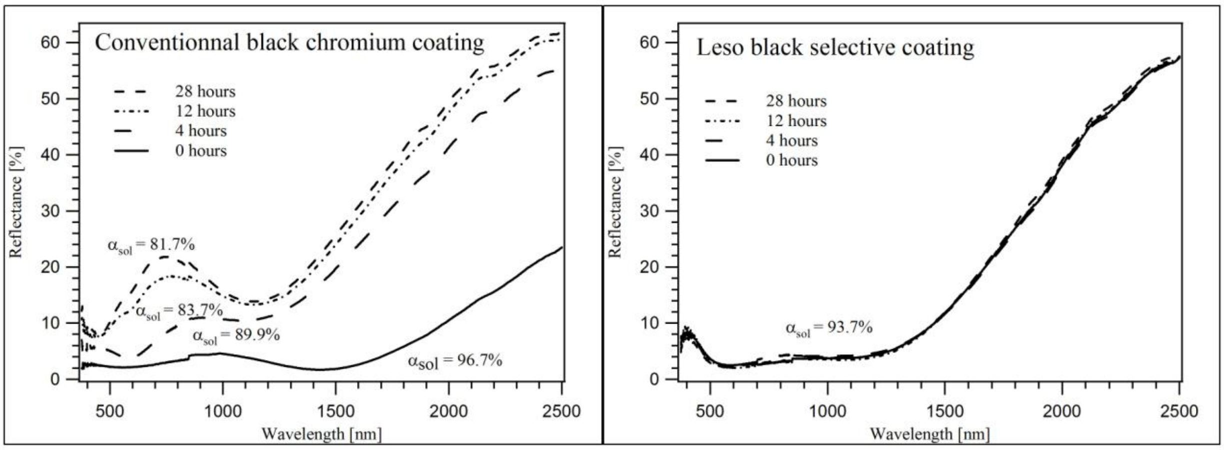

Figure 5: Aging test at 360°C during 28 hours. On the left, the graph represents the evolution of the reflectance of black chrome coating after 0 hours, 4 hours, 12 hours and 28 hours. On the right, the same evolution for the novel nanocomposite solar absorbing coating is represented.

CONCLUSION

The developed sol-gel method has proven to produce coatings with good spectrally selective optical properties. The study has shown that it was possible to produce a double-layered coating with solar absorptance higher than 94% and thermal emittance of 11%. Despite the fact that optimisation is not yet terminated the optical performance is already competitive.

These results are especially encouraging because of the fact that the first aging test shows an exceptionally high durability. Finally it is important to point out that the novel nanocomposite coating production process is completely free of chrome.

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THERMOCHROMIC FILMS OF VO_2:W FOR "SMART" SOLAR ENERGY APPLICATIONS

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ABSTRACT

Overheating is a problem with the use of active/passive solar energy in thermal solar energy systems. A solution to these problems might be provided by a thermochromic material such as vanadium dioxide. In order to simulate the optical behaviour of multilayered coatings, knowledge on its optical properties is necessary. We determined point-by-point the dielectric function for VO_2:W by ellipsometry. For validation, the solar spectra were measured by spectrophotometry. Such data have been compared with the computer simulations based on the determined optical properties. Finally, we collect optical data by infrared-imaging to detect the switch in emissivity of VO_2:W at around 45°C.

INTRODUCTION

Thermal solar collectors are more and more widespread as a source of renewable energy for domestic hot water production and space heating. The durability of the solar collector materials is however a critical point. Over-heating and the resulting stagnation temperature of the collector are a common problem. During stagnation, high temperatures lead to water evaporation, glycol degradation and stresses in the collector due to the increasing pressure. The elevated temperature leads to degradation of the materials that compose seals, insulation materials and also the selective coating. A solution to this problem could be a coating with optical properties changing at a precise transition temperature. Inorganic materials are able to resist at high temperature preserving a long durability. An organic thermochromic paint exposed to an intense solar irradiation is likely to be much less durable than an inorganic material.

Vanadium dioxide VO_2 undergoes a reversible crystal-structural phase transition from monoclinic to tetragonal (rutile type) accompanied by a strong variation in conductivity, specific heat, optical and magnetic properties.

Vanadium dioxide has already been proposed as a thermochromic coating for windows with variable solar gains adapting to the ambient temperature. At lower temperatures this material behaves as a semiconductor allowing some transmission of solar radiation. Above a critical transition temperature the behaviour switches to metallic, implying an increase in reflectance and a decrease in solar transmission. By doping the material with elements such as tungsten [1], it is possible to lower the transition temperature making it suitable as a thermochromic coating for windows. By doping it e.g. with aluminium [1], it is possible to increase the transition temperature, suggesting its use in solar thermal collectors.

Further applications can be envisaged in the fields of sensing, storage and even logic devices, for example accordable IR mirrors for LASER applications [2, 3, 4, 5], optical storage media [6], uncooled microbolometers [7, 8], modulators and polarisers of submillimitre wave radiation [9].

Thermal evaporation is a simple vacuum deposition method with a high deposition rate resulting in a relatively fast amortization of industrial production equipment. To our knowledge, it has never been applied for preparing VO_2 based films. Reports exist on VO_2 deposition by sputtering, CVD, laser ablation deposition, electron beam deposition, etc. These deposition methods are more expensive, technologically complicated and time consuming than thermal evaporation.

In this study we aim to determine of the most prominent parameters allowing to obtain good switching films, and to characterize the thermochromism of VO_2:W by temperature-dependent electrical and optical measurements.

EXPERIMENTAL SECTION

Thin films of VO_x:W were deposited by thermal evaporation (PVD): the material is melted in an electric resistance crucible so that its pressure is increased to a suitable deposition value. In the high vacuum chamber for thin films deposition, samples up to a size of approx. 20 x 20 cm^2 can be deposited with high homogeneity. As shown in figure 1 (a), samples obtained by our deposition machine are good and homogeneously black selective.

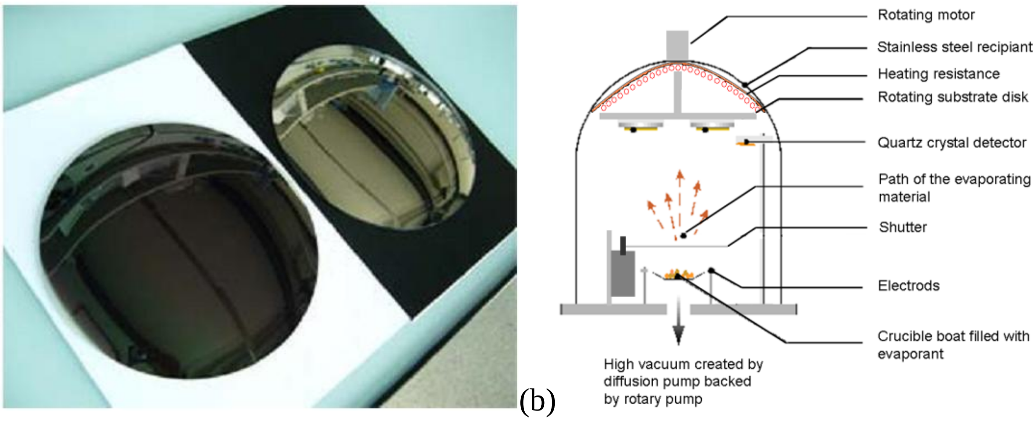
(a)  (b)

Figure 1: (a): Black absorbing VO_x (left) and mirrorlike film samples (right). (b): a schematic representation of the thermal evaporator used for our experiences.

The deposition of vanadium dioxide was obtained evaporating vanadium in a very well controlled oxygen atmosphere.

In order to obtain a good crystallization of VO_2, substrates were heated up to 550°C during the depositions. A substrate heater was especially installed in the vacuum chamber for this purpose.

In most cases, slides of iron-free white glass were used as substrates.

For measurements of ellipsometry and XPS, thin films were deposited on a silicon wafer (500 µm thick, front side polished, back side etched).

Spectrophotometry in the visible and near infrared wavelength range up to 2500 nm was carried out in order to determine the optical performance of the prepared VO_2:W films. In the visible range the optical properties were investigated using a spectrograph: Oriel MultiSpec 125™ 1/8m and the Oriel detector Instaspec II™. The Optronic Laboratories Monochromator OL 750-M-S and the associated photosensible detector OL 730 PbS were used for measurements in the near infrared wavelength range. The optical system is equipped with an integrating sphere. In this way, it is possible to measure the total hemispherical transmittance/reflectance (*total* = *diffuse* + *specular*). The optical apparatus can measure even only the diffuse part.

The thermal emissivity of surfaces was inferred from the reflectance measurement of IR variation originating from a heated black hemisphere (at 100°C, instrument: Inglas TIR100).

The thermographic images were taken by an Inframetrics Imaging Radiometer model 760 IR.

XRD analyses were performed at EPFL in the Physics Department (Rigaku equipment with a CuK_α radiation) in the Bragg-Brentano configuration under the supervision of R. Sanjines.

XPS analysis was performed at the University of Basel in the Physics Department under the supervision of A. Romanyuk. The photoelectron spectra were recorded *ex situ* using a VG ESCALAB 210 system.

Ellipsometry is a highly accurate method for investigating the optical properties of thin films. To our knowledge, only little information is available about ellipsometrically determined VO_2:W *n* and *k.* Tazawa [10] determined these optical constants from experimental reflectance and transmittance spectra. Ellipsometric measurements were performed at the University of Basel with the Ellipsometer Sentech Instruments GmbH SE850. For high accuracy and reliability, at four different angles of reflection were used for the measurements of the ellipsometric quantities ψ and Δ.

The computer simulations of the spectral reflectance are based on the method of the characteristic matrices [11].

RESULTS AND DISCUSSION

Evidence for the presence of tungsten in these films was found by XPS analyses. A tungsten resistance crucible was use for evaporating vanadium. In our opinion, the W-doping of the films is due to diffusion of W-atoms from the crucible to the molten vanadium.

Four points resistivity measurements

The temperature-dependent conductivity was investigated by a four probes resistivity measurement from ambient temperature up to 130°C.

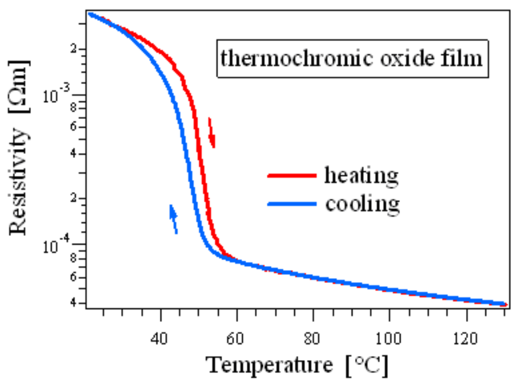


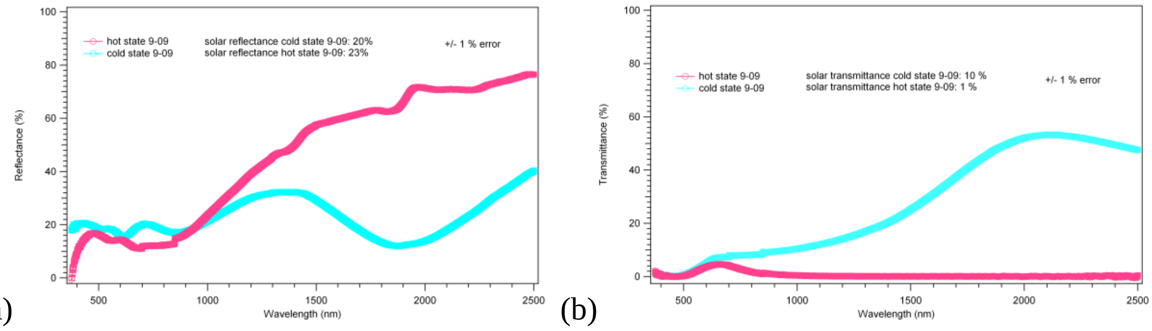
Figure 2: A switching sample which shows a transition temperature around 48 °C.

The resistivity transition results in a high jump of about 2 orders of magnitude.

Optical transmittance and reflectance analyses

To our knowledge, transmittance and reflectance values of spectra VO_2:W thin films are rare in the literature. We measured them in the visible and in the near infrared wavelength range, from 375 nm to 2500 nm.

All of the thin films are deposited on the larger glass substrate: 60 mm x 70 mm x 1 mm.
We measured the substrate temperature with a thermo camera, making sure that the cold state corresponded to the ambient temperature, around 25 °C, and the hot state to around 90 °C.



(a) (b)

Figure 3: (a): Reflectance of a VO_2:W sample on glass at ambient temperature and at 90°C. (b) Transmittance of a VO_2:W sample on glass at ambient temperature and at 90°C. For each curve the respective fraction of transmitted and reflected energy in the range of the solar spectrum is calculated.

The reflectance between the semiconducting and metallic state changes considerably. Around 2000 nm it switches from 14 % to 71 % [see Fig. 3 (a)].
The transmittance switches from 53 % to around 1 % at the transition around a wavelength of 2100 nm. The optical spectra exhibit systematically a small jump at 880 nm. This can be explained by the use of different detectors for the visible and IR range.
The film's colour clearly changes during the transition from yellowish to brownish making it possible to visually control whether it is in the metallic or in the semiconducting state.
The fraction of the transmitted and reflected energy in the solar range is evaluated by integration of the transmittance and reflectance spectra weighted with the AM 1.5 solar spectrum.

Reflectance analyses by Inglas TIR100 and Inframetrics Imaging Radiometer

Through Inglas TIR100 measurements, the emissivity of a VO_2:W film on a glass substrate was evaluated at 85 %. The same value was found for an uncoated glass. Therefore, in the semiconducting state of VO_2:W, the substrate plays a prevalent role in determining the emissivity behaviour of the entire system (substrate + film).
Due to the measurement principle (infrared reflectivity of a sample at ambient temperature), the emissiometer is not suitable for measuring the emissivity of a heated sample.

For the estimation of the emissivity of our samples in the hot (metallic) state we used a thermographic camera. Our thermographic camera is able to detect radiation in the infrared range of the electromagnetic spectrum (roughly 3 µm - 12 µm).

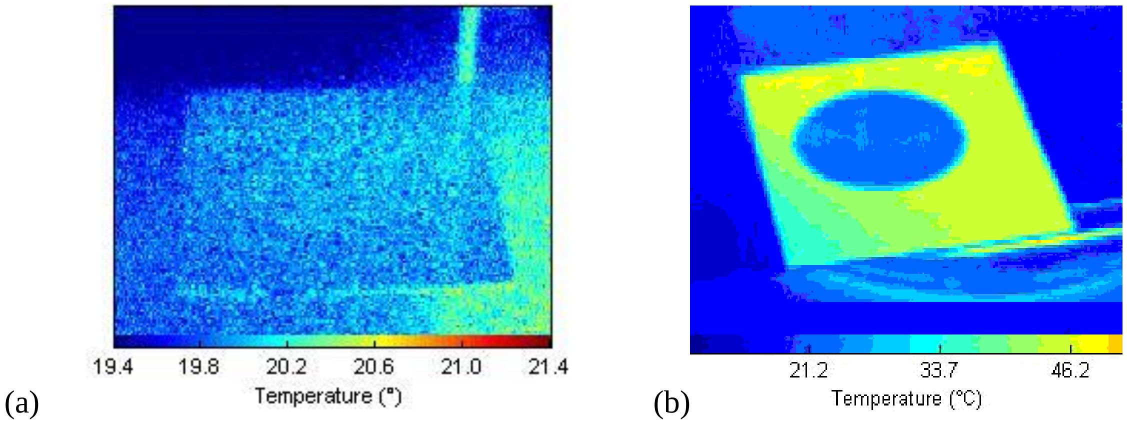


Figure 4: (a): At ambient temperature, VO_2:W is in the semiconducting state transparent for IR radiation. Therefore, the coating is not visible in the thermographic images. (b): In the metallic (hot) state, the film is clearly visible in the thermographic images. The entire system (substrate + film) emissivity is estimated to change from 85 % to 34 %. The saturation of the signal was avoided in all images.

The thermal emissivity of a typical VO_2:W film on glass is estimated at 85% in the cold semiconducting state, and at 34% in the hot metallic state. This corresponds to an emissivity change by a factor of 2.5.

Ellipsometry analyses

These ellipsometric measurements were performed to determine the optical constants in the visible and near infrared range with great accuracy.

The following procedure allows us to determine *n* and *k* of VO_2:W in the semiconducting and metallic state: fitting point by point the measured curves and every time changing the assumed film thickness. We looked for a thickness value which would minimize the root mean square error (RMSE). The initial thickness test value was found by the quartz crystal frequency shift during deposition. A fine adjustment of this value was obtained fitting the measurement with a polynomial formula and looking for the thickness which best minimized the fitting error.

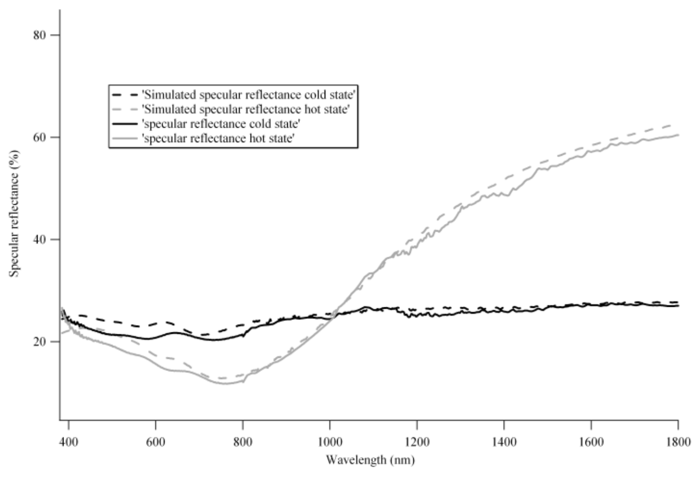


Figure 5: A comparison between a computer simulation and our specular reflectance measured in the semiconducting and metallic states.

We used the optical constants found in this way to simulate the optical behaviour of a VO_2:W layer on a silicon wafer. For a comparison of the simulated reflectance spectra with experimental data see Fig. 5. Only the specular reflectance from the coated front side was taken into account by the simulation. This corresponds to the measurement of specular reflectance from a silicon wafer with an etched back side. The maximum difference between simulation and measurement occurs in the visible spectral range and amounts to 2.5%.

CONCLUSION

Thermal evaporation by resistance heating has been used for depositing VO_2:W films on glass slides and silicon wafer. This deposition technique has the potential for high deposition rates which can be achieved with less complex equipment than that necessary for e.g. reactive magnetron sputtering or electron beam evaporation. To our knowledge, it has never been applied for preparing VO_2 based films.

By W-doping, the transition temperature can be lowered to approximately 45°C.

Our spectrophotometric measurements indicate a maximal transmittance switch for VO_2:W films on glass from 53 % in the semiconducting state to around 1 % in the metallic state at a wavelength of 2100 nm. The maximal reflectance switches in a complementary way, from 14 % to 71 % at a wavelength around 2000 nm.

Between the two states, the emissivity of VO_2:W on glass jumps from 85 % to 34 %.

We investigated the optical constants *n* and *k* by ellipsometry in the visible and near infrared. The reproducibility and the accuracy of the ellipsometric measurements have been verified.

The optical simulation based on the determined *n* and *k* values yields results which are rather close to the spectrophotometric data.

ACKNOWLEDGEMENTS

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Sustainable Building Envelopes

ADVANCED SOLAR HOUSING RENOVATIONS IN EUROPE

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ABSTRACT

I strongly favour renovating housing because older structures often have a charm and personality lacking in "modern" box architecture. A renovation for me is "advanced" if it fulfils contemporary expectations for appearance, functionality, space and light; and when purchased non-renewable energy costs are drastically reduced. Too often, however, renovations are only superficial. This is tragic because renovation will not be an issue again for many years thereafter. For this reason, clients should be convinced to set high standards. To achieve ambitious goals, many components and concepts can drastically reduce heat losses. However, in existing buildings conservation opportunities are often limited by existing construction or historic preservation. In such circumstances, producing energy is an economical alternative to extreme conservation. The obvious means is harnessing the sun, be it by photovoltaics, solar thermal or passive solar design. When a renovation includes a sensible mix of conservation and solar measures, and drastically improves living quality, it can truly be said to be an "advanced solar housing renovation". Exemplary renovations from across middle Europe and their performance are presented here, based on documentation completed in a Subtask of IEA-SHC 37. It is interesting to compare insulation thicknesses, air tightness, size of solar thermal and pv components, type of back-up heat supply and not least, the affect on the architecture and quality of living of the projects.

INTRODUCTION

Successful, innovative renovation projects are a good means to convince a client to set ambitious goals and helpful in setting realistic targets. Exemplary renovations from seven countries have been documented in an IEA-SHC project [1]. The combined strategies of conservation and solar reduce non-renewable energy demand up to 90 percent. Primary energy use for space and water heating has been reduced to between 40 and 70 kWh/m^{2}a. The renovation strategies not only save energy, they also improved living quality, comfort and functionality, as well as increasing real estate values. As in new building design, careful detailing is the key to beauty, effectiveness and durability in renovation projects (fig. 1).

Figure 1: A renovated apartment building in Staufen, CH with roof-integrated PV, new deeper balconies and uninterrupted insulation (www.setz-haus.ch Photo AEU)

INSULATE AND TIGHTEN THE ENVELOPE

Goal, benefits and problems

Reducing heat losses is the basis for a rational renovation. When the façade or roof needs repairing, insulating at the same time decreases heating bills improves comfort and eliminates a cause of mould. Renovating to the "Passivhaus" standard [2], however, often poses problems in renovation, i.e. anchoring thick insulation and detailing wall openings of window and door. Exterior insulation of historic buildings is often prohibited and interior insulation leaves thermal bridges. Three examples are presented here: gutting the building to the structure (but still preserving much of its immense gray energy content), a gentle renovation of an historic building and a renovation including an innovative solar façade insulation system.

Strategy insulate the exterior

For non-historic buildings, exterior insulation is the standard solution, but to insulate to the PH Standard is advanced. The apartment building, Hoheloogstrasse in Ludwigshaven, is an example of an extreme renovation (figure 2). Wall, roof and the basement ceilings received 20, 24 and 12 cm of insulation. Windows were replaced with PH-quality units, thermal breaks were eliminating and mechanical ventilation with heat recovery added. As a result, the annual heating energy demand was reduced from 250 to 15 kWh/m^2. After stripping the building to its structure, it was possible to integrate heat recovery ventilation and construct modern, spacious apartments. Finally, PV was integrated into the entire south-facing roof [3].

Strategy insulate room-side of walls

Because this villa in Modena is under historic preservation (figure 2) innovative measures were needed. The solution was to build a masonry wall on the room side of the existing wall. The cavity between it and the old wall is insulated with coconut and cork panels, 40 and 60 mm thick, reducing the U-value from 1.75 to 0.25 W/m^{2}K. New insulating glass windows were installed on the room side of the old windows to preserve the character of the facade. Primary energy demand for space and water heating is reduced 81% from 367 to 70 kWh/m^2. The old 104 kW boiler could be replaced by a 35 kW condensing gas boiler. 12 m^2 of vacuum tube collectors on the south façade of the interior court space help cover this reduced energy demand [4].

Figure 2: Historic villa in Modena IT renovated with interior insulation (V. Calderaro)

Strategy Solar Insulation (GAP)

The heating costs of a 50 unit apartment building built in 1957 Linz AT were reduced by 88 %. The comprehensive renovation included an innovative solar insulation system of prefabricated panels (figure 3). Sunlight passes through a glass layer and is trapped in the air gaps of corrugated cardboard (with a fire suppressant). The resulting warm air buffer cuts heat losses by the façade. The static U-value is 0.15 but the dynamic U-value over the heating season approaches zero. To reduce thermal bridges, the balconies were glazed and at the same time enlarged. Conventional insulation was added to the roof and the ground floor (U = 0.16 and 0.20 W/m²K). New windows were installed (U_w = 0.86 W/m²K) with louvered blinds within the glazing unit for sun shading. Finally, through-wall ventilation units provide good room air quality with 70% heat recovery. As a result of this package of measures, heating demand was reduced from 150 to 20 kWh/m²a [5].

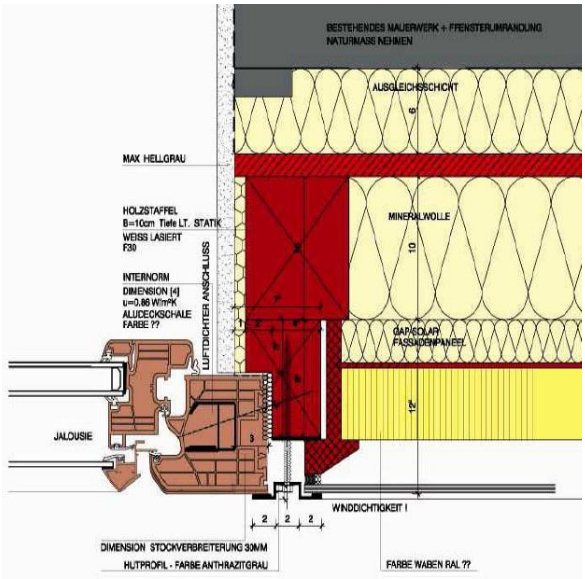

Figure 3: Cross section of the solar insulation system of the Linz apartment building. (Source: Domenig-Meisinger)

USE SOLAR HEAT TO REDUCE NON-RENEWABLE ENERGY USE

Goal, benefits and problems

If the goal is to reduce dependency on non-renewable energy, at a certain point energy delivered from a solar thermal system can be less expensive than energy saved from conservation measures, i.e. the marginal cost of the last increment of insulation or triple verses double glazing. Installing solar collectors or a pv system as part of a renovation is not always easy, however. Panels may be forbidden because they disturb the character of a historic village. Figure 4 shows the outline of the proposed and refused location for roof solar panels. The building commission allowed that the panels could be mounted on the shed to the left, which is shaded by a noble, old, nut tree.


Figure 4: Collector may not be installed on farm house, must be on the rear shed, requiring the nut tree to be cut down. (Photo: AEU Ltd.)

Well done renovations drastically shorten the heating season. A solar active system can then cover the minimal space heating demand of the spring and fall as well as the hot water demand, allowing other systems to be shut down for much of the year. This saves wear and extends component life spans. Two system types are reviewed here, a water system and an air system. Each has its special advantages for a given application.

Strategy: Solar water systems

Three years after a young Swiss couple purchased a single-family house built in 1942 the oil furnace had to be replaced. This was the motivation to completely renovate the house, including a 13 m^2 drain-back solar system (fig. 5) with an 800 L storage tank. The renovation also included adding roof, wall and basement ceiling insulation (220, 200 and 80 mm). The windows were replaced with units glazed with a U_g of 0.55. The oil burner was replaced with a wood pellet stove and a ventilation system with 80% heat recovery was added. As a result, the solar system is able to cover much of the space heating in spring and fall and all the domestic water heating demand in summer. The annual primary energy demand for space and water heating was drastically cut from 230 to 47 kWh/m^2, or an 80% reduction. This means instead of burning 3,500 litres of heating oil per year and they burn only 1 ½ tons of wood pellets [6].

Figure 5: Drain-back solar collectors on the Fehr house. (Photo: H. Fehr)

Strategy: Solar air systems

Solar heat from a collector can be transported by air, instead of water. No anti-freeze is needed and a possible leak causes no damage. Over the years this technology has been used in the renovation of many houses, schools and industrial buildings [7]. An example of a very practical application, solar heating second homes, is given here.

Often after a stone rustico, wooden chalet in the Alps, log cabin in Scandinavia or masonry cottage in the Mediterranean has been purchased, it must be renovated. While vacant it becomes cold, damp and mouldy. When the owners arrive, the air and bedding smell musty and it takes forever to achieve a comfortable mean radiant room temperature. Too often the solution is an electric heater set at a low temperature during the owner's absence. Because occupancy is only for short intervals, investment in insulation or better windows is difficult to justify. Thus, the heating, even at a low temperature, consumes much energy. Solar air collectors can deliver sun-warmed air by free convection thereby maintaining a minimum room temperature and dryness. A small pv-powered fan can increase the air flow and hence collector efficiency. Figure 6 shows an application in Koroni, GR. The two 6m^2 collectors each have a 50Wp pv section to power a circulation fan delivering up to 200m^3/h of sun-warmed air into the house. [8].

Figure 6: Renovation of a 2nd home in Koroni GR with a pv-powered solar air collector (Grammer Solar AG)

USE PV TO OFFSET NON-RENEWABLE ENERGY USE

Some of the housing renovation projects studied included a PV roof. Decisive is the price at which the local utility is required to buy back the solar electricity. For example in Switzerland as of Jan. 1, 2009 electricity providers must buy back solar power for 25 years for all approved pv installations built since Jan. 1, 2006. For systems $\leq$10 kW the buy-back rate for attached PV systems is €0.46 and for systems integrated into the roof or façade €0.56. [9].

An exemplary project where PV was part of a comprehensive renovation is the apartment building in Staufen. The 110 m² PV installation on the south-facing roof (fig. 1) has a nominal output of 14.7 kWp. In 2006 it fed 14’300 kWh into the grid. The motivation of the owner, Guido Erni, was to provide retirement income. Also part of the renovation were insulation of the attic floor (140 mm), facade (200 mm) and basement ceiling (100 mm); a new ventilation system with 85% heat recovery and replacement of the oil furnace by a heat pump. The results: primary energy use for space and water heating was reduced 65% from 154 to 54 kWh/m² [10].

USE PASSIVE SOLAR DESIGN TO REDUCE ENERGY USE AND IMPROVE LIFE QUALITY

Replacing windows with highly insulated units can reduce heat losses to such an extent that solar gains cut heating costs (fig. 7). To minimize unnecessary window opening time and drafts, frame vents can be installed. [11]. Enlarging window openings in walls, when possible, amplifies these savings and admits more daylight. Daylight can also be led into interior spaces by a light pipe [12 + 13].

Figure 7: High performance windows being replaced in the Kroeven Project, NL (Erik Franke Architekten)

An example of using passive solar gains is the renovation of the row houses Kroeven in Roosendaal, the first large-scale Passivhaus [2] renovation in Holland. Single pane windows were replaced by triple pane glazing in Passivhaus frames. Thus the heat loss from the windows was reduced below the free solar gains over the winter, even in this overcast, northern location. Walls were insulated with 200 mm XPS and roofs with 360 mm of cellulose. A new ventilation system was added. The combination of conservation and passive solar design resulted in a 90% savings in energy consumption. The annual primary energy for space and water heating was cut from 219 to 21 kWh/m² [14].

CONCLUSIONS

Renovating existing housing can provide living space with superior comfort, very low energy consumption and a special charm. The examples presented here from Austria, Germany, Greece, Italy, the Netherlands and Switzerland demonstrate that it is possible to achieve energy savings up 90 percent while preserving the special character of the projects. Solar energy is a viable, economic alternative to the costly, last increment of conservation measures in order to achieve the goal of drastically reducing dependency on non-renewable energy and production of CO_2. In some of the projects photovoltaic panels were included in the renovation package. When the primary energy value of the solar electricity is deducted from the greatly reduced energy demand for space and water heating, these projects achieve a nearly zero-energy balance.

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SMART SOLAR HOUSING RENOVATION

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ABSTRACT

After World War II, the demand for houses in the Netherlands was enormous. Large housing construction programs were established in the fifties, sixties and seventies. Nowadays, these houses are facing some societal, economic and technological problems. On the other hand, many of the occupants are quite happy with their low rent homes and neighborhoods and do not want to move. As the need for energy efficient housing will increase in the next few years, renovation will become an inevitable strategy for housing associations to improve the overall energy performance of their housing stock. If housing associations decide to upgrade their houses resulting in an increased rent for the occupant, 70% of the occupants have to agree with the measures as planned and the increase in rent involved. If less than 70% of the occupants agree, the renovation cannot be executed. For housing associations, acceptance of the measures taken is therefore an important issue.

To improve the acceptance by the occupants, their interests should be taken into account. Two main aspects can be distinguished. First, the nuisance for the occupants should be minimized. With traditional renovation methods, occupants have to leave their homes during a few weeks or even months. Or if not, they cannot use their facilities like the toilet, shower and kitchen. This causes lots of resistance by the occupants before and during the operation and therefore lowers the amount of occupants that are willing to agree with the renovation plans. Besides this, the occupants should be able to influence the exact measures taken and the increase in rent involved. Second, measures regarding energy efficiency like solar thermal and photovoltaic applications, adding thermal insulation and replacing the installations can be beneficial for the occupants, as a reduced energy cost could compensate the increase in rent.

This research is focused on the offsite manufacturing of wall and roof elements for renovation offering the occupants freedom of choice, a renovation process with only very limited hindrance and a reduction in energy cost after the renovation.

The roof element is designed in order to fit any orientation and yet be able to generate the heating energy need for the dwelling using solar panels. Special attention is given to the possibility of individual renovation process. The design consists of passive house elements like thick thermal insulation, high performance windows, an airtight structure and a heat recovery ventilation unit.[1] The combination of these passive house elements with solar applications can bring a zero heating energy concept.

INTRODUCTION

Housing built in the post World War II period from 1945-1975 can be characterized as relatively simple buildings, designed and built in large numbers. The design and layout was not yet influenced by the 1973 oil crises showing single pane windows, no thermal insulation and many thermal bridges. The result today is that the energy consumption for heating only today is relatively high, some 200-300 kWh/m2 a year. Current housing construction in The Netherlands is expected to have an energy need for heating of some 80 kWh/m2 a year.

As the demand for housing in the post World War II asked for many houses, the space offered was kept to a minimum.

Row housing built from 1945 to 1975 shows a relatively standard floor plan. The houses are approximately 5.5 meters wide and 7 meters deep. They consist of two floors and an attic. The foundation is made of brickwork or concrete and the ground floor of a wooden beam floor or concrete. The load bearing structure consists of a house dividing wall perpendicular to the façade with spanning floors made of wood and later concrete. The façade has no load bearing function and therefore can be very open. All walls are made of brick. The roof type is a pitched roof. Overall the houses have a sober design. The technical condition of the structure is in general relatively good.

There are approximately 1.3 million of these houses in the Netherlands and around 770.000 are in the social housing sector. This is about 11% of the total Dutch housing stock.

Most of the neighborhoods are placed close at the center of a city, because of the early expansion directly after WW2. The neighborhoods are also relatively spacious; most houses have both a front yard and a backyard.

The technical state of the installations differs among the houses. Sometimes installations have been replaced and improved during renovation and maintenance.

Occupants experience nuisance because bad acoustic properties of the construction, mainly the separating wall between two houses. The thermal and acoustic problems are mostly caused by the low quality of the building envelope. Improving this envelope is crucial for improving the quality of the houses.

The houses built from 1945 to 1975 have a bathroom of approximately 3 m2, a kitchen of approximately 6 m2 and a living room of approximately 24 m2. These rooms are considered tight regarding current living standards. Extra space is required to meet current living standards.

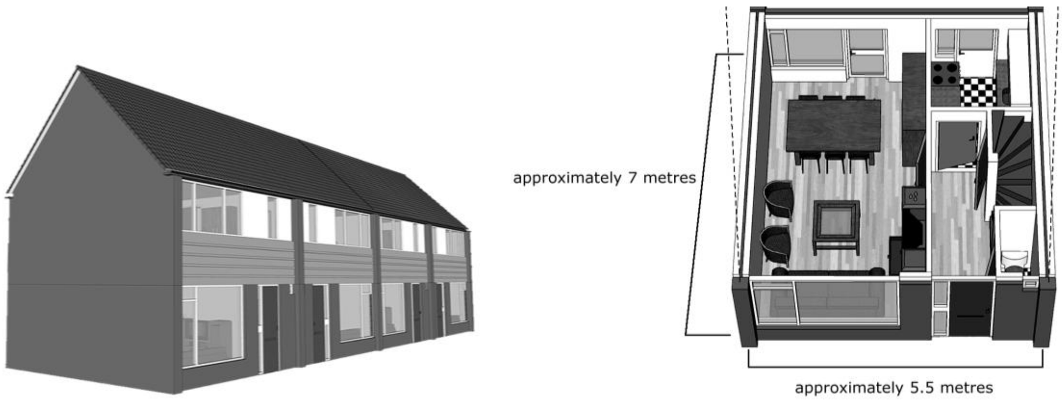

Figure 1 : Typical post World War II row housing, left a row of four, right ground floor plan.

Current restructuring generally consist of demolition and building new homes. It is obvious that this approach is quite expensive and will result higher rents for the new built houses. Also the process will take at least two years, in many cases significantly longer, and during this period people have to live somewhere adding extra pressure on the tense housing market for low income tenants.

A low cost renovation approach offering speed, some extra space and a serious reduction in energy operating cost, is most welcome for the outdated housing stock.

METHOD

For this research various energy demonstration projects have been analyzed in combination with the interviews with the people involved, both the responsible housing corporation officials as well as the people living in the houses, after all the most important group. This research showed a need for a limited increase of space and a need for technical improvement.

The extra space can be realized using industrial off site manufacturing of large elements containing the technical requirements like e.g. a heat recovery ventilation system. Special attention is given to the connection of the renovation element with the existing structure obviously showing many variations in dimensions.

The passive house concept is analyzed and adapted to the local situation like natural ventilation of first floor bedrooms all year round and heating at ground level only.

The solar energy potential on existing housing is very high. In the Netherlands with some 30 m2 of PV panels and a proper orientation some 3500 kWh of electricity can be generated. The electrical energy output depends on the orientation of the PV panels and in an existing situation this orientation cannot be influenced.

The SmartBuilding® theory aiming at a reduction of materials use, energy use, construction timen, reduction of building mistakes and reduction of building costs is used for the renovation process design.

This philosophy states that the building process should be organized in such a way, that installations, pipes and canals are installed in a single step in the construction phase, ensuring a clear, efficient process without interference of other disciplines. Besides this, the separation of structure, installations and finishing ensures flexibility both during construction and in the future [2].

RESULTS

Two different approaches can solve the problems of the outdated post WWII neighborhoods; demolish and rebuild or renovation on a large scale. The First approach creates large amounts of waste (approximately 130 tons per house), destruction of capital and the occupants are forced to leave their homes. The rebuilt houses mostly have a higher rent and some occupants can’t return to their neighborhood. Another fact is that the current pace of construction will not be able to keep up with this approach. Approximately 20,000 houses are being demolished each year in the Netherlands. At this pace, it will take over three hundred years to replace and renew the entire Dutch housing stock. This is obviously far too long when the houses are being discarded after fifty or sixty years. The advantage of this approach is that the houses can be built according to current standards or even better.

The second approach, large scale renovation, will extend the technical and functional lifespan of the terraced houses. A disadvantage is the building quality and energy performance; these are restricted by the current construction. Advantages of this approach are the absence of large amounts of debris, saving the social structure of the neighborhood and occupants do not have to leave their home during the whole process of upgrading the housing.

The second approach is chosen because it minimizes waste, saves the social structure and occupants can stay during the process.

SMARTRENOVATION UNIT.

Keeping all the different actors and their interests in mind, a new approach to renovation is established: SmartRenovation forges links between the housing corporation, the architect, the occupants and the contractor by offering a toolkit for upgrading the post World War II terraced houses by adding prefabricated units to either the front or the back of the house [3]. These units enlarge the room for living and add energy efficient measures like thermal insulation and new installations. In order to connect the prefabricated units to the post World War II terraced house, openings in the façade need to be made and a special connector is used.

SOLAR ROOF

A solution to improve both living conditions for the upper floor and better orientation for PV panels is to convert pitched roofs into one-sided inclination roofs. By extruding existing walls on one side, an inclination of 20 degrees can be obtained for every house. A 20 degree inclination in any direction ensures more than 85% of the power generated compared to an optimal angle and direction. (In The Netherlands; 37 degrees, facing south)

The solar roof is a system of prefabricated elements which can be put on the (existing) beams. The elements consist of a ceiling, an insulation layer, watertight foils, a ventilation cavity and on top of it PV panels. Working with complete prefabricated elements ensures high quality and time savings on site.

The energy needed for heating after the renovation will be around 40 kWh/m^2 per year. Calculations show (Table 1) it is possible to supply this energy demand with PV-panels at a sloped roof with an angle of 20°, i.e. the SolarRoof. (figure 2)

	Values
Energy needed for heating	40 kWh/m^2 per year
Total surface house	100 m^2
Total energy needed for heating	4,000 kWh per year
Typical energy supply PV-panels depending on orientation 85% to 100%	98 to 110 kWh/m^2 per year
Total surface roof construction	40 m^2
Total energy supply SolarRoof	3,920 to 4,400 kWh per year

Table 1: Calculation values of the energy demand and the energy supply by the SolarRoof.

Figure 2: Visualization of the renovation process; the existing structure (left), the stripped structure with the Solar Roof (middle) and the new building envelope (right).

+FACADE

The +Facade is made of a prefabricated wood frame with thermal insulation material, high efficiency windows and piping for ventilation. The element is 300 millimeters thick, as high as the house and between 2.5 and 3 meters wide. The orientation of the element is vertical along the facade of the house; this way it is only connected at the top, roof side, and at the bottom, at the existing foundation which is used to support the element. This is possible because the element is lighter than de former layer of brickwork.

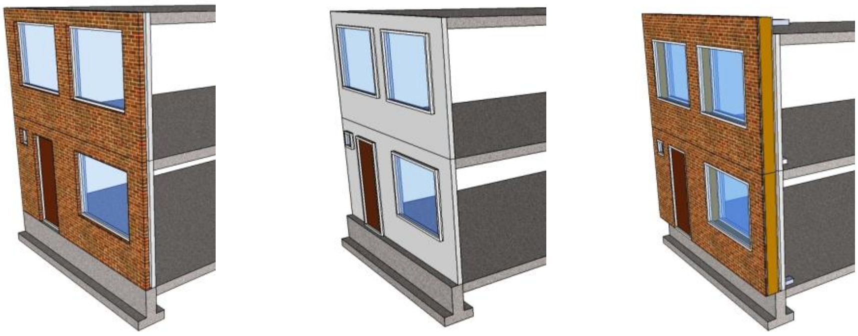

Figure 3: Visualization of the renovation process; the existing structure (left), the stripped structure without the outside layer of the brick cavity wall (middle) and the new facade structure with the +Facade component including the existing windows and new piping for ventilation.

Another advantage of the vertical orientation is the possibility to place piping for ventilation from top to ground floor without a section. A very important aspect is managing the tolerances because of the prefabrication, the irregularities at the surface of the existing construction and the variation in sizes of housing.

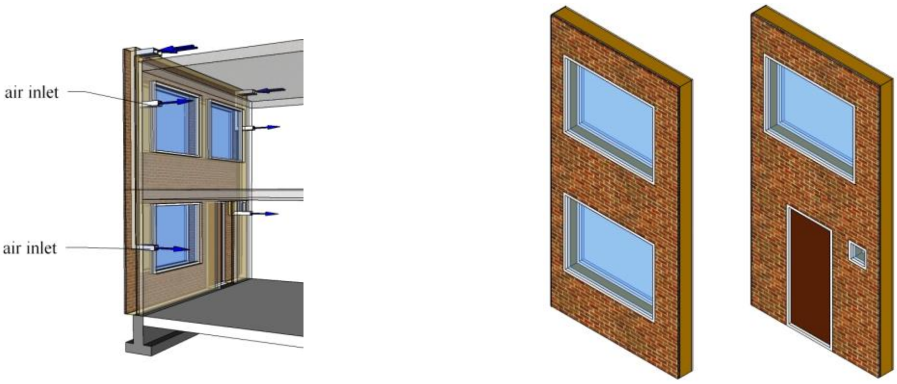

Figure 1: Visualization of the +Facade-elements with piping for ventilation and air inlet (left) and the vertical orientation of the elements (right).

The construction process is divided in three steps. First the outside layer of brickwork is removed. The inside brick layer and the windows are left in place so the occupants can stay in the house during the renovation process. Second the +Facade element will replace the function of the outside layer of brickwork i.e. rain protection and add thermal and acoustic insulation to the building envelope. Third the ventilation canals are joined with the heat-recovery ventilation unit at the attic.

Depending on the orientation of the facade energy generating elements can be used; like a solar wall, climate window, PV- panels, preheating the air inside the air cavity, etc.

CONCLUSION

The SmartRenovation unit enlarges the house, so a larger bathroom and kitchen can be made, and adds thermal insulation to the facade. The Solar Roof adds thermal insulation to the roof structure and integrates PV-panels in the Construction for the use of solar energy. The +Facade-element improves the thermal insulation of the facade and allows new piping for ventilation. A combination of the three components will increase indoor climate and energy performance, thermal insulation, air tightness and the use of solar energy. The components are all made of large, prefabricated elements; the construction should be able to take place in two days and quality of the component is maintained. The occupants can stay in their houses during this construction process.

DISCUSSION

The payback time of solar applications in the current Dutch economical situation is too long. Subsidies in the Netherlands are very irregular. There's a maximum available amount of money for a subsidy. When the maximum is reached the subsidy stops and declarers have to wait till next round of subsidies. Better is a constant flow of money through extra taxes on energy, like in Germany. Though governmental policies do not lead sufficiently to a solid investment, a solution for quick installation of facade and roof elements causes less resistance from occupants and fines will be lower for housing associations. The money saved, can then be used for the expensive PV panels in the roof. This is after all a sustainable investment. Since the savings on the energy bill are for the occupants, but they are not paying for the renovation, Housing Associations can increase the rent if they can prove and realize energy savings for the occupants.

ACKNOWLEDGEMENTS

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THE PERFORMANCE AND OPTIMISATION OF A NOVEL FAÇADE PANEL FOR ENERGY-EFFICIENT BUILDINGS

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ABSTRACT

A suitable multi-criterion optimisation method is identified and deployed to optimise a cellular spandrel panel for a high performance fibre reinforced polymer (FRP) façade, with the objective to minimise the construction and in-service energy costs. Furthermore, the significance of various façade components to the overall thermal performance is identified and compared.

INTRODUCTION

The in-service performance of commercially available curtain walling systems has undergone steady progress over the recent decade chiefly through the technological developments of high performance glazing. The improvements are such that the principal factor that limits the thermal performance is currently the framing, which is typically based on the use of thermally broken aluminium extrusions. However, the industry-standard combination of aluminium frames and the glazing edge conditions leads to thermal losses and relatively high thermal transmittance (U-value).

Fibre reinforced polymer (FRP) is a relatively novel construction material with several advantageous properties, such as high specific strength and stiffness, low thermal conductivity, high corrosion and weather resistance. Its use in facades, therefore, provides the opportunity to reduce the number of parts (compared with aluminium-based systems) due to the absence of thermal breaks, which may in turn bring a step-change to curtain wall thermal performance and energy efficiency of buildings.

A façade prototype was proposed by Arup (Figure 1[1] and Figure 2), the U-value of which easily achieves the target of 1.3W/m^{2}K. It consists of four main component types, i.e. glazing, spandrel panel, mullions, and joints (where joints include the pultruded FRP profiles which are used at the interfaces between the components). All the components, with the exception of the glazing, are pultruded FRP profiles. Arup have done some structural calculations [1], in which the cellular panel was modelled as a continuous beam on short columns. Thermal performance was also investigated by Arup using BISCO software. The effects of the number of webs were assessed [2], with the assumption that the cavities were filled completely with aerogel, while the possibility and feasibility of partly filling the gap was not considered.

This study aims to develop a method to optimise the spandrel panel on the façade module proposed by Arup in terms of the structural and thermal performance, with the objective of minimising the total cost of construction and energy consumption. In doing so, it is necessary to construct accurate analytical and numerical models that predict the structural and thermal performance. Finite element analysis is performed to investigate and optimise the structural performance using ANSYS v11.0 and an analytical model for thermal analysis is constructed in MATLAB v7.6.0. Finally, an office building is modelled by Virtual Environment v5.9 to evaluate and compare the total costs and eventually to outline a method for determination of the optimal solution.

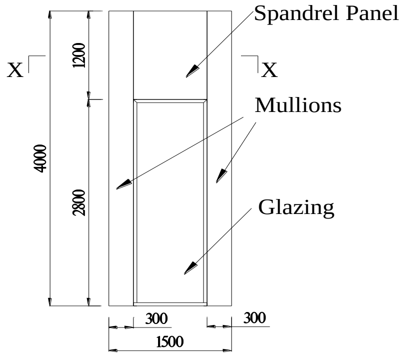

Figure 1: Front elevation of an FRP façade module, which consists of glazing, spandrel panel, mullions and joints.

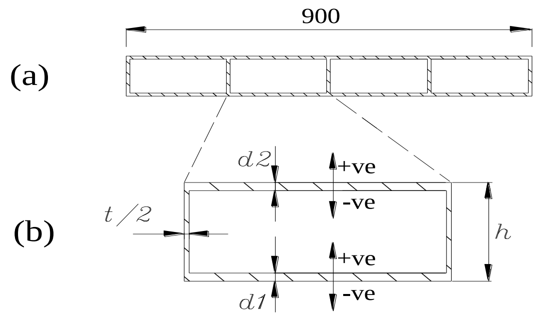

Figure 2: Cross-section of a cellular spandrel panel: (a) plan view X-X; (b) a single cell; d1 denotes the thickness of the external skin and d2 denotes that of the internal skin. The arrows denote sign convention.

STRUCTURAL ANALYSIS AND RESULTS

Two, three, four-cell spandrel panels, each measuring 900mm (W) × 1200mm (H), are investigated. Material properties are taken from manufacturers' data [3], which are valid for a temperature range of -20°C to 60°C.

Four load cases (Table 2) are considered to satisfy CWCT standards [4], and load case combinations are shown in Table 3.

	Description
WL	Uniformly distributed wind load of ±2.4kN/m^2, acting externally
DL	Uniformly distributed load of 1.0 kN/m^2, acting internally
HLL	A horizontal line load of 0.74 kN/m acting at a height of 1.1m above the finished internal floor level, acting internally
PLI/PLE	A point load of 0.5kN applied with a contact area of 100mm square, acting internally/externally

Table 2: Load cases.

Serviceability Limit State		Ultimate Limit State	
I	(WL)+(DL)	i	1.5×(WL)+1.5×(DL)
II	(WL)+(HLL)	ii	1.5×(WL)+1.5×(HLL)
III	(-WL)+(PLI)	iii	1.5× (-WL)+1.5×(PLI)
IV	(WL)+(PLE)	iv	1.5× (WL)+1.5×(PLE)

Table 3: Load case combinations.

Three constraints are identified:
• The thicknesses *d1, t, d2* are no less than 4mm, and should be increased at an interval of 0.5mm due to manufacture limitations; *h* ranges from 23 mm to 120 mm;
• Stresses at any point should not exceed the allowable stresses;
• The out-of-plane allowable deflection should be no more than 6mm (span/200).

Finite element analysis and optimisation are performed by ANSYS v11.0. Firstly, an initial model is built. And then zero-order optimisation method is applied with the assumption that the control variables are continuous. Finally, the optimal solution is adjusted according to manufacturing requirements, using direct search method from Hooke and Jeeves [5]. Optimal solutions are presented in Table 4.

			Constraints	**2 cells**	**3 cells**	**4 cells**
Critical load cases combination			-	III	IV	IV
Normal Stresses (MPa)	Along-fibre direction	Maximum	185	29	30	26
		Minimum	-185	-32	-37	-40
	Across-fibre direction	Maximum	77	20	27	26
		Minimum	-77	-22	-28	-27
Maximum Shear Stress(MPa)			19	6	8	5
Deflection(mm)			6	6	6	6
d1 (mm)			*d1*≥4	6.5	4.5	4
d2 (mm)			*d2*≥4	6	4	4
t (mm)			*t* ≥4	5.5	4.5	4
h (mm)			23≤ *h*≤120	68	52.5	35
Cross-section Area (mm^2)			-	12019	8661	7636

Table 4: Optimal structural solutions for spandrel panel

Discussion

Load cases combination III/IV are critical, because the point load (PL), which stems from maintenance, e.g. a cleaning cradle resting against the wall or a person standing on a ladder leaning against the facade, results in a much larger deflection than other load cases. Small increases in *d1* significantly reduce the deflection induced by the point load (PL).

Deflection constraint is always active, leaving large differences between the actual stresses and the allowable stresses. Therefore, future work could involve balancing the stiffness and strength by changing the material and the aspect ratio of the fibres, the material of the matrix, the fibre-matrix volume ratio or manufacturing methods, which might potentially lead to a further reduction of material cost.

A two-cell panel requires the largest volume of FRP, because the number of webs reduces to such a level that both *d1* and *d2* need to be increased substantially to keep the deflection within the limits. However, this could be an advantage because the number of thermal bridges is reduced.

THERMAL ANALYSIS AND RESULTS

Spandrel Panel

The initial thermal performance objective is a total U-value of $1.3W/m^2K$, which means if other components are kept as originally designed, the U-value of the spandrel panel should be $1.7W/m^2K$. One cell is simplified as a vertical cavity within an FRP enclosure. Indoor and outdoor temperatures are assumed to be 20°C and 0°C respectively. Conduction, natural convection, radiation are all considered to form the network. The convection heat transfer between the webs and the air is considered negligible for two reasons: firstly, since the conductivity of aerogel is extremely low, the temperature difference across the enclosed air cavity is very small- within 6K. Secondly, based on previous work [6], the aspect ratio of the cavity is sufficient to make the effects of the vertical webs negligible.

An analytical model, which can be used to predict the U-value under different geometric parameter combinations, is constructed in MATLAB v7.6.0. However, the U-value cannot be brought down below 2.5 W/m^{2}K by only adjusting the parameters in the feasible design region. Therefore, an insulation layer of aerogel is inserted to improve the thermal performance. The simplified network is presented in Figure 3.

Surface conductances are determined according to EN ISO 6946 [7]. Effective conductance for the natural convection of the air is calculated according to Yin et al [6]. Effective conductances for thermal radiation between the outside FRP skin, the webs, and the surface of the insulation layer are calculated according to Holman [8].

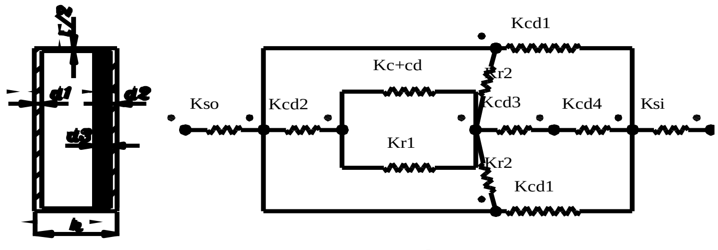

Figure 3: (a) Cross-section of one cell, d3 denotes the thickness of aerogel insulation layer; (b)Simplified network. (Kcd) conductance of FRP or aerogel;(Kc+cd) effective conductance for conduction and convection of the air in the cavity;(Kr) effective conductance for radiation among the four enclosed FRP surfaces;(Ks) surface conductance.

The analytical model shows that the U-value of the spandrel panel depends largely on the thickness of the aerogel layer, as shown in Figure 4, while the numbers of cells, the thickness of the FRP outside and inside skins, webs, and the depth of the air cavity all have little effects. For a three-cell panel, when 7.5mm aerogel is inserted, a U-value of approximately 1.7W/m^{2}K can be achieved with *h* ranging from 35mm to 120mm (Case 1). However, the original design by Arup achieves an overall U-value of 1.1W/m^{2}K, which requires the U-value of the spandrel panel to be 0.4W/m^{2}K. This would require 100mm aerogel infill (Case 2). Figure 5 shows U-value of the structural optimal two-cell spandrel varies with the thickness of the insulation layer.

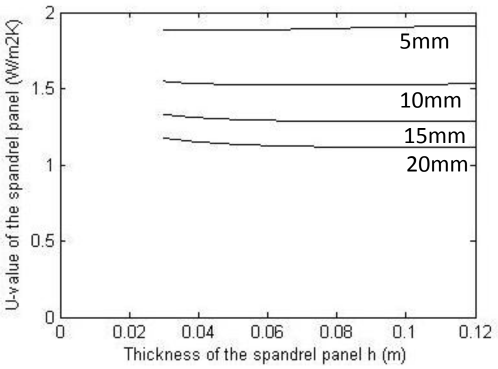

Figure 4: U-value of a three-cell spandrel panel with respect to several specific thickness of aerogel layer shown in mm and varying thickness. d1= d2= t= 4mm.

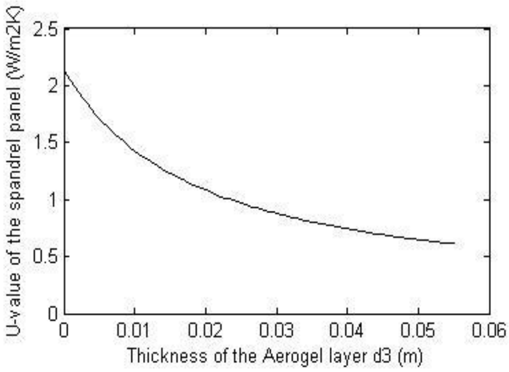

Figure 5: U-value of the optimal two-cell spandrel panel with increasing thickness of aerogel insulation layer.

Building Energy Simulation

A simplified building energy simulation and cost comparison is undertaken to investigate a method for determination of the most cost effective design. A 27m×27m five-floor office building is modelled using Virtual Environment v5.9. The building is assumed to be located in London, and the façade service life is 25 years. The indoor temperature is maintained at 20°C throughout the year. The cost of FRP is trivial, so it is excluded at this stage. Discounted cash flow analysis is applied to calculate the annualised capital cost. The real discount rate is assumed to be 8% during a capital repayment period of 25 years, and the energy prices are assumed to be constant. Results are presented in Table 5.

		Case 1	Case 2
Total U-value (W/m^2K)		1.3	1.1
U-value for spandrel panel (W/m^2K)		1.7	0.4
Energy cost per year	Electricity (£)	9.0k	8.7k
	Gas (£)	2.1k	2.6k
	Total (£)	11.1k	11.3k
Energy cost per year per spandrel panel (£)		31.3	31.0
Cost for aerogel per spandrel panel (£)		15.5	208.8
Cost for aerogel per spandrel panel for Year One (£)		1.5	19.6
Total annualised cost for Year One (£)		32.8	50.6

Table 5: Cost comparison when the U-value of the façade is 1.3W/m^{2}K and 1.1 W/m^{2}K.

By comparing the two cases, it is clear that a more economic way is to use a thin layer of aerogel rather than completely filling the cavity. Therefore, basing on the structural optimal solutions, insert a minimal thickness of aerogel which can achieve the U-value of 1.7W/m^{2}K for the spandrel panel. Results are shown in Table 6.

		2 cells	3 cells	4 cells
FRP cross-section area (mm^2)		12019	8661	7636
Minimal thickness of aerogel *d3*(mm)		6.5	7.5	8
U value of spandrel panel (W/m^2K)		1.7	1.7	1.7
Cost per spandrel panel for Year One	FRP (£)	0.01	0.01	0.01
	Aerogel (£)	1.3	1.5	1.6
	Energy (£)	31.3	31.3	31.3
Total annualised cost for Year One(£)		32.6	32.8	32.9

Table 6: Cost comparison for the structural optimal spandrel panels.

Discussion

Figure 6 shows how the total U-value changes with each component when others are kept unchanged as originally designed. With the lowest gradient, the spandrel panel is the least effective component for changing the overall U-value of the façade module. Figure 7 shows that the joints are the main heat-losing components. Therefore, it would be far more beneficial to improve the thermal performance of the joints.

The price of aerogel is around £2/litre. Since the U-value of the spandrel panel does not affect that of the whole façade as much, it is not economic to fill the cavity completely with aerogel to improve the total U-value slightly. However, it is worth inserting a thin layer of aerogel. In addition, aerogel is being considered only due to an aspiration to develop a translucent façade system, but when translucency is not required or feasible, other more economic insulation materials may be used instead. Future work will seek to identify the viable costs of insulation.

The energy cost model is a highly simplified one which is used to identify the most economic solution by comparing the differences among the candidates. The study explores the methodology rather than aiming to obtain the accurate energy cost. Future work will involve constructing a more comprehensive and practical model to predict the actual energy cost.

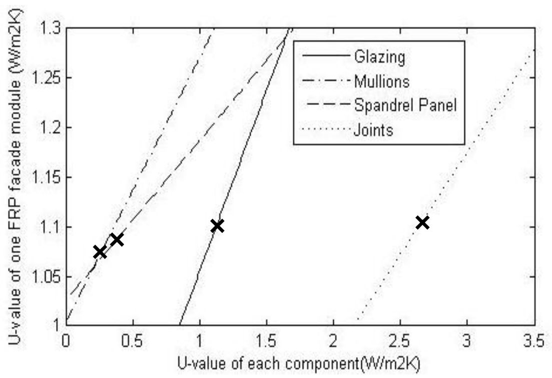

Figure 6: U-value relationships between each component and one FRP façade module, when other components are kept unchanged. The original design value is denoted by x.

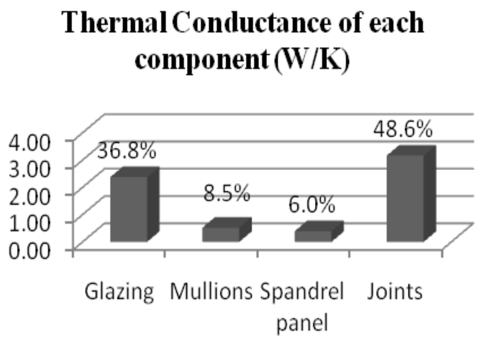

Figure 7: Energy loss through each component for one façade module (original design).

SUMMARY

3-D spandrel panels are modelled and the optimal geometric parameter combinations are obtained. Knowing that the point load (PL) is critical and the deflection constraint is always active, structural optimisation is achieved in the first instance to determine the cross-section of the spandrel panel. The air cavity is subsequently filled with a thin layer of aerogel to satisfy the thermal insulation and translucency requirements. Future work should focus on improving the thermal performance of the joints.

ACKNOWLEDGEMENTS

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DEVELOPMENT OF VACUUM GLAZING WITH ADVANCED THERMAL PROPERTIES

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ABSTRACT

Windows constitute a weak link in the building envelope and hence contribute significantly to the heating energy demand. By evacuating the glazing cavity, theoretical heat transfer rates two to five times lower compared to conventional gas-filled windows are predicted and have been practically confirmed in a few cases. Of central importance to any practical realization of vacuum glazing is the edge-sealing issue. Therefore we begin with a short overview of common methods. The sealing technology defines many secondary parameters and properties relevant to both fabrication and the final product. Advanced evacuated glazing systems will require new innovative approaches to tackle problems associated with a large scale *in vacuo* sealing. We present a second look at the topic with emphasis on a novel edge sealing method which was recently developed in our laboratory. In addition a transient pressure balance model relevant for service-life will be presented. A comparison of fabrication methods shows advantages and drawbacks of current technology and a significant potential for improvement with the method presented here. Additional steps towards upscaling are discussed in the outlook, raising hopes for a timely realization of next generation evacuated glazing systems.

INTRODUCTION

With ever increasing glazed facades in modern architecture, significant energy losses are accrued due to the poor insulation performance of glazings when compared with wall constructions. Hence an improvement of current glazing technology is of great importance to reduce the total heat loss in buildings. The heat transfer mechanisms in gas-filled glazing cavities include radiative exchange between the glass surfaces, convection and gaseous conduction of which the last two account for the main losses in modern windows [1]. A drastic reduction of gaseous heat transport can be achieved by evacuation of the glazing cavity. The success of vacuum glazing is contingent on the realization of a hermetic edge seal which can maintain a high vacuum inside the cavity ($p < 0.1$ Pa) over decades. Even twenty years after the first working prototypes, the edge seal still remains a major challenge keeping further commercial realization of next generation evacuated glazings with advanced properties at bay.

THE IDEAL EDGE SEALING METHOD

Zoller first described this concept of an evacuated glazing in his patent in 1913 [2]. A laser welding technique for producing evacuated glazing was investigated at the US Solar Energy Research Institute [3] The deflection due to atmospheric pressure was reduced by spherical glass spacers with radii roughly 0.25–1.5 mm, periodically spaced between the glass sheets. However, difficulties with the edge sealing prevented the manufacture of complete glazing units. Collins and his group at the University of Sydney [4] first fabricated a double vacuum glazing unit by a glass solder process operating around 500°C. A 0.1–0.2 mm wide cavity was evacuated to a pressure below 10^{-1} Pa. Radiative transfer is lowered using a low-emissivity coating on the inner surfaces. The high process temperature imposes limitations on the use of low-emissivity coatings and tempered glass. In collaboration with the University of Sydney, a Japanese company developed a commercial double vacuum glazing unit with a thermal transmittance of roughly 1.5 $W \cdot m^{-2} \cdot K^{-1}$, other similar products followed later on.

In an attempt to overcome the restrictions imposed by the high-temperature glass solder process, a low-temperature method was investigated at the Universities of Ulster and Patras. In this case, a weak but leak tight seal was made from indium wire below 200°C and the assembly reinforced for mechanical toughness by epoxy gluing [5]. From an economic point of view, this method is unsuitable due to the high cost and low abundance of indium metal. Baechli [6], a Swiss inventor, developed a hermetic sealing technique based on soft soldering of glass panes which are metallised on the outer perimeter prior to soldering.

Except for the Baechli method, all edge sealing methods tested and mentioned so far employ sealing under ambient conditions followed by a consecutive evacuation through a pumpout port. This does not only complicate production but it is impractical for large glazing manufacture because the reduced pumping speed at submillibar pressures results in long pumping times. In addition, restricted outgassing and surface cleaning possibilities in between the panes raise major questions about long-term stability. Significant improvement over current technology can be achieved, if the following criteria for an ideal sealing process are met:

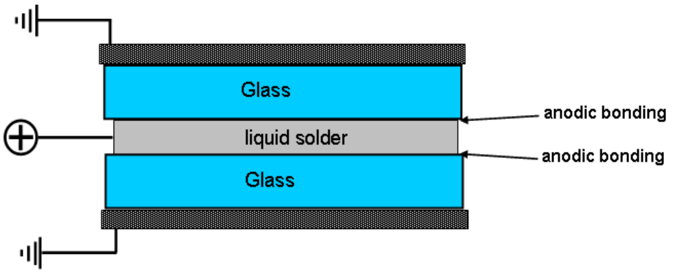
- medium process temperature to prevent damage to low-ε coatings and to prevent loss of tempering. An ideal sealing temperature is between 150°C and 350°C because outgassing ("baking") of the glass panes *in vacuo* is faster at elevated temperatures.
- sealing *in vacuo*: A "seal and forget" process eliminates the necessity for evacuation through a pumpout tube and with it a number of related problems.
- surface cleaning (UV/ozone or plasma sputtering) and baking of individual glass panes in a vacuum environment separated by a minimum distance (>10cm) eliminates limitations due to photofragmentation reactions and long-term outgassing respectively.
- a fast and inexpensive process is essential for economical large-scale production.

Only an integral approach which satisfies all of these requirements can yield "advanced thermal properties" as claimed in the title. There is very little solution space for finding new technologies which are low-cost and meet the above criteria. Two promising solution approaches worth mentioning are the ones of Pro-VIG, Germany [7] and Empa respectively.

EXPERIMENTAL

a) Edge sealing experiments

Anodic bonding with activated liquid solder alloys was investigated as a promising sealing method [8]. The anodic bonding process can produce mechanically strong connections between an insulator and a metal without the need for sample pretreatment or activation [9], whereas working with a liquid metallic sealant allows perfect adaptation to both glass surfaces along the entire perimeter, a key prerequisite for satisfying the extreme tightness requirements. Working with only inorganic materials (metal and glass) ensures vacuum compatibility for *in vacuo* sealing and eliminates the potential outgassing of the sealant over time. Figure 1a shows a schematic of a typical sealing experiment: a positive electrical potential from a high voltage power supply is applied to a (liquid) tin based solder metal which is caught between two glass sheets and results in simultaneous bonding of the metal to both glass pieces. Both sheets are heated by means of two resistively heated metal counterelectrode plates which are held at ground potential, each in contact with the side opposite to the liquid metal.



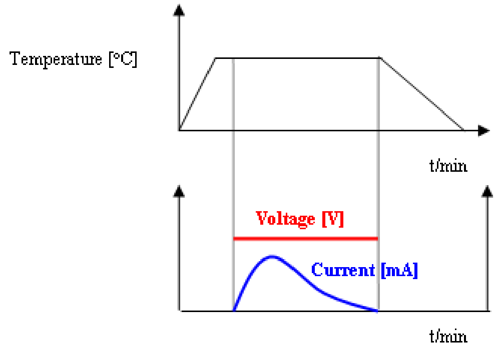


Figure 1a: anodic bonding setup schematic *Figure 1b: Temp., voltage & current profile*

All experiments presented here were conducted under high vacuum conditions. Typically, a piece of SnAl0.6%$_w$ solder alloy (melting point ~ 225°C) is sandwiched in between two 5cm by 5cm 4mm thick precut float glass squares and contacted to the positive lead of the high voltage power supply. The assembly is then placed between two heatable Cu metal electrodes inside a vacuum chamber and the system evacuated to a base pressure below 0.07 Pa ($7 \cdot 10^{-4}$ mbar). The assembly is then heated to the desired sealing temperature. After a 15min. equilibration period which ensures melting of the solder alloy (Figure 1b), a DC high voltage (red line) is applied and the corresponding bonding current observed (blue line). Following the decay of the current below 5% of its peak value (typically within 10 minutes), both high voltage power supply and heating are turned off. Upon cooling to room temperature, the vacuum system is vented and the sealed specimen recovered.

b) Transient pressure increase service life model

A central question governing the practical applicability and chance for success of future commercial products is the service life aspect: If a pressure of 10^{-1} Pa is to be maintained over a typical lifetime of 30 years, no significant pressure build-up must occur during that period. Here we present a phenomenological approach to describe the service life in terms of the different sources of pressure increase inside the cavity. The four sources 1) through 4) of matter as well as the getter 5), which are symbolized in Figure 2, have to be considered relevant to the systems transient pressure behaviour and service life:

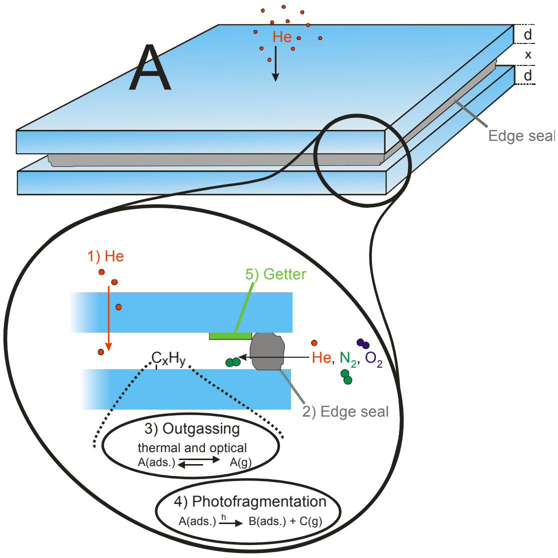


Figure 2: Five phenomena relevant for complete pressure balancing

1) ***Permeation of gas molecules (mostly He)***
2) ***Leakage through the edge seal***
3) ***Thermal and optical desorption of organic adsorbate species***
4) ***Photogfragmentation reactions of large adsorbate molecules***
5) ***Removal of accrued gas by trapping with a non-evaporable getter material***

In this work we present, in a phenomenological form, the key parameters for each one of the five phenomena which need to be taken into account and provide estimates for pressure increase values from each one under conditions closely matching large scale production.

RESULTS

a) Edge sealing experiments

A typical bonding specimen is shown below in Figure 3a. It was fabricated from a coin-shaped SnAl0.6%$_w$ specimen at 300°C. Two 150µm thick Al strips were used as a spacer. A voltage of 780V was applied for 10 minutes (Figure 3b) yielding a peak bonding current density of around 0.3 mA·cm^{-2}. In the photographic image one can distinguish between the original (**o**) area and a region of freshly squeezed out (**f**) solder. The former is greyish and shows clear signs of oxidation whereas the latter exhibits a defect free mirror like surface.

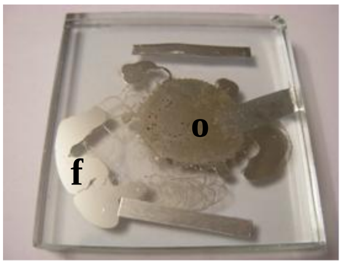


Figure 3a: Image of SnAl Coin bonding specimen

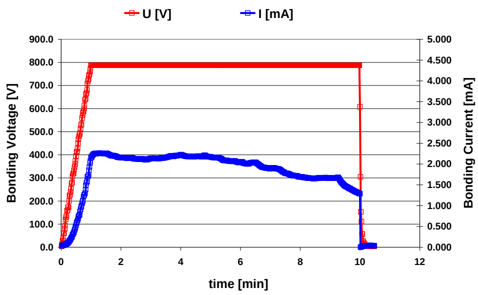


Figure 3b: I/V profile of SnAl anodic bonding (300°C)

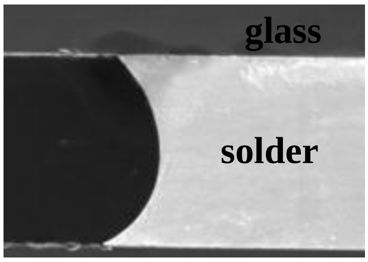


Figure 3c: SEM inspection of the bonded interface

Scanning electron microscopy (SEM) analysis of the interface was used for bond characterization: A polished cross sectional cut of the specimen was coated with a thermally deposited carbon film and characterized by SEM and EDS. An image of the complete cross section (Figure 3c) showed wetting of the glass by the alloy after anodic bonding, the control experiment without anodic bonding (melting SnAl alloy only) did not show the same wetting.

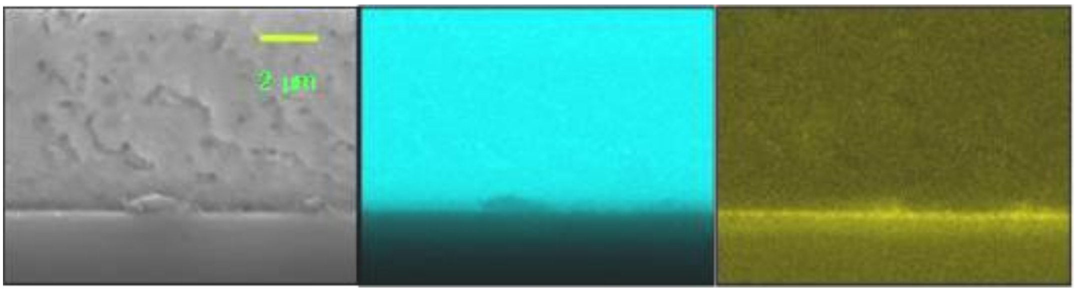


Figure 4: Interface analysis of SnAl0.6%m bonding specimen

Figure 4 shows an SEM image of an interfacial cross section (left) with the solder being on top and the glass on the bottom. The Sn element EDS map in the center matches the expected distribution of Sn for the metal/glass interface. The Al map on the right features a bright strip along the glass/solder interface suggesting enrichment of the active component Al along that same interface. Significant amounts of Al^{+3} ions formed by anodic oxidation (evidenced by a large bonding current) diffuse into the glass under the action of the E-field during the anodic bonding process. This observation counts as strong evidence for the activating role of Al. Using a 3.5cm by 3.5 cm wire frame, the liquid solder anodic bonding produced leak-tight specimens with a leak rate < 10^{-10} mbar·l·s^{-1}, the detection limit of our He leak testing device. Experiments on laboratory scale (0.5m by 0.5m) prototype manufacture are now in progress.

b) Transient pressure increase service life model

In Table 1, the results of the pressure / service life model are summarized: the key parameters and their effect **(+ … ++++** and **- … ----** causing a **minor … major** pressure increase or decrease respectively) for the five relevant phenomena in symbolized in Figure 2.

1) Gas permeation		2) Seal leakage		3) Outgassing		4) Fragmentation		5) Getter	
Glass type	++++	Seal integrity	++++	*In vacuo* assembly	++++	Surface cleaning	++++	Molecular species	- - - -
Gas species	+++	Bond integrity	++++	Surface cleaning	++(+)	Type of adsorbate	+++	Getter composition	- - -
Temperature	++(+)	Sealant material	++(+)	Outgassing Temp.	++	Irradiance	++(+)	Outgassing Temp.	- - -
Pane thickness	+					Optical spectrum	++(+)		

Table 1: Key parameters and their effect on the transient cavity pressure (by phenomena 1-5)

Based on our model calculations, the permeation of ambient air constituent gases through glass driven by the inside/outside pressure difference 1) strongly depends on the permeating species. Helium permeates by orders of magnitude more rapidly and is the main source of pressure buildup despite its minute concentration in ambient air. High alkali content glasses exhibits much lower permeation rates compared with fused silica or borosilicate glass. This makes standard float glass an ideal candidate for vacuum glazing applications. For a 6mm float glass evacuated glazing we predict a permeation-induced pressure increase after 100 years below 0.05 Pa at T = 35°C. Like any diffusion process, gas permeation is strongly temperature dependent and can become lifetime limiting at long-term exposures at temperatures above 70°C.

The seal tightness defines the amount of leakage through the edge seal 2) and is an intrinsic property of the sealing system and technology used. For reasons of outgassing and permeability, only inorganic materials (metals and metal oxides) are suitable sealants. Of utmost importance is the absence of bonding defects and perfect adaptation to both panes along the entire sealing perimeter. Leakage of such complex systems is difficult to model numerically. Instead, the direct measurement of bonding specimens is a good way to assess the performance of edge sealing technologies. In our case, bonding specimens fabricated in our laboratory exhibited leak rates below the limit of detection of the instrument i.e. $< 10^{-10}$ mbar $\cdot$ $l^{-1} \cdot s^{-1}$. For a realistic seal tightness of 10^{-13} mbar $\cdot$ $l^{-1} \cdot s^{-1}$ in an advanced vacuum glazing, a pressure increase less than 0.1Pa after 30 years will be due to seal leakage.

Thermal and optical outgassing 3) is strongly design and sealing method dependent and has been studied in the case of solder glass specimens [10]. From a simple adsorption/desorption point of view, a sample which is equilibrated at T > 200°C and $p < 10^{-5}$ Torr (such as typically done in HV systems), will not outgas any further once cooled to ambient temperature. Hence no significant pressure increase from thermal and optical outgassing (< 0.03 Pa) is expected for samples fabricated *in vacuo* at temperatures from 200° to 300°C.

Another possible source of pressure buildup not discussed in the literature thus far is the photofragmentation 4) of long-chain aliphatic molecules such as tensides, silicones, and hydrocarbons on the glazing surface under the action of sunlight, particularly its short wavelength components. Such soap-like contaminants are omnipresent and adsorb more or less irreversibly on any surface from ambient air. Under optical irradiation they will slowly but steadily decompose into smaller fragments through a variety of photo-fragmentation reactions. The potential for a possible pressure increase by such a mechanism is tremendous: If a surface were covered to the extent of only 5% of a monomolecular layer with such a soapy molecule, complete fragmentation would bring about a pressure increase inside the cavity of more than 10 Pa! The potential for photofragmentation induced transient pressure increase can be drastically reduced if these long chain hydrocarbon based contaminants are removed. For this purpose, surface cleaning methods such as UV/ozone or plasma cleaning known from surface science and semiconductor clean room technology can come in handy. We have conducted an extensive Time-Of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS) surface analysis study of decorated glass surfaces before and after cleaning. A reduction of the primary mass peak signature of the model contaminant sodium dodecyl sulfate (SDS) of more than 10^3 upon a 10min ozone treatment was found. Further, a significant decrease in other long-chain hydrocarbons was observed as well, indicating that the oxidative degradation reaction goes more or less to completion. In other words only small volatile molecules are left after the cleaning which are pumped off easily during *in vacuo* assembly hence and will be removed from the system completely prior to sealing. Hence, surface cleaning can reduce the potential for photodegradation induced pressure increase by at least three orders of magnitude which corresponds to a maximum pressure increase below 0.02 Pa assuming a 5% monolayer coverage of long-chain organic surface contaminants.

Under consideration of ideal process conditions, it seems possible that all sources of pressure increase are kept within a limit such that the total pressure buildup after 30 years is below 0.1Pa. In this case, the use of getter materials 5) becomes expendable. Otherwise, detailed investigations regarding the nature of compounds which accumulate inside the evacuated gap is necessary, after which the proper getter material type and loading can be determined.

CONCLUSION

In the beginning the importance of the edge sealing technology was pointed out. Future “advanced” products are contingent upon the combination of *in vacuo* assembly and proper surface cleaning procedures. We have developed a promising vacuum compatible liquid solder anodic bonding technique with activated tin-solder for fabricating a metallic seal with excellent hermeticity and sufficient mechanical strength in one step without the need for glass premetallization. The integrity of large perimeter seals, particularly under cyclic thermal loading conditions, remains to be tested and the bonding system optimized for large scale manufacture as well as maximum durability and strength.

In parallel we have postulated a service life analysis description for vacuum glazing. Our model takes into account four sources to the total pressure increase and one possible sink, the getter. Understanding all relevant phenomena defines a set of parameters which will ascertain the required 30 year service life of a glazing without performance loss. Of utmost importance is the interrelation between *in-vacuo* sealing, process temperature and surface cleaning.

ACKNOWLEDGEMENTS:

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M-GLASS: INNOVATIVE COATINGS FOR SUN PROTECTION GLASSES BASED ON THE THEORY OF THE OPTIMISED SPECTRAL TRANSMITTANCE

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ABSTRACT

In this paper new coatings for sun protection glasses for windows and glass façades are presented. These coatings reduce the solar-thermal load of building's interior by one third in comparison to current sun protection glasses on the market. Apart of the comfort improvement for occupants the energy necessary for cooling of buildings is reduced and therefore these new coatings can contribute to the measures needed to reduce global climatic changes.

On the CISBAT 2005 Conference we presented a theoretical model for an optimised spectral transmittance τ_{min} for sun protection glasses [1]. This transmittance predicts a lower limit of the energy load coefficient τ_e/τ_v of 0.33.

The present contribution deals with the experimental realisation of the optimised spectral transmission $\tau_{min}(\lambda)$. Based on multiple cavity bandpass filters new multilayer coatings for sun protection glasses were developed. The transmittance of the new coating should be close to the optimal spectral transmittance and the transmitted light has to be colour neutral. In the course of our design studies for the optical multilayer stacks it turned out that the same coating materials can be used as for commercial sun protection glasses. The energy load coefficient τ_e/τ_v for the new coatings is between 0.34 and 0.40.

Currently the transfer of the M-Glass design to industrial production is performed by the Glas Trösch AG (Bützberg, Switzerland) in close collaboration with the University of Basel. Various prototypes of M-Glasses in the τ_v-range between 0.40 and 0.58 have been developed. New designs especially in a lower τ_v-range are currently examined and lower *g*-factors are envisaged.

INTRODUCTION

Overheating of buildings due to extreme heat loads by solar radiation has become a well known phenomenon caused essentially by architectural preferences for highly glazed façades on one hand and on the other hand by climatic changes. Measures to solve the problem of overheating could be appropriate architectural design, variable shading and blinds, switchable window glazing and sun protection glazing. For switchable window glazing, having a variable transmittance, first products are now available on the market. The investigation of two products are described in another contribution to this conference [2]. Sun protection glazing in comparison have a static, selective transmittance which ideally only transmits radiation in the visible wavelength range. Investigations on commercial sun protection glazing which are summarised in a database [3, 4] have shown that the blocking of the infrared radiation is not sharp and long tails with significant transmittance in the near infrared (NIR) region are present. The new developed multilayer coatings described here are based on the theory of the optimised spectral transmittance τ_{min} which reduces the unnecessary energy input to buildings [1]. This reduction is achieved by steep slopes of the transmittance function at violet and red wavelengths to reduce the fadeouts in the UV- and NIR-region. In order to obtain a colour neutral transmission, after cutting off part of the red and violet light, the amount transmitted in the green (around 550 nm) has to be reduced. This leads to the characteristic M shape of the optimised spectral transmittance.

METHOD

The thin film multilayer systems described here were deposited by magnetron sputtering on 4 mm thick float glass in the laboratory in-line plant of the Glas Trösch AG. The base pressure of the deposition chamber is 10^{-6} mbar. Before the deposition the float glass substrates were mechanically cleaned in a commercial glass cleaning plant. In order to obtain homogeneous and flat films the substrates were moved across the different magnetron cathodes with constant speed during deposition. Speed as well as the power applied to the magnetrons depended on the material to be deposited. As sputtering gas pure argon was used. For oxide layers, like zinc oxide, reactive sputtering from a metallic target was used, for which oxygen was let through a mass flow controller into the chamber. The thickness of the layers was controlled by deposition time and rate, after calibrating the deposition rate by ellipsometry measurements.

The optical characterisation of the coatings was performed on an UV-Vis-IR-spectrophotometer Cary 5 from Varian and the windows stand developed at the University of Basel [5]. The Cary 5 is equipped with an Ulbricht sphere and has a wavelength range from 250 nm to 2500 nm. With the window stand transmittance and reflectance can be measured over a wavelength range from 350 nm to 2150 nm and angle dependent for 0° to 75° angles of incidence.

RESULTS

The M-glass multilayer coatings described here are based on a double cavity bandpass filter, which contains ten layers made of silver (Ag), titanium (Ti), and zinc oxide (ZnO). Silver was chosen as metal as it is a very good infrared reflector and is transparent in the visible [6 - 10]. Further it is the standard infrared reflector used in industry for sun protection coatings. Zinc oxide as a wide band gap semiconductor (3.3eV) is transparent for visible and infrared radiation and has a relative high refractive index of n=1.8 - 2.0 [11, 12]. To prevent oxidation of freshly sputtered silver films during the following reactive sputtering deposition of the ZnO layers a thin blocking layer is needed. Titanium was chosen, as it becomes transparent for visible and infrared radiation if it is later oxidised to titanium dioxide (TiO_2) during the reactive ZnO deposition [13, 14].

The thicknesses for the individual layers of the multilayer coating were determined by simulations with the simulation software TFCalc and than adjusted during the deposition. The boundary conditions for the simulation and the deposited coatings were:

- the transmittance should be equal or at least close to the theoretical optimised spectral transmittance $\tau_{min}(\lambda)$
- the light transmitted by the coating should be colour neutral
- the colour properties of the coating should be stable for all angles of incidence
- the light transmittance τ_v for perpendicular light incidence should be 0.5 or greater

The measured spectral transmittance of such a thin film multilayer coating for perpendicular incidence is shown in figure 1. Further given in this graph is the theoretical curve of the optimised spectral transmittance τ_{min} and the simulated transmittance on the bases of which the layer thicknesses for the deposition were determined. It is obvious that measured, simulated, and theoretical transmittance are not identical. Other samples, not shown here, have shown, that a better agreement of the measured and the theoretical transmittance is only achieved when other boundary conditions of the list given above are not strictly fulfilled. The main discrepancies between measured, simulated, and theoretical transmittance are the absolute values of the peaks and the dip, and the slope around 650 nm which is shifted to higher wavelengths. This shift and the increase of the transmittance could be solved as it is based on the fact that the silver layers in the deposited multilayer coating are thinner than determined during simulation. For this coating the light transmittance τ_v is 0.561. The energy load coefficient τ_e/τ_v of this M-coating is 0.398 which is not as low as the theoretical limit of 0.334, but much lower than the value of 0.5 the currently obtained lower limit for sun protection glazing on the market. The reason for the increase of the energy load coefficient τ_e/τ_v for the measured in comparison to the theoretical transmittance is the shift of the slope at 650 nm to higher wavelengths. This shift increases the amount of near infrared radiation that is transmitted through the glazing, and therefore increases the value of the direct solar transmittance τ_e while it has a smaller impact on the light transmittance τ_v.

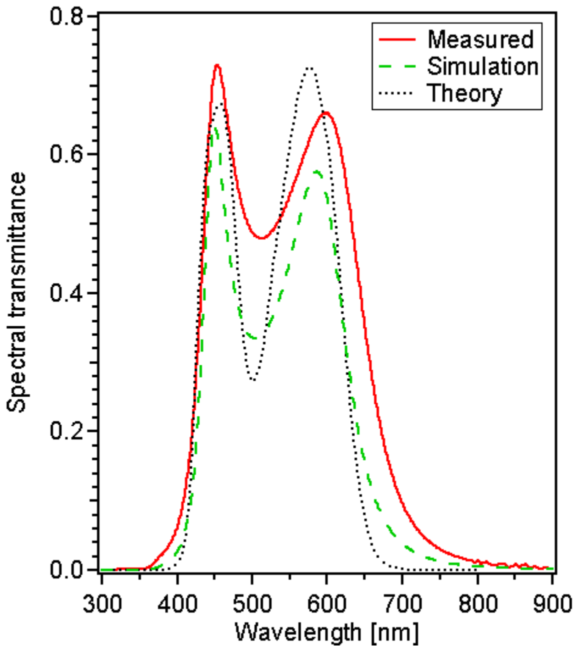

Figure 1: The measured spectral transmittance of the multilayer coating, the simulation used for the deposition, and the theoretical curve of the optimised spectral transmittance for perpendicular light incidence.

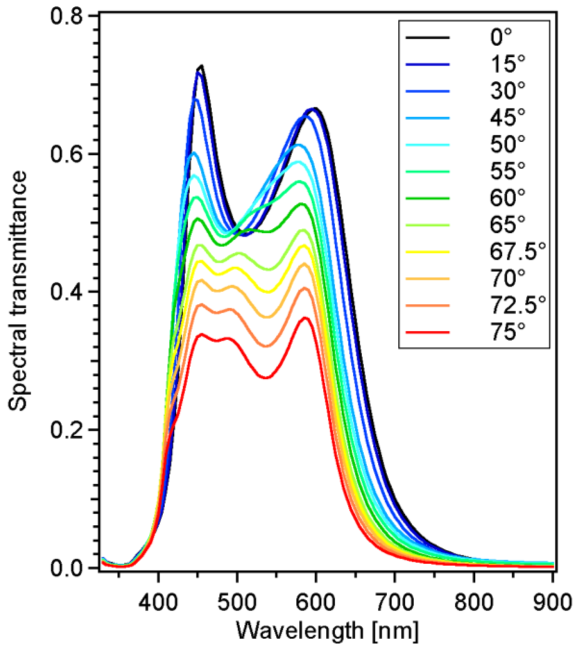

Figure 2: The measured spectral transmittance for different angles of light incidence.

To fully characterise the optical and energetic properties of a multilayer coating the angle dependency needs to be investigated. The measured transmittance for different incident angles (ϕ = 0° to 75°) is given in figure 2. Up to an angle of 55° the shape of the transmittance is barely changing. But it is getting narrower as the right slope is shifting to the left to smaller wavelengths. For larger angles of incidence the shape of the transmittance is changing, but the two initial peaks are visible independent of the angle of incidence. The shift of the right edge and the change of shape has influence on the values of the solar direct transmittance τ_e and the light transmittance τ_v and therefore on the energy load coefficient τ_e/τ_v of the coating as depicted in figure 3. With increasing angle of incidence the obtained values for the light transmittance τ_v (blue) and the direct solar transmittance τ_e (red) are continuously decreasing. The relative change of the two values is different which results in a reduction of the energy load coefficient τ_e/τ_v (green) when the angle of light incidence ϕ is increased. This is a welcome feature during summer, when the angle of incidence on a glass façade is higher than during winter. In other words the energetic impact is higher during winter than during summer, and therefore reduces heating costs in winter and cooling loads in summer.

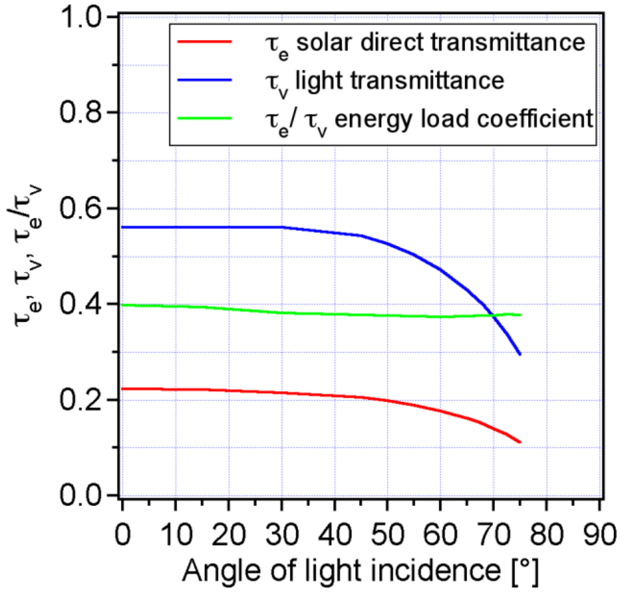

Figure 3: The evolution of the light transmittance $\tau_v(\phi)$ (blue), the solar direct transmittance $\tau_e(\phi)$ (red), and the energy load coefficient $\tau_e(\phi)/\tau_v(\phi)$ (green) for different angles of incidence ϕ.

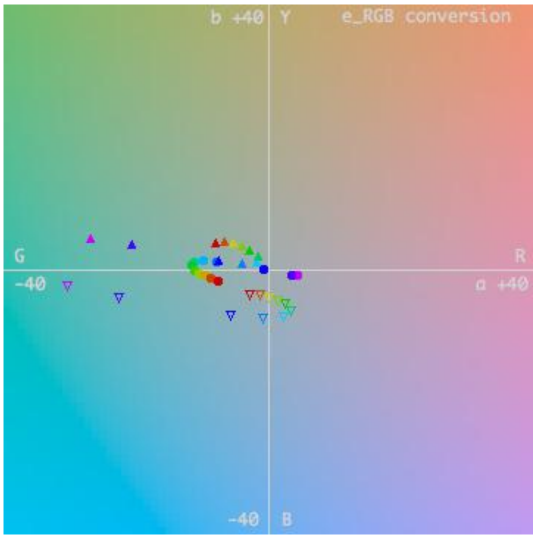

Figure 4: The colour evolution in the CIE Lab colour space at constant luminosity L of the transmittance (full circle, ●), reflectance glass side (full triangles, ▲), and reflectance layer side (empty triangles, ∇), if the angle of light incidence ϕ is changed. For the smallest angle a purple symbol and for the largest a red symbol is used.

Besides the optical and energetic properties the colour of the transmitted and reflected light plays an important role in the characterisation and during the selection procedure of sun protection glazing used for a building. One critical feature as already defined in the boundary conditions is, that the transmitted light should be colour neutral. Transferring this to the CIE *Lab* colour coordinate system, where *L* denotes the light intensity and *ab* the colour axis (*a*: red to green; *b*: yellow to blue), the colour values for the transmitted light should be a=0 and b=0. The angle dependent colour values determined from the measured transmittance and reflectance respectively are given in figure 4. In this graph the value for *L* was chosen arbitrarily to obtain a suited graphical representation and the angles of incidence are colour coded starting with violet for the smallest angle (0° or 15° for transmittance or reflectance, respectively) and going to red for the largest angle of incidence (75°). The colour values for the transmitted light are represented by the filled circles ●, whereas the filled triangles ▲ represent the light reflected from the outside, the glass side of the sample, and the empty triangles ▽the light reflected directly from the multilayer coating surface. In figure 4 we see, that the values for the transmitted light (●) are located in the centre of the *ab*-plane and the light is therefore in an regime which is still recognised as colour neutral by the human eye. Therefore the boundary condition defined for the development of the new M-shaped sun protection coatings, which is also a general boundary condition for all coated window glasses, is fulfilled. The colour values of the light reflected from the outside (▲), which is relevant for the optical appearance of a building, are all located in the top left, the green quadrant of the *ab* plane. This means that the green hue of the reflected colour is not changing when the angle of incident is changed. The values of the layer side (▽) are of minor importance, as they change when a second glass pane is added to obtain an insulation glass.

DISCUSSION

With this experimental realisation it was possible to show, that multilayer systems consisting of ten layers using standard materials like silver, zinc oxide and titanium oxide are sufficient to achieve coatings which have a spectral transmittance that is close to the theoretical optimised spectral transmittance τ_{min}. Using different layer thickness combinations the value of the energy load coefficient of these coatings varies between 0.34 and 0.40. The above described coating has a relative high energy load coefficient but in this coating the focus during the realisation was on finding an optimum for all defined boundary conditions. The boundary conditions were a colour neutral light transmittance, angle independent optical properties and colour, the M-shaped spectral transmittance, and a light transmittance of 0.5 or greater.

The advantage of using a M-glass instead of a normal commercial sun protection glass can be shown illustratively by dynamic temperature simulations for a simple room in Zurich, where only the glazing is changed. Details concerning the assumptions made for this temperature simulation are given on the glass database of the University of Basel [3, 4, 15]. The used room (10 x 6 x 2.7 m^3) has a south facing glass façade of 21 m^2. When the temperature in this room is calculated over a ten day sunny period it is obvious that for both, a commercial sun protection glass (Pilkington, Insulight TM Sun Silber 37/32, τ_v= 0.41, τ_e/τ_v=0.681) and a M-insulating glass (τ_v= 0.44, τ_e/τ_v=0.412), the mean temperature increases. In fact, the rise of the room temperature with the Pilkington glass after this sunny ten day period is 10°C whereas it is only 5.1°C when the M-glass is used. This means the temperature increase is 1.96 times higher for the room with the Pilkington glass. In other words the energy needed for cooling is reduced by 51,2% when the M-glass would be used instead.

Currently the M-glass coatings are transferred to industrial production with the Glas Trösch AG (Bützberg, Switzerland) in closed collaboration with the University of Basel.

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ACTIVE LOWEX GEOTHERMAL WALL INSULATION SYSTEM

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ABSTRACT

We have designed a new building wall that utilizes the low value energy from a ground source heat exchanger (GSHE) to increase the external temperature of the wall above cold outside temperatures during the heating season. This makes the buildings feel as if it has been moved to a warmer climate, or alternatively seem as if it is has been buried underground where there is a constant moderate temperature. This drastically reduces the heat loss from inside the building as the temperature of the wall is constantly between 8 and 14 degrees Celsius all winter depending on depth and operation of the GSHE.

We present the first realization of this concept in a wall being designed for the B35 low exergy (LowEx) building project in Zurich, Switzerland. With a relatively thin construction of only 38cm, we show how the wall can meet passive house standards. But this is just for the coldest month of January, because the active insulation performance varies over the year according to the outside temperature. A successful calculation of a wall U-value for use in the Swiss energy norm is also demonstrated. In the end, a very high performance wall has been designed that is not excessively thick. In essence the system allows for an additional 10 m^2 of living space on each floor of the building compared to what would be available with typically thicker passive house walls.

The active wall is part of a fully integrated low exergy (LowEx) system. The heat pump performance in an integrated system can be maximized because the heating demand for the heat pump is held constant by the wall, thus eliminating losses due to cycling on and off, or due to variable speed drive inverters.

These concepts are all parts of the group of LowEx systems that are being demonstrated in the B35 building (www.viagialla.ch). The high performance thin wall is realized using high performance foaming concrete with a layer of EPS foam and an outer layer of insulating plaster. The integration of a new special GSHE and heat pump with heat recovery are also being designed and planning is nearly complete with construction beginning in 2009.

INTRODUCTION

High performance buildings place strict requirements on the walls of a building, to reduce the amount of heat loss. Buildings that meet the passive house standard can often be recognized not just from their energy performance, but already at first sight because of the thick well-insulated walls. Unfortunately thick walls are not always aesthetically pleasing and they also consume valuable interior space.

This new concept for wall insulation was a result of the desire to reduce the thickness of walls needed to meet the demands of high performance buildings, while also providing a thinner installation option for retrofits. Instead of increasing the resistance to heat flow through the wall using static insulation, we recognized the inherent value in ground heat and used that to decrease the temperature gradient across the wall. Research into ground heat extraction especially for integration into heat pump systems has been studied for many years [1, 2, 3]. Research has shown that with proper sizing of a ground source heat exchanger based on heat demand, a relatively constant temperature can be extracted throughout the winter [4]. Still, typical ground temperatures are at least 10°C cooler than comfortable temperatures demanded for buildings with Zurich having temperatures of about 8°C and increasing about 3°C for every 100 m of depth [5]. Therefore ground heat cannot be used directly *inside* the building.

Through our research in the field of exergy and buildings [6], which considers the second law of thermodynamics, we were interested in maximizing the performance of heat pumps. This performance (COP) is the ratio of heat supplied Q to electric work input, W, and it is limited by the temperature difference that the heat pump must overcome as shown in Equation 1, where T_h is the heating temperature, T_g is the supply temperature and the η_{Carnot} describes the internal losses of the system and is usually around 0.45 to 0.50 for a good heat pump.

$$COP = \frac{Q_{supply}}{W_{elec}} = \eta_{Carnot} \frac{T_h}{T_h - T_g} \tag{1}$$

The lower the temperature difference is, the higher the COP becomes and therefore the more heat you get per unit electricity. In this case, the heat from the ground is freely available low quality energy that could be considered dispersed energy or ‘anergy’ as described in previous work [7]. The performance of the heat pump is only dependent on the temperature of the ground heat and not on its quantity. Unfortunately the temperature is fixed by ground conditions, but by viewing this anergy as freely available we are able to consider an application that might demand a large quantity. Figure 1 describes how heat from the ground can be used directly at its lower temperature in an external layer of the façade to reduce the temperature gradient and thus transmission losses of the building during winter.

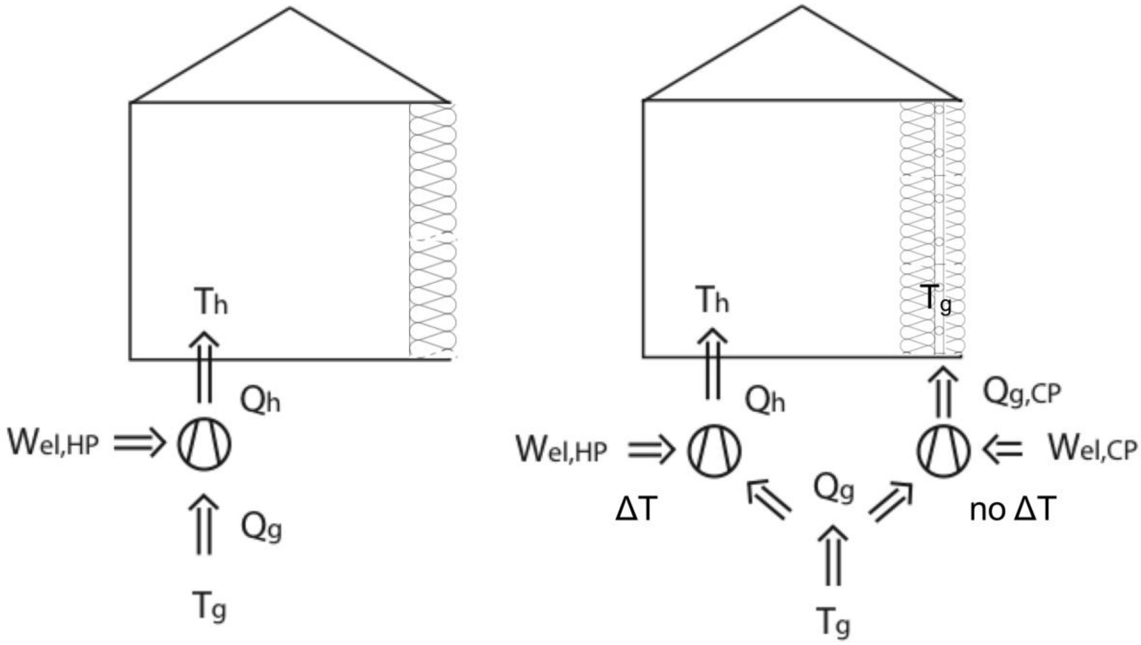

Figure 1: In a standard ground source heat pump setup all the heat, Q_h , must be provided at a higher temperature, T_h , which requires electric heat pump compressor work, $W_{el,HP}$, to extract the ground heat, Q_g. whereas with the active insulation system part of the ground heat can be used directly without the need for a temperature lift with only a small amount of electric work for the circulation pump, $W_{el,CP}$.

This low exergy (LowEx) active insulation system reduces the heating load of the heat pump by cancelling out all outdoor temperatures that would be below the ground temperature. In other words, the building walls do not feel any extreme temperatures of winter. It is as if they are buried in the ground, and the benefits of buried or earth-contact buildings has a long history and proven benefits [8].

It was initially unclear whether the idea would be feasible. There would be additional pumping costs and the temperature outside is not always lower than ground temperature over winter. An initial study was done looking at the potential design and performance of the system and its subsequent feasibility [9]. This found that a system of inexpensive 1cm pipes with 5 cm spacing between each other could provide an even temperature using ground heat at 12°C at the outer layer of the wall when covered with only 2 – 4 cm of insulating plaster. It was also shown that at the outside design temperature for Zurich of -8°C with just a 6-cm thick active wall layer attached to an 18cm concrete wall, a performance could be achieved that was equivalent to 20-cm of quality static insulation achieving an equivalent U-Value of 0.10 W/m^2K that is below passive-house standards. The effect of varying the amount of insulation below and above the piping layer was analyzed as well as the topology of the piping installation. The required mass flow rate was considered to estimate the pressure losses and pumping costs, which were less than 1% of the heat energy lost per m^2 of wall.

A second study was done in parallel looking at the integration and influence of the active insulation system [10]. This compared two 10x10x10 meter buildings. One had a ground source heat pump and integrated active insulation, and the other had the same heat pump, but in this case an amount of static insulation equal to the total active insulation thickness was used. The active insulation also included the pumping costs for the wall as well as the extra pumping required for the larger amount of heat from the ground source heat exchanger. What is more interesting is that the cyclic on-off losses of the heat pump due to varying outside temperature could be eliminated. The end result was that the active insulation system, when designed with a total thickness of 5-cm or 7-cm had about a 15 and 20% better performance for the winter season in Zurich. Even though the performance at low temperatures is many times higher than the static insulation [9], the frequency of higher-than-design-temperature periods marginalized the improvement somewhat. It is expected that the system would perform even better in consistently colder climates with good ground heat accessibility.

In this analysis we look at the application of this wall system in its pilot installation for the B35 building in Zurich. The goal was to analyze the wall performance so that it could be input into the SIA 380/1 energy verification by the building engineering firm.

METHOD

The SIA 380/1 requires the surface area of the building and the U-value of those external surfaces to determine the energy requirements. The virtual U-value for the active insulation system has already been evaluated for simple constructions [9], but in this case a realistic analysis of the actual construction shown in Figure 2 was needed.

The wall incorporates an expanded concrete with low thermal conductivity and a core of EPS foam is installed in the center. The active insulation piping is attached to the outside with a covering of insulating plaster for a total thickness of only 38cm.

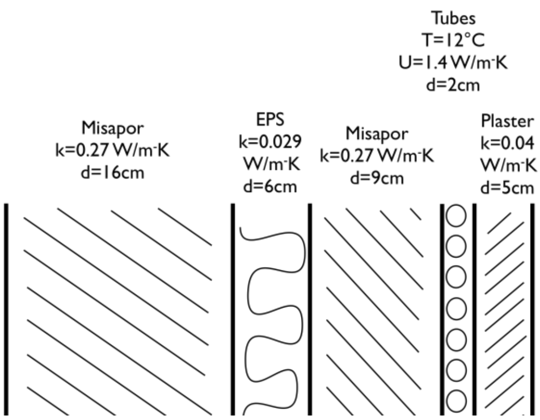

Figure 2: B35 wall construction layers and piping outside piping system

The same model from the previous analyses [9,10] was used with this wall construction to analyze the system. As shown in the previous models, the U-value changes for different outside temperatures, so a realistic annual value had to be evaluated. First the static U-Value was calculated for the wall without any fluid flowing through it. Then the operation of the active insulation was analyzed over a range of temperatures, and the outside temperature where the benefit of the active system becomes negligible compared to the static wall.

The annual performance was determined by using hourly weather data from 1999, 2003, 2006 and 2007 for the temperatures of Zurich, and the average U-value for the wall for different temperatures and different times of year were calculated. An average U-value was calculated for the entire year, the winter half of the year, and for each month to give an idea of the variation in performance with the changing seasons

RESULTS

The wall performance over a range of outside temperatures is shown in Figure 3. The static U-value of the wall is about 0.25 W/m^2K. The active system achieves better results than the static U-Value for outside temperatures below around 0°C. At the design temperature for Zurich of -8°C the system achieves the performance of a passive house.

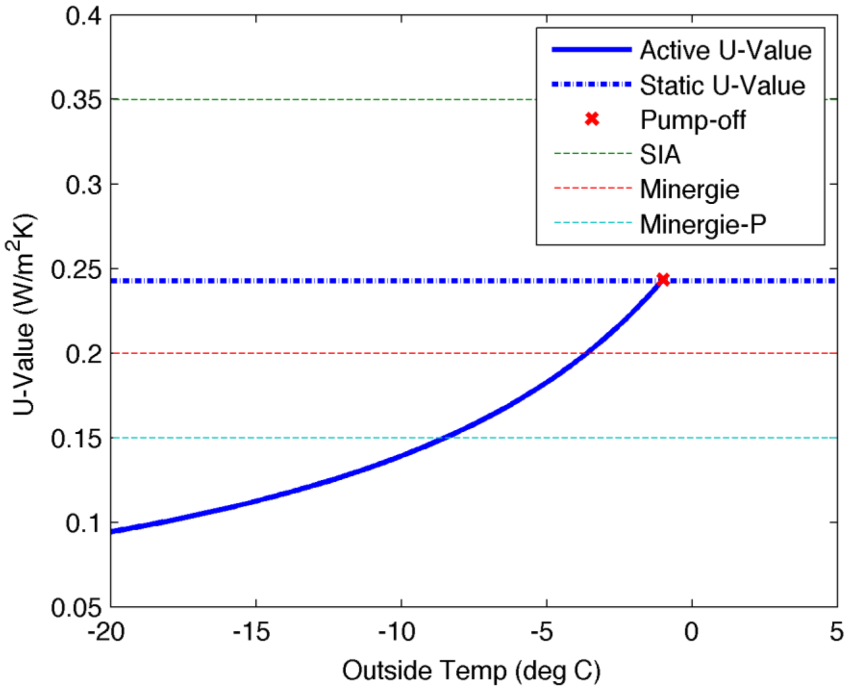

Figure 3: B35 active insulation performance

Table 1: Average U-Values

Weather Year	Year Ave	15.Oct-15.Apr
2007	0.215	0.201
2006	0.209	0.189
2003	0.209	0.190
2000	0.210	0.191

For the annual operation of the wall the average annual U-values for each year are give in Table 1. The annual averages are close to the Minergie standard of 0.2 W/m^2K and for the winter season the values meet the Minergie standard in most cases.

The average monthly U-Value for 2006 are shown in Figure 4. The variation between the results for different years was not significant enough to present. In this case the static value of just below 0.25 W/m^2K during the months where the wall is not active, to 0.15 W/m^2K during the month of January. This means that for the month of January the wall performs like a passive house or Minergie-P wall. Most Minergie-P walls have to be on the order 60-cm so at 38-cm this wall achieves the same performance during the coldest season with only 2/3 the thickness.

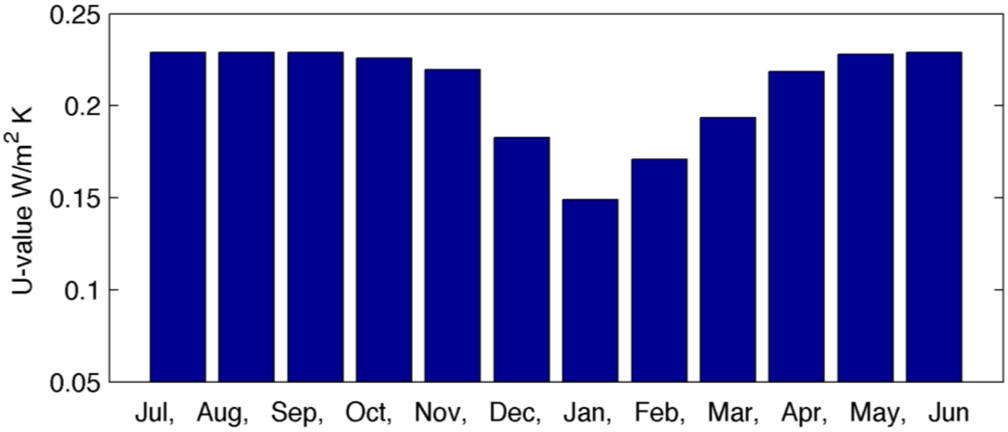

Figure 4: Monthly average U-Value for the active insulation system

This data was presented to the engineering firm and they decided to use the annual average of 0.21 W/m^{2}K for their SIA 380/1 energy norm calculations of the B35 building. This was a conservative selection, but it provides a certain factor of safety. The SIA 380/1 calculation resulted in 131 MJ/m^2 of heat loss per year, beneath the annual allowance of 155 MJ/m^2.

DISCUSSION

We have looked at how one might implement an active low exergy geothermal insulation system, and calculations were successfully made to allow for a standard energy analysis of the B35 building, but the value used was actually quite conservative. Still, it was enough to meet the energy standards.

What is more interesting is how to evaluate the performance of the wall relative to absolute U-value standards like those of Minergie and Minergie-P. Is it possible to have a wall with better performance during different parts of the year, and does this allow it to meet the standards? This has not yet been addressed, but presents the potential for a very interesting debate. These standard have the goal result of reducing heat loss mostly during the cold season, so the performance improvement in the winter is ideal. But if it can still be said to meet the standard should be discussed.

Figure 5: B35 building rendering with a sketch of the active insulation piping system shown over one wall

There are other potentially beneficial aspects that have also not yet been analyzed. This includes the ability of the system to absorb solar radiation, and to use that to regenerate or even store higher temperature heat in the ground heat exchanger. The active walls of the B35 building are planned to be black as shown in Figure 5, which will increase the albedo and increase the feasibility of this storage possibility in the summer. The installation of the insulation system will also help reduce the possibility of overheating by controlling the wall thermal mass.

Other important future work includes determining an optimal working fluid. Preliminary work has shown that more viscous materials can quickly increase the pumping costs of the system. Still, freezing would be a very detrimental event as the system will be permanently installed so there will have to be good safeguards against this possibility.

The system should also be considered for retrofit scenarios, because buildings built up through the 1970's often have poorly insulated block walls that would be ideal for the installation of this system. This would also facilitate the retrofit of low temperature (low exergy) heat pump installations that are only possible when transmission losses are reduced.

Future analysis will continue to test the feasibility of this system. The cost of the installation will also be considered after this first pilot project, and could be initially prohibitive. Nevertheless, it is a unique and interesting concept that deserves further testing and analysis.

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Solar Energy Concentration Without Moving Parts in Sustainable Building Envelopes

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Abstract

Solar energy concentration in building integrated photovoltaic, thermal and daylighting applications uses non-imaging and luminescent devices embodied in low solar concentration facade elements without moving parts. The adoption of new materials or interactions between materials is often the key to achieving satisfactory device performance. Low attenuation of transmitted light may be achieved by innovative device geometries often in combination with components with close to ideal optical properties. A particular example of a novel system including switchable mirrors is discussed.

1. Introduction

The cost of wide-scale implementation of building integrated photovoltaic (BIPV) and building integrated solar thermal (BIST) as building façade cladding can be reduced by substitution of some of the expensive photovoltaic materials by lower cost concentrating systems (Zacharopoulos et al., 2000; Gajbert et al, 2001). Reflective/refractive devices or luminescent concentrators may be used.to increase the power flux on to the solar cell surface.

2. Non-Imaging Optical Concentrators

A wide variety of two and three dimesional, symmetric and asymmetric compound parabolic concentrator (CPC) designs have been reported (Mallick et al., 2006; Norton et al., 1991; Brunotte et al, 1996, Zacharopoulos et al., 2000; Adsten 2002). For example, the "Maximum Reflector Collector", when characterised experimentally for high-latitude bi-facial cell BIPV applications (Adsten, 2002) achieved a 56% highest optical efficiency. Optical efficiency of 91% was predicted for dielectric-filled (CPC) BIPV covers (Zacharopoulos et al., 2000) and 85% for an air-filled asymmetric CPC BIPV system (Mallick et al., 2002a). A non-imaging static concentrator utilising refraction and total internal reflection to give a geometrical concentration ratio of 2.0 and a lens efficiency of 94% (Shaw and Wenham, 2000) with an annual averaged optical concentration ratio of 1.88 for direct insolation within ±60º and ±25º in the East-West and North-South directions respectively. A "flat plate static concentrator" with optical efficiencies of 87.6% and 85.6% for mono-facial and bi-facial cells respectively has been developed for BIPV applications (Uematsu et al., 2001). An asymmetric photovoltaic CPC also designed for BIPV applications (Mallick et al., 2004a) increased the maximum power by 62% (i.e. the power by a factor of 1.62) when compared to the same PV system without concentrating elements (Mallick et al., 2004b) for a design geometrical concentration ratio of 2. The performance was less than that anticipated due to increased PV temperatures and ohmic losses in interconnections between the solar cells (Mallick et al., 2006). Non-imaging Fresnel lens concentrators for medium concentration photovoltaic applications have been designed, manufactured and a comparative cost analysis reported (Leutz et al., 1999a).

3. LUMINESCENT CONCENTRATORS

The concentration restriction limits of non-tracking non-imaging optical systems, due to phase space conservation do not apply to luminescent solar concentrators (LSC). LSC in BIPV applications have the capability to (i) concentrate diffuse radiation as well as direct without tracking, (ii) separate the solar spectrum into two or more parts, each of which may be converted to electricity with greater overall efficiency using different solar cells (iii) when compared with geometric concentrators heat dissipation problems are reduced, and (iv) if the luminescent concentrator materials are of lower cost than the displaced PV, then the cost of BIPV electricity is lower. Building previous work on the LSC with the replacing of dyes with quantum dots (QD's) has realised quantum dot solar concentrators in flat plates (Barnham et al., 2000, Chatten et al., 2003, Gallagher et al, 2002; 2004; 2007, Rowan et al, 2006; Rada, 2008) stacked plates (Farrell et al., 2006) different geometries (Rowan et al., 2007, Kennedy et al., 2007) and thin films (Schuler et al, 2007). The use of photonic layers (Goldschmidt et al., 2006) to trap the absorbed incident radiation and the use of passive luminescence layers (van Sark, 2004, van Sark et al., 2006) for up-conversion (Richards, 2006) and down-conversion (Shalav et al., 2007) have been investigated. In each case a layer above the solar cell is designed to absorb photons outside the cell bandgap and emit within the cell bandgap. Mixing dyes and using different size distributions of QDs could broaden absorption. QDs embedded in dielectric layers directly above traditional devices might readily add 3 – 5% to device efficiency with little extra cost. (van Sark, 2004). Commercially-available QDs do not presently have yet have a high enough quantum yield to enable a highly efficient device to be fabricated (Gallagher et al., 2004; 2007a; 2007b, Sholin et al., 2007, however NIR QDs do show promise for this application (Kennedy et al, 2009).

4. CONCENTRATION OF SOLAR ENERGY USING SWITCHABLE REFLECTORS

Consider a device that consists of solar absorbers, switchable reflectors and non-switchable reflectors. The solar absorbers can be either thermal, photovoltaic or photochemical. The switchable reflector can change from being fully or partially transparent to all or some of the incident solar radiation to being fully or partially reflective to solar radiation. (Griesson and van der Sluis, 2001; Janner et al, 2001). With a single non-switchable reflector located at B in Figure 1 some of incident rays will be lost.

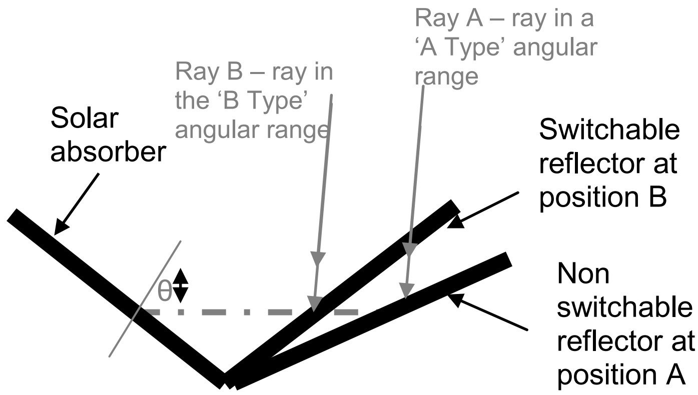

Figure 1: A single switchable reflector device

At times when rays in the type A angular range are incident, the switchable plane reflector is transparent and the type A ray passes through the switchable mirror and is reflected by the non-switchable mirror onto the solar absorber. The incident angle θ is within the solar absorbers, high absorptance (for PV) or high absorptance transmittance products (for a glazed solar thermal absorber angular range). At times rays in the type B angular range are incident the switchable plane reflector is reflective, the type B ray is reflected by it onto the absorber. The incident angle θ is within the solar absorbers angular high absorptance (for a PV absorber) or high transmittance – absorptance (for a glazed solar thermal absorber). The switchable and non-switchable pairs A1 - A2 and B1 - B2 act to optimally reflect rays in the type A and type B angular ranges respectively. The system may also use parabolic reflector sections displaced to form a CPC as shown in figure 2. This has the advantage of increasing the extent of both the type A and type B angular ranges and enabling a greater proportion of the diffuse component of incident solar radiation to be collected. For anisotropic skies the diffuse component collected would be larger than that for a fixed CPC. Positions C1-C2 and D1-D2 have an angular acceptance range that overlaps each other but each collect rays at angular ranges unavailable to the other.

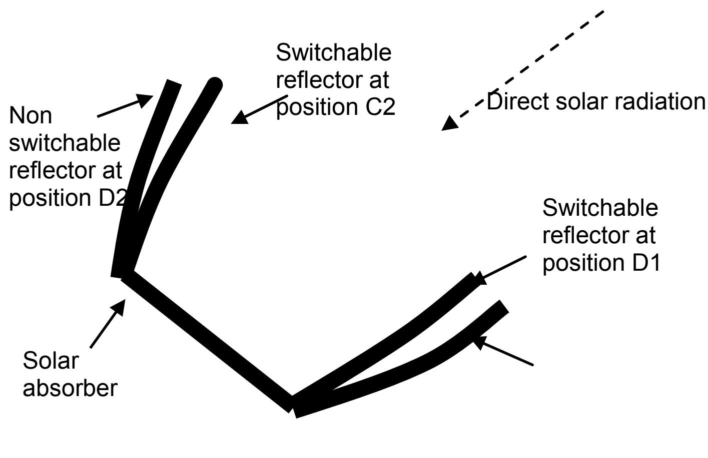

Figure 2: A switchable CPC device

The system may be aligned (i) on a north-south in the northern hemisphere or south-north in the southern hemisphere, (ii) east-west axis or (iii) on both axis to form a two-axis tracking system. When aligned on a north-south axis, reflector switching is in relation to the diurnal insolation of the incident angle of the direct component of solar radiation. In this instance the type A angular range would refer to the angular incident range associated with the morning and the type B angular range would refer to that for the afternoon. When the system is aligned on an east-west axis, the reflector switching is in relation to seasonal changes in the average incident angle for the direct component of solar radiation. The viability of this system depends on the specific life-cycle cost trade-off between the factors in Table 1.

Advantages	Disadvantages
• Greater amount of solar energy collected. • Cost lowered by reduced area of expensive solar energy absorber. • No moving parts; obviating need for, and cost of, motors, controls and associated input power. • Minimal maintenance requirement.	• Optical losses greater than a tracking system as insolation passes through an additional transparent element. • Cost of switchable mirrors may not reduce overall cost of energy produced taking optical losses into account. • Long-term optical performance of switchable mirrors is unproven.

Table 1. Factors to be included in the evaluation of switchable mirror concentrators.

5. CONCLUSION

Critical aspects of non-imaging and luminescent concentrators for BIPV and BIST applications have been outlined. The key research challenges lie in achieving high long-term optical efficiency in durable systems.

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CLIMATE TAILORED BUILDING ENVELOPES FOR JAPAN AS AN EXAMPLE FOR A SUBTROPICAL CLIMATE

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ABSTRACT

While well established values concerning energy efficient buildings are available for central European climate, the number of investigations in subtropical climate is rather small. The growing concern for dramatic climate change in combination with decreasing resources results in a growing interest to evaluate the potential of transferring the knowledge generated in Europe to other countries. A main barrier for this transfer is the lack of an appropriate building envelope that allows the design and construction of tight and well insulated buildings in subtropical climate, also considering user behaviour different from the Europeans'. Within this CTI (innovation promotion agency)-funded project a flexible wooden wall concept was developed, that can be tailored to any climate condition while keeping the cost within reasonable boundaries. As the main problem encountered in subtropical climate is high humidity in combination with high temperature, the sorption qualities of the used materials are of prime concern. Another important aspect in the development was a high level of earthquake safety. Further, the possibility to use local resources for the wall offers the option to make the resulting building a truly sustainable one, showing synergies with regional economic and social problems.

In order to optimize the system, basic research on material properties, concentrating on wood, wood fibre, wood compound and soil materials is conducted as part of the project. Several complete wall sections whose build-up is based on preliminary results will be tested and evaluated in climate chambers and help to develop a software tool to allow architects and business partners the calculation of an optimal make-up of the building envelope.

To gather on site experience Japan has been chosen as the most promising country. As the existing construction systems in Japan have been taken over from the United States after the Second World War but have never been adapted to the local climate, the Japanese building stock currently suffers from severe damages due to mould and condensation. The average lifespan of a Japanese single family house is only about 20 years, creating a huge economical as well as ecological impact. The Japanese climate is also very diverse, allowing for field tests under a wide range of conditions within only one country. First wood-based buildings have already been built in northern Japan and several single family houses and small settlements will follow within the supervision of the present project during the next years.

Besides the projects core, the realization of energy efficient buildings, close connections to the Japanese forest industry have been developed. The wall components allow the usage of low quality sugi (Japanese cedar), therefore providing a market for local wood and offering a chance to operate the local forests which would solve several critical ecological, economical

and social problems associated with neglecting the local wood resources in favour of cheaper wood imports.

INTRODUCTION

In the last 30 years many breakthroughs have been made in the field of energy efficiency in houses. Over the time calculation methods where developed, their results proven by field tests and in some countries legal frameworks where enacted that forced new and/or refurbished buildings to reach a high standard. The main part of this progress and the associated developments however, were made for moderate climates.

The threats of climate change and shrinking fossil resources results in a constantly growing interest in sustainable solutions by countries with climatic conditions that differ from those where the solutions originated. A main driver for this interest is the fact that the implementation of energy efficient houses is one of the rare synergies where increased comfort can be accompanied by improved health conditions and lowered energy consumption. The question is to what extent the available experience and technologies can be applied to such countries.

Despite huge interest, the number and scope of energy efficient buildings in other climate regions remains relatively small. Furthermore many projects that aimed to develop such solutions were not evaluated on site for their performance.

Several key barriers for such a transfer and the current conditions can be identified as:

- Lack of experience with the local user behaviour/ culture creates wrong assumptions resulting in mistakes in calculations and therefore flawed concepts that do not work on site
- Lack of economical possibilities on site (most projects in subtropical climate are strictly low tech) make such projects unattractive to ambitious companies
- Local construction methods do not comply well with key ideas of energy saving
- The imported concepts do not comply with local infrastructure and tend to remain dependant on imported components, and hence do not provide a synergy with local production lines
- Many projects do not include an evaluation of their performance as associated additional costs are high

The economic situation however, perceived by many as the main barrier, will change in the future. Especially countries like India and China will continue to develop their industry, resulting in growing prosperity, a growing demand for comfort at home and, as a direct result, growing energy consumption. With their ongoing industrial development these countries will also be more and more able to afford the necessary tools and technologies for energy efficient buildings. Creating sound overall concepts now and evaluating their performance will generate business possibilities in these countries in the conceivable future. From an ecological point of view the reduction of climate change impact to a low level will simply not be possible without establishing efficient and sustainable buildings in these countries.

Large areas of these countries are characterized by periods of high temperatures in combination with high humidity, conditions unknown in Europe and therefore not taken into account in most established building concepts. What is lacking most at the moment is a wall system that can be adapted to local conditions and needs in these subtropical areas. One of the basic ideas of energy efficient buildings is a tight building envelope. The resulting difference between inner and outer conditions as a main driver for transport of heat and humidity will result in demand for constructions and materials that are able to cope with such conditions. At the moment the unknown user behaviour/ inner condition in combination with extreme outside conditions often results in mould and humidity damages of the envelope and health problems on the user side (sick building syndrome).

The basic layout for such a system was developed in the start-up of the CTI funded project with the participation of EMPA, Tokyo University and ETHZ. The general make-up of which can be seen below:

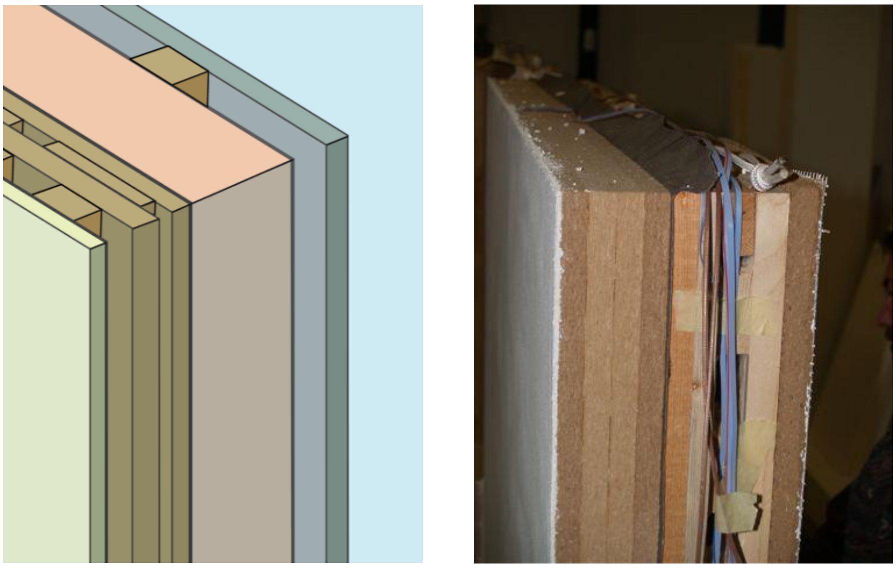

Figure 1: Schematic make-up of the system (left) and real wall specimen with temperature and humidity sensors at different depth (right).

The main idea behind the present approach is developing a layer based construction system as opposed to the established post and beam systems like 2 by4 wood frame construction. This allows for a heterogeneous building envelope without demanding structural decisions that later turn out being problematic from a building physical point of view. The basic idea is having a system where for every layer the optimal material can be chosen based on its prime function alone, while not interfering with other aspects or other materials. The ideal make-up of the envelope is calculated for every project/ climate condition individually.

As for field testing, Japan offers ideal conditions for gathering on-site experience in subtropical climates. Its climate diversity offers a wide range of conditions to evaluate buildings while cooperating with the same companies under the same legislative conditions. As one of the richest countries in the world Japanese customers can afford the needed technology while the current building standard is very low. Though the legislative restrictions on imports are extremely strict and the standard on earthquake safety is very high, there are only soft regulations concerning insulation and efficiency measures, leading to a comfortable freedom in designing concepts. As there is explicit interest in the exchange from the Japanese side several companies and universities are interested in cooperation – an exchange without which the project would have not been possible.

METHOD

The Project aims to design, build and optimize energy efficient one-family houses in subtropical climates and evaluate their performance. Towards this goal within the project the following subprojects are conducted:

- Measuring of promising materials properties and characteristics under subtropical conditions

  This research concentrates on measuring building materials that can field a good eco-balance as the project aims to develop energy efficient buildings in the first place but also puts effort into making it an ecological as well as a sustainable solution. Within the group of measured materials, emphasis is laid on materials that allow for usage of local renewable resources (wood and clay). The tests encompass standard tests as well as tests specifically designed to cover expected problems (especially regarding earthquake behaviour and fire safety).

- Modelling the wall system using WUFI and Helios simulation tools, verify the simulation results by climate chamber tests and develop a simplified software tool for the business partner and associated planners in Japan

  The existing simulation tools are sufficient to adequately model the wall system. However for fine-tuning and controlling the results are compared to climate chamber test in order to validity them. Based on the simulation results a software tool is to be created that offers working build-ups of the system for any climate condition entered by the user. The tool is meant to be a help and quality check for associated planners in Japan

- Evaluate the performance of the building envelope by supervising realised buildings in Japan

  To evaluate the performance of the system under realistic conditions the project is cooperating with several Japanese construction companies. Realized buildings are equipped with sensors to allow for evaluation and long term screening.

- Build up synergetic connections to related businesses, environmental and social projects

  A major problem in Japan is the lacking market for local wood. The Japanese forests mainly consist of sugi (Japanese cedar) that have been planted after the Second World War. As they have been planted to dense, there is urgent need to cut about every third tree, resulting in enormous costs as there is no infrastructure yet and the resulting wood is of low quality. The ability of the developed system to use such wood allows for close cooperation with the Japanese forest industry.

RESULTS

Although the project has started recently, several milestones were already achieved.

- Material properties

  Several materials have already been included in the wall system and several more are currently being tested. The choice of the materials, being traditional ones (clay, wood) has turned out to be the main driver for gaining user acceptance in Japan. While the concepts for saving energy and emissions remain vague for Japanese customers the positive feeling towards traditional "eco-materials" is very positive.

- Simulation tool

  The software tools (WUFI, Helios Hygro) currently used for modelling the system need an expert on building physics to operate them. A simplified tool is needed to allow cooperating architects and construction companies in Japan to correctly design an optimal make-up of the building envelope. As the climate diversity in Japan is much larger than anticipated during the start of the project, the many variables would result in a huge amount of simulations needed to develop the database of the tool. To reduce the amount of necessary simulations, sensitivity tests for the system are currently conducted.

- Field tests

  Several single family houses have already been built in Japan using the system as a whole or the structural parts:

Figure 2: One family house in Aomori (northern Japan),the walls (left) and the roof (right).

Most of them have been needed for gaining a license in Japan and are not equipped with sensors, however, as structural aspects and the gathering of experience values with the construction process were the main aim of these buildings. Future buildings will be evaluated on building physical aspects as well as consumption of energy and resources.

- Synergies with related projects

  As the usage of local sugi is aimed for in the structural parts of the wall system, the licensure was time consuming to get. The Japanese laws for structural systems are extremely strict because of the common earthquakes and are deeply affected by the logic of the 2 by 4 system imported from the United States after the war. Most of the components used are now licensed with both imported and local wood with roof elements with 8m span being the last sole exception to be licensed in the coming year.

DISCUSSION

The project is currently focussed on developing and optimizing the wall system. The main aim of the already realized buildings in Japan was the gathering of experience regarding the local building law, the established construction infrastructure/ approaches and licensing the single components. The building services so far had to be taken over from established concepts without any major changes in many cases. While this helped to keep the prices on a reasonable level and worked well with the customers, as they did not have to be schooled on the usage of new systems, the future goal is to provide a sound and sustainable house technical system as well. Aimed for is a working synergy of building services and the building envelope. Many of these systems will have to be imported at first, generating problems especially in the case of damages and needed repairs. As soon as larger numbers of houses are built, this problem will decrease however.

The project did to this day mainly cover buildings in the northern part of Japan. The local climate conditions are not subtropical, but already include a higher overall humidity than climate conditions in Europe with comparable annual temperatures. Therefore even in northern parts of Japan first experience values with high humidity could be gained. Future steps will lay emphasis on moving to the even hotter and more humid areas of central and southern Japan as well as on further raising the energy and comfort standard of the built houses. As there is currently no binding law on energy standards in Japan (only a soft recommendation) there is enormous freedom for concepts in this regard. This is seen as a chance to establish sound energy efficient solutions that are connected with other ecological local projects form the very beginning, creating a sustainable overall concept without legislative barriers.

ENERGY-EFFICIENT BUILDING REFURBISHMENT IN NORWAY

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ABSTRACT

Energy-efficient building refurbishment in Norway is becoming a main focus. With the help of dynamic computer simulations of energy and indoor environment for a case building in Norway, the impact of an additional ventilated glass facade on energy demand and indoor environment was analyzed. A focus was put on a comparison of energy demand and thermal comfort levels of various cases. Here, it became obvious that airflow in the double façade system (dfs) needs to be integrated into the existing ventilation system. Main parameters to study were:

- different construction standards (insulated vs. single glazing) and their energy demand implications
- simulation robustness in dependence of different assumptions (air tightness of the existing building)
- comfort criteria and energy issues (thermal vs. visual comfort vs. heating cooling demand)

The results show that significant efforts are needed in order to establish ventilated double-skin facades in Norwegian buildings as high energy efficient solutions. In particular, significant improvements of construction details regarding insulation levels and air tightness of the envelope are needed. The best solution provides a heating energy demand reduction of 40%, but the importance of a clear ventilation strategy and level of details became obvious. Also, condensation problems have to be addressed.

The design of energy robust, energy efficient, and comfortable buildings depends on building simulation. The strategy developed for improving building performance with an additional ventilated glass layer is an important step towards a more sustainable building stock in Norway.

INTRODUCTION

Energy usage for room heating, cooling and ventilation still accounts for more than one third of the total, primary energy demand in the industrialized countries, and is in this way a major polluter of the environment with CO2 and greenhouse gases. To successfully achieve the targets set out in the Kyoto protocols, it is necessary to identify innovative energy technologies and solutions for the medium and long term. They should facilitate the implementation and integration of low carbon technologies, such as renewable power generation devices within the built environment [1].

One focus has to be put on the energy efficient refurbishment of the existing building stock. Here, appropriate solutions have to be identified and possible technologies have to be developed that integrate into the building. One possibility might be an advanced façade system. A lot of developments in façade design has focused on ventilated double façade systems for new buildings [2, 3]. However, there exists very little work on exploring the possibility of energy efficient refurbishment by applying a ventilated double façade system to an existing building.

METHOD

With the help of dynamic computer simulations of energy and indoor environment for a case building in Norway the impact of an additional ventilated glass facade on energy demand and indoor environment was analyzed. A focus was put on a comparison of energy demand and thermal comfort levels of various cases. Main parameters to study were:

- different construction standards (air tightness, thermal bridges, and facade design) and their energy demand implications
- simulation robustness in dependence of different assumptions (thermal bridges in and air tightness of the existing building)
- airflow control strategies and their energy demand implications
- comfort criteria and energy issues (thermal vs. visual comfort vs. heating cooling demand)

A model of the existing building with an extra glass layer on the outside has been developed. Dynamic thermal building simulation has been coupled with airflow network in order to simulate the airflow through the ventilated double-skin façade.

Thermal model

Three different models were developed using TRNSYS and TRNFLOW [4-6]:

- base case model
- ventilated double-skin façade with insulated glass
- ventilated double-skin façade with single laminated glass

Two different rooms were taken to compare the results; an office room in the 3rd and a hotel room in the 5th floor. The model description is detailed in Table1.

Climatic data	Trondheim (meteonorm file)
3. floor	office room: 5.3m x 6 m (internal gains: equipment 11W/m^2, 2 persons (2 x 75 W), lights 8W/m^2, operation 12 hours/5 days/52 weeks)
5. floor	hotel room: 5.3m x 6 m (internal gains: equipment 1W/m^2, 2 persons (2 x 75 W), lights 8W/m^2, 16 hours/7 days/ 52 weeks)
Ventilation system	2 fans per room (120 m^3/s, balanced ventilation), 17 °C supply air temperature
Walls	External walls with U-value = 0.6 W/(m^2 K)
Shading:	Automatically controlled venation blinds in cavity (no shading in base case)

Table 1: Description of simulation model.

specifications		Base case	Double façade system	
		Existing fasade	dfs (1)	dfs (2)
Window properties	Glass layers	Insulating glass (4/16/4), air filled	Additional insulating glass (4/16/4), lowE, Krypton filling	Additional single glass 10 mm
	U-value	2.6 W/(m^2K)	1.1 W/(m^2K)	5,46 W/(m^2K)
	g-value	0.76	0.60	0.77
Air leakage, m=Cm x $(\Delta p)^n$	Leakage between	room and outside	room and dfs (1)	Same as dfs (1)
	Cm	0.0128 kg/s @ 1Pa (based on $0.6h^{-1}$)	Same as base case	Same as dfs (1)
	n	0.65	Same as base case	Same as dfs (1)
Other leakage, m=Cm x $(\Delta p)^n$	Leakage between	-	dfs (1) and outside	Same as dfs (1)
	Cm	-	0.0021 kg/s at1Pa (based on $0.1h^{-1}$)	Same as dfs (1)
	n	-	0.65	Same as dfs (1)

Table 2: Description of airflow and leakage.

Airflow model

Airflow modeling was coupled to the thermal model (see Figure 1). Here, the dsf consists of 16 different zones that were linked using the specifications in Table 2.

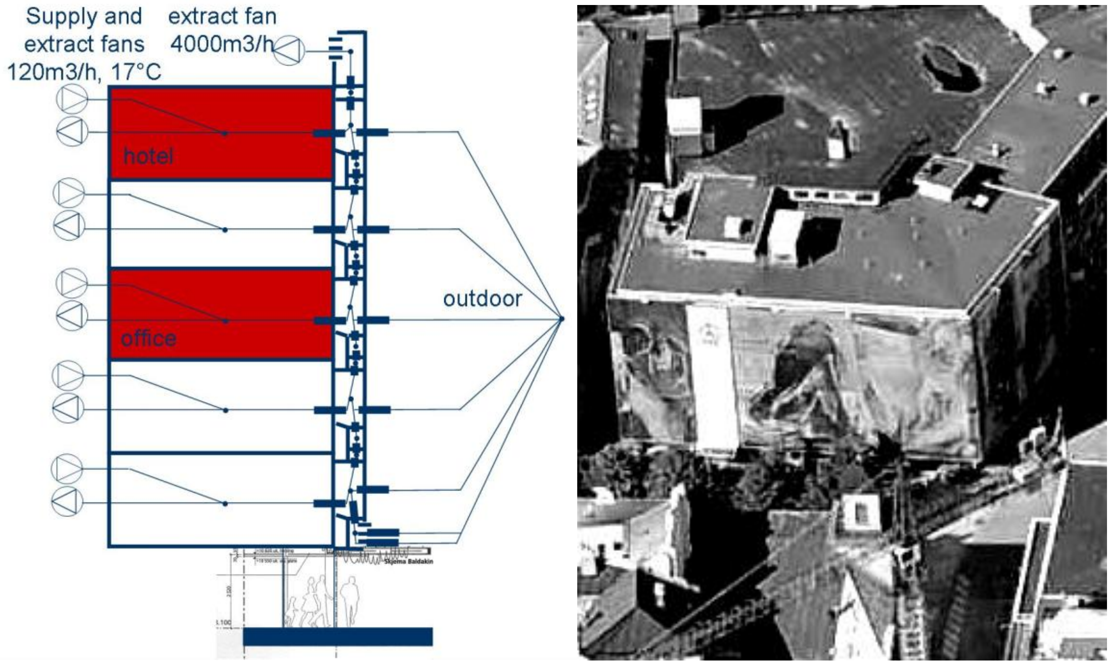

Figure 1: Model and airflow description and real building with textile facade.

In order to evaluate the winter and summer performance the following parameters were examined:

- Temperature (inside window surface)
- Energy (power)
- Thermal comfort (with values as described in Table 3; according to ISO 7730 [7])

Parameter	values
Clothing [Clo]	1
Metabolic rate [MET]	1
Activity [W/m^2]	0
Air speed [m/s]	0,1

Table 3: Values for thermal comfort calculations.

RESULTS

Results can be seen in Figures 2 to 4. They are divided into temperature, energy, and thermal comfort in the following sections.

Temperatures

Figure 2 presents the temperatures of the window at the inside of the hotel room for a typical winter week and a typical summer week. It can be seen that window temperatures are higher for the dfs than the base case in the winter. In the summer temperatures are lower than in the base case.

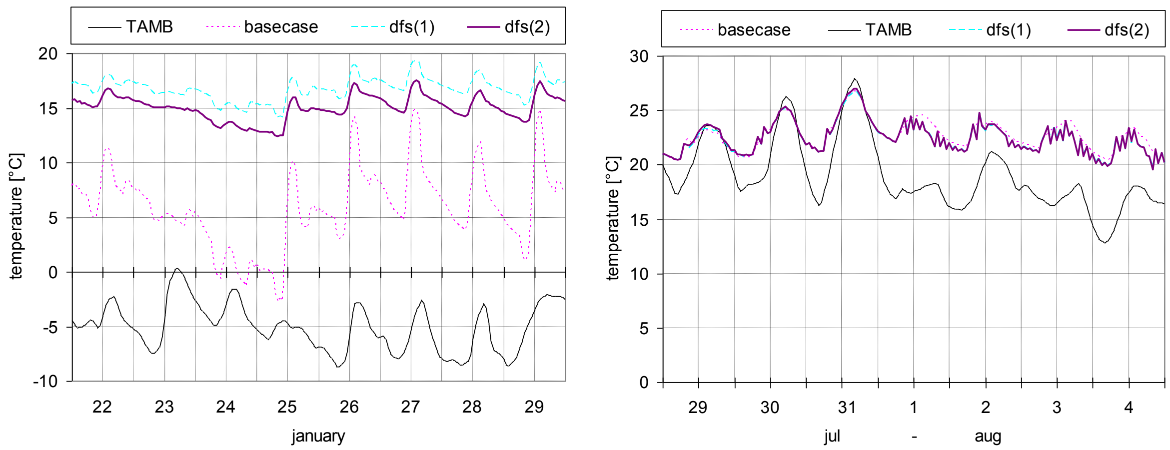

Figure 2: Temperature distribution in hotel room (5th floor) winter (left) and summer (right).

Energy

Figure 3 presents the power needed for the office and the hotel room for a typical winter week. It can be seen that power distribution in the office (left) is reduced for both dsf types (1 and 2) with slightly more reduction for dfs (1). The power distribution in the hotel room (right) shows an increase for both dsf types (1 and 2) with higher increase for dsf (2). Figure 4 shows the net energy demand results for both rooms (left) and a reduction in energy demand in percentage compared to base case for all rooms (right). It can be seen that energy demand in the different rooms vary. Energy demand for heating in the office room (3rd floor) is reduced by 59% while energy demand in the hotel room (5th floor) is increased by 89%.

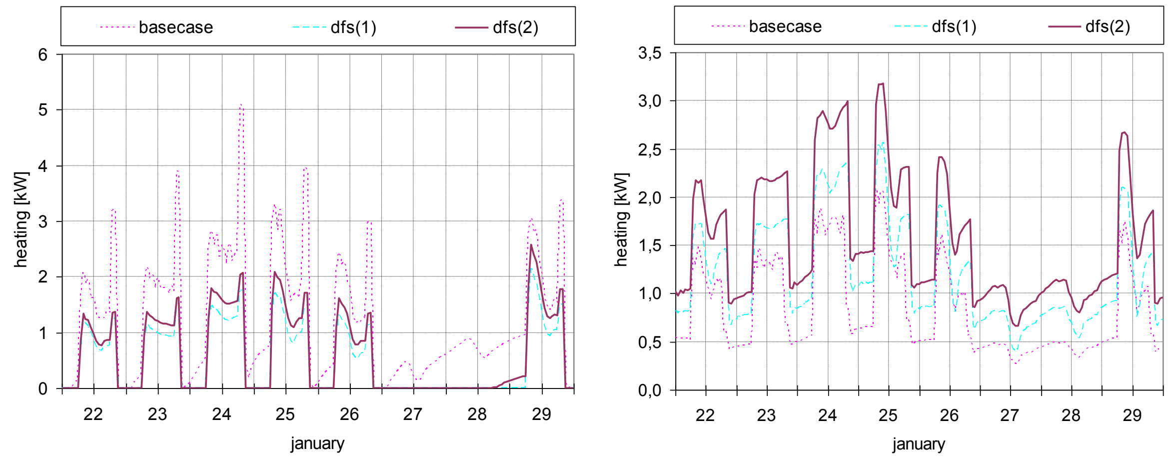

Figure 3: Power distribution for office (left) and hotel room (right).

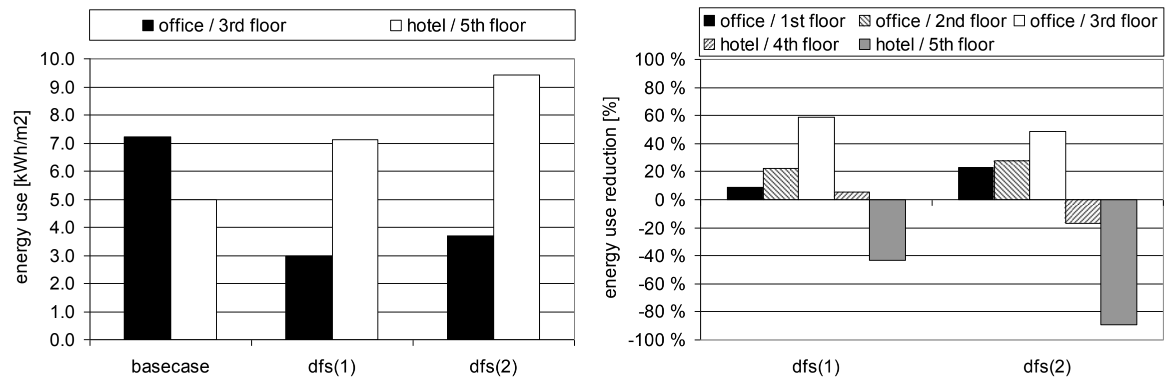

Figure 4: Summed net energy demand for heating in office and hotel room (left) and percentage energy demand for heating compared to base case in all rooms (right).

Thermal comfort

Figure 5 presents thermal comfort of the office and hotel room for a typical summer week.

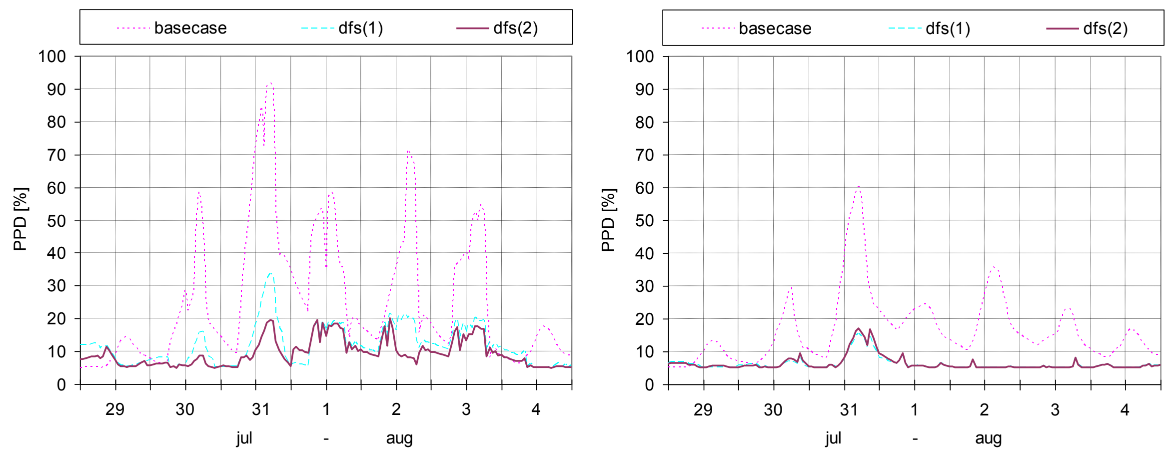

Figure 5: Thermal comfort for a typical summer week in office (left) and hotel room (right).

DISCUSSION

The results show that energy efficient refurbishment of an existing façade with double façade system is possible. Temperatures on the inside of the windows as well as thermal comfort are improved with both types of dfs (1 and 2). Energy savings seem to depend on the vertical airflow within the dfs and range between 59% and -89% for the different rooms.

The construction of a dsf in combination with high air leakages in the old façade results in airflows between rooms and dsf cavity. The amount of airflow increases because of the dfs which leads to an increase in energy demand for heating. Especially the hotel room in the 5th floor needs between 43% and 89% more heating (with an additional insulated glass layer (dfs 1) and single glass layer (dfs 2) respectively).

The solution (1) with insulated glass seems to perform better with respect to glass temperatures, thermal comfort, and energy savings than solution (2).

More work is needed in order to optimize the construction of a ventilated dfs in respect to operational energy savings. One possibility could be to reduce air leakages in the old façade construction.

Condensation of humid cold air on the outside and inside of the dfs layer could lead to unwanted effects and should therefore be evaluated.

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REVISITING SERVICE LIFE PREDICTION OF VACUUM INSULATION PANELS IN BUILDINGS

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ABSTRACT

Vacuum Insulation Panels (VIPs) have been used for building applications in Switzerland for 10 years. Until 2003, only little scientific data on degradation, its extent and relevant modes, was available. Within a project of the International Energy Agency (IEA) these topics were addressed and a first prediction presented to the scientific community at the CISBAT conference in 2003. Today, 6 years later, predictions based on laboratory results are compared to experimental data obtained from on-site measurements carried out at a roof terrace construction and in a freezing room floor.

INTRODUCTION

VIP's in buildings were fist applied in 1999 [1] in Switzerland and nearby Vorarlberg/Austria. Following to these applications, the need of a profound understanding and quantification of the service life of VIP's was acknowledged by the Swiss Federal Office of Energy (SFOE) [2]. A first study supported by this office was performed by a team around A. Binz and M. Erb [3], gathering internationally available information on this topic, which led to the coordination of the IEA Annex 39 (2001-2005).

The service life prediction of vacuum insulation panels applied in buildings is based on essential investigations performed at ZAE in Würzburg [4,5], which contributed essentially to the mentioned IEA Annex 39 [6]. A series of measurements on 3 fold metallised laminates, the dominant type on the European market, has been performed at Empa since 2003. The first public presentation of our results was at Cisbat2003, pointing out that VIP service life fulfil the 25 years requested for insulation materials in buildings.

CHOICE OF SPECIMENS

Based on results of IEA Annex 39, it was shown that area size and seal length are the two main geometric parameters influencing service life of VIP's. In order to quantify these influences and extrapolate them to common production sizes (e.g. 1 x 0.6 m), two different sets of specimens are needed. Based on our experience VIP's of 500 x 500 x 20 mm and 250 x 250 x 20 mm, fulfil the requirements best. Smaller sizes might not allow a clear determination of the areas size effects.

MEASURING METHOD

The increase of inner pressure was measured by means of a laser detected foil lift-off measurement in a vacuum chamber. Moisture uptake was determined gravimetrically. A complete description is given in Simmler 2005 [7]. In absence of an established procedure for performing aging experiments on VIP's, the tests starting in 2003, were continued until 2005 to ensure a sufficient amount of data [7] to deliver statistically relevant results.

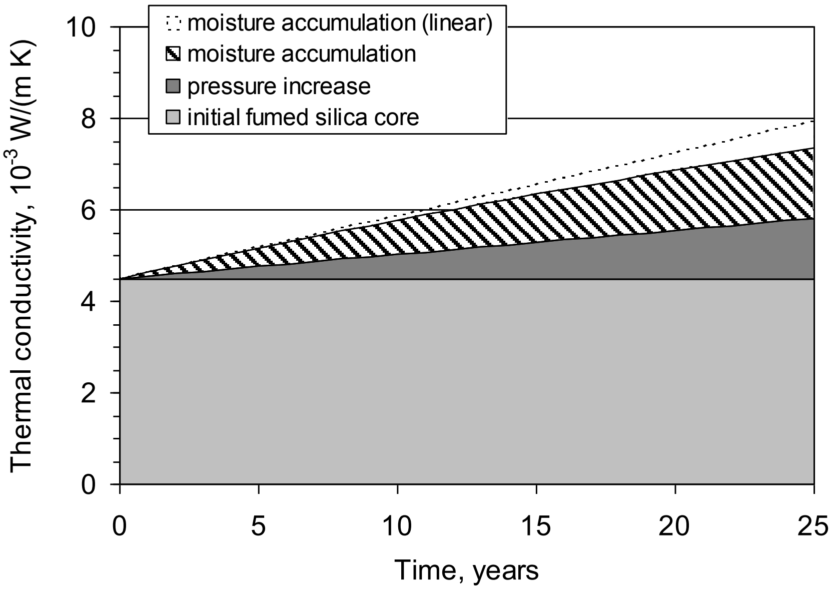

Figure 1: Predicted effect of pressure increase and moisture accumulation on the thermal conductivity of VIP (format 100 x 60 x 2 cm^2) over a period of 25 years. The dotted line indicates the increment omitting moisture saturation [7]

AGING IN THE LAB VERSUS AGING ON A ROOF TERRACE

It is of major interest to establish, whether results of laboratory based ageing (see Figure 1) can be compared to on-site aging of VIP's. For this reason series of 7 VIP samples have been installed in a roof terrace construction (Figure 2). The roof was regularly opened (3 times a year, up to now 12 times) to take out the samples for measurements. Results of these investigations (Figure 3) and comparison with laboratory aged samples have been described in [8]. The measured pressure increase in the VIP's of the terrace roof has been predicted quite accurately by using the measured pressure increase of laboratory conditioned VIP' s taking into account the difference between the predicted and the effectively measured temperature on the outer side of the VIP's. The reason for the mentioned deviation between predicted and measured temperature lays in the fact that the DRY-data corresponded to a typical site in Swiss midland and not to the effective site of the terrace construction.

Figure 2: Example of a slim balcony insulation with VIP giving equal levels for indoor and outdoor zones (Left, photo from 2003. Today, panels for on-site installation are often shipped with glued-on protection layers.) Installation at the test site (right).

The other contributing to the aging of VIP is the increasing water content. This has been overestimated by prediction, which cannot be explained for the time being, but acceptable, as it lies on the safe side.

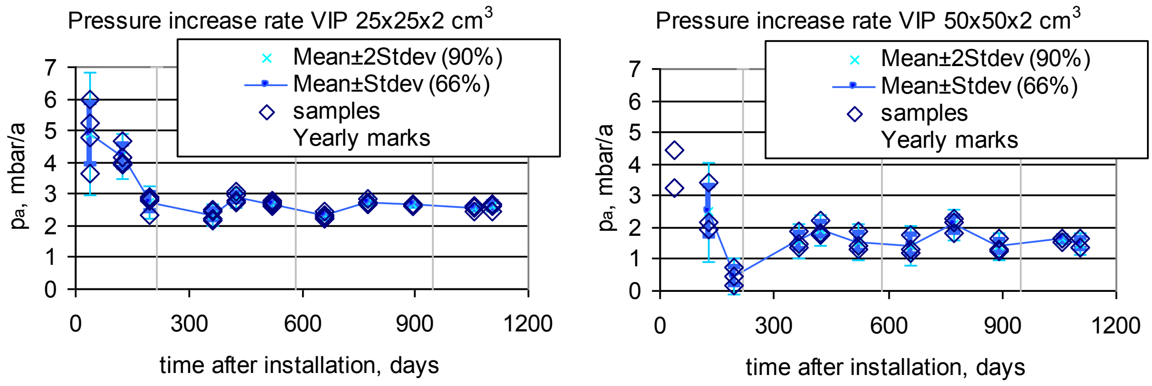

Figure 3: Yearly pressure increase rates as determined for the two VIP sizes on a terrace roof. More than a year is recommended for such kind of measurements as seasonal influences are visible and have to be considered.

VIP ENVELOPE

The mean permeation barriers in the VIP envelope are three aluminium layers put on polymer substrates by evaporation (web coating). In order to detect possible deterioration imposed by heat and moisture loads, focused ion beam analysis has been carried out for new [9] and heavily aged samples [10].

FAÇADE

Besides roof terraces, façade applications including VIP's have moved into the interest focus of s Swiss distributors who have already started designing system solutions. In addition to the impact of temperature and humidity loads, those of shear and other mechanical loads will become also decisive for these kinds of applications.

QUALITY LABEL

VIP producers in Germany and Belgium are now organized in a consortium called 'RAL-Gütegemeinschaft`[11] and have created a **RAL Quality Mark** which includes the above mentioned values for service life prediction of 25 years. The used procedure was build up in a SFOE financed project "Qualitätssicherung und Deklaration von Vakuumisolationspaneelen" together with the three Swiss partners and was conducted by one of the authors (Hans Simmler).

VIP IN REFRIGERATORS

The service life of VIP has already been an important topic in refrigerator units. The most wide spread VIP's in refrigerators on the European market are those with pyrogenic silica core, the same used for building application. Nevertheless, Japanese producers, who dominate the world market in this area, have VIP's with fibre or foam core material. It is well known, that they have a shorter service life, even when using getters a desiccants. Some have barrier envelope including rolled aluminium foil of 7 to 9 micrometer thickness. Despite of their lower permeation, the thermal bridge effect occurring on edges is significant, Ghazi Wakili 2004[12] so that they can not compete with those envelopes discussed earlier.

In connection to the refrigerators, it shall be added here, that VIP's were used for this application clearly earlier than in the building sector. Service Life prediction for VIP's with getters has been presented former VIA Conferences (e.g. Bonecamp 2000 and Küçükpinar

2001 at Vacuum Insulation Association symposia). The main Issue being the amount of getters needed to reach a certain service life by keeping the pressure below 0.03 mbar.

VIP IN COOLING/FREEZING ROOMS

Another common application of VIP in buildings is the floor of freezing rooms in supermarkets. The floor height can be reduced and allows a shorter ramp and therefore more space for others usage, while having flexibility in rearranging and relocating cold storage rooms of different sizes.
To confirm service life data for this kind of application, an indirect method was applied, as regular reopening of the floor construction was not feasible (Figure 4). Pressure increase by a special device (Va-Q-Perm®) has been reported at IVIS 2007 [13]. These values are low as expected due to the low temperature (Figure 5).

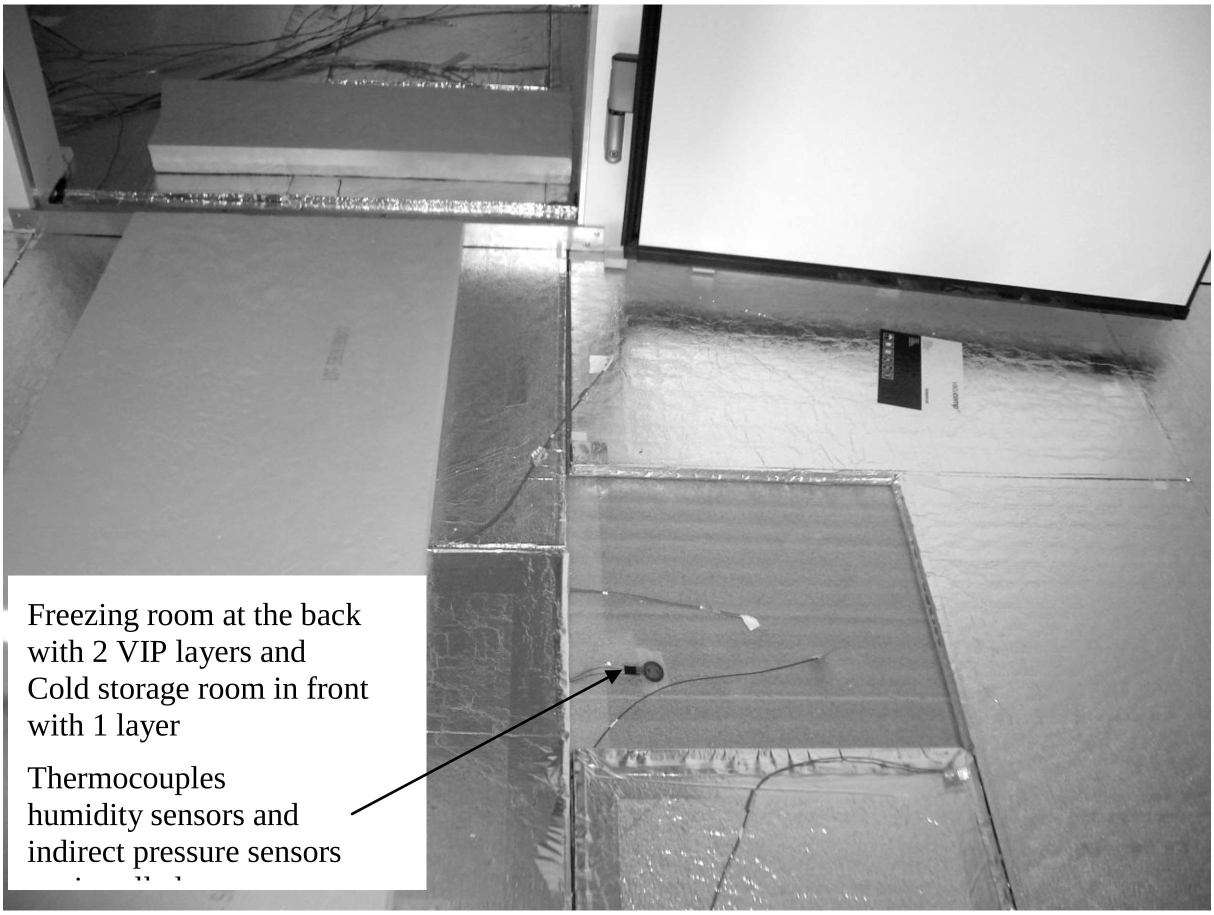

Figure 4: VIP installed in the floor of a cold storage room

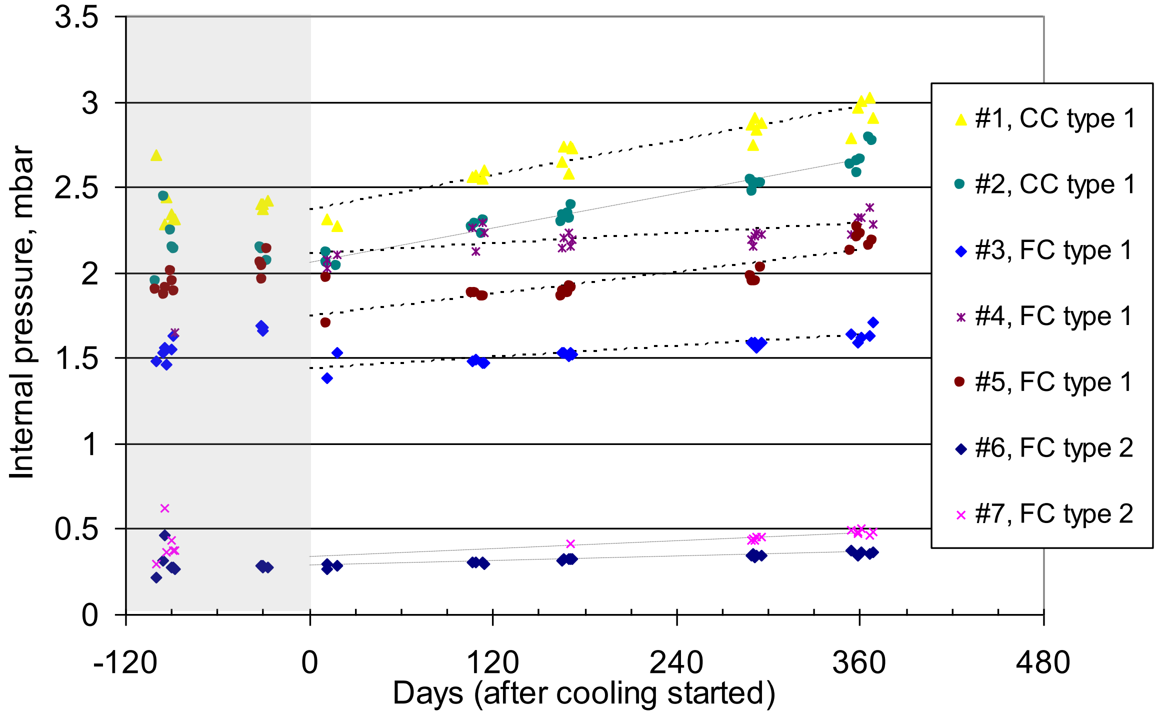

Figure 5: The pressure measured indirectly shows an increase of 0.6 mbar/year for the cooling room and about 0.2 mbar/year for the freezing room.

FINAL REMARKS

VIP's in building applications with a thermal conductivity by production of 3.5 to 4.5 mW/m·K, and with the tested laminates, are appropriate to fulfil the requested service life of 25 years. By that time, they will have reached a predicted value below 8 mW/m·K for a thickness of 20 mm and below 7 mW/m·K for a thickness of 30 mm or thicker. VIP's with a core made of pyrogenic silica and a barrier envelope with three aluminium layers of 100 nm each fulfil the above requirement contrary to those with a core made of fibre or foam.

In the meantime, first products are offered on the market with about 5 time lower pressure increase. This will allow the use of small size VIP's in applications such as window jamb and the box for roller shutters.

ACKNOWLEDGEMENTS

The authors thank the Swiss Federal Office of Energy for financial support and the staff at Empa that contributed to the related measurements and measuring devices: Reiner Braun, Stefan Carl, Roger Vonbank, Rudi Blessing and Beat Margelisch.

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29.5.09), 1999 is more likely, no information if twice of even only once metalizes laminates had been used.).
1999 a house of the Architect Zweier in Vorarlberg, with Instill Type VIP, containing a foam core and getter.
Very first one applied in buildings known to me was at the Façade of the ZAE Building end of 1998 [Caps2001 VIA conference, Rome], resp. 1999 according to Fricke2008 [Vacuum 82 (2008) 680–690]. Application in refrigerators is much older, according to Fricke2008 in the beginning of the 1990s by Degussa in Hanau manufactured VIPs for application in refrigerators.

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ELECTRICITY CONSUMPTION REDUCTION BY THERMAL INSULATION OF BUILDINGS IN HOT CLIMATE

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ABSTRACT

The present paper discusses the importance of thermal insulation in buildings in hot climate. The thermal performance and the energy performance of two rooms built in the renewable energy laboratory of Djibouti are reported here. One of the rooms is insulated with polystyrene and gypsum board on walls and glass wool in the roof while the other does not have any insulation. Results obtained show that an important energy saving can be realized with such simple thermal insulation.

INTRODUCTION

Djibouti is a country which is hugely dependent of imported fossil fuel for its electricity generation. Despite very interesting solar energy, wind energy and geothermal energy potentials, almost all the installed capacity is assumed by heavy oil fired power plant [1, 2, 3]. Solar energy could be a serious alternative in urban areas and especially for household sector. The average daily global solar irradiation is equal to 5.38 kwh/m²/day [3]. But before using solar energy for electricity production in urban areas, we must see how we can drastically reduce energy consumption levels of actual buildings. In fact solar energy using can only be useful if it is thought in a maximum energy conservation way. The purpose of this work is about the reduction of air conditioners energy consumption in Djibouti. We have focused our study on air-conditioners because almost 45% of the total electricity demand is related to air-conditioners [3]. In fact in the summer period of the city of Djibouti (April-September), climatic conditions are rather a challenge for human bodies in term of extreme temperature (up to 45°C), dusty and hot winds and considerable variations of relative humidity (in average 40% in July and 80% in September) [4]. Those very difficult summer climatic conditions are responsible of the high electrical load of air-conditioners [5] which can be seen in Figure 1. This figure shows the daily load curves measured for two days of the 2004 year by the Djibouti Electricity Company. The first day (January 18) corresponds to the "cold" season of the city of Djibouti. The maximal temperature in January is around 29°C and most of the households do not use the air conditioner. The second day (September 19) corresponds to the summer period and maximal temperature can reach up to 40°C. The great difference in the electricity power demand is attributed to cooling devices such as fans, fridges and mainly air conditioners. Energy demand related to air conditioners is huge not only in Djibouti but in most of the countries with very hot climate. Al-Rabghi *et al* [6] report that energy demand for air-conditioners is tremendous for Saudi Arabia (hot and dry climate) and Prapapong V. *et al* [7] report that in Thailand (hot and humid climate) the energy demand for air-conditioning is a matter of concern.

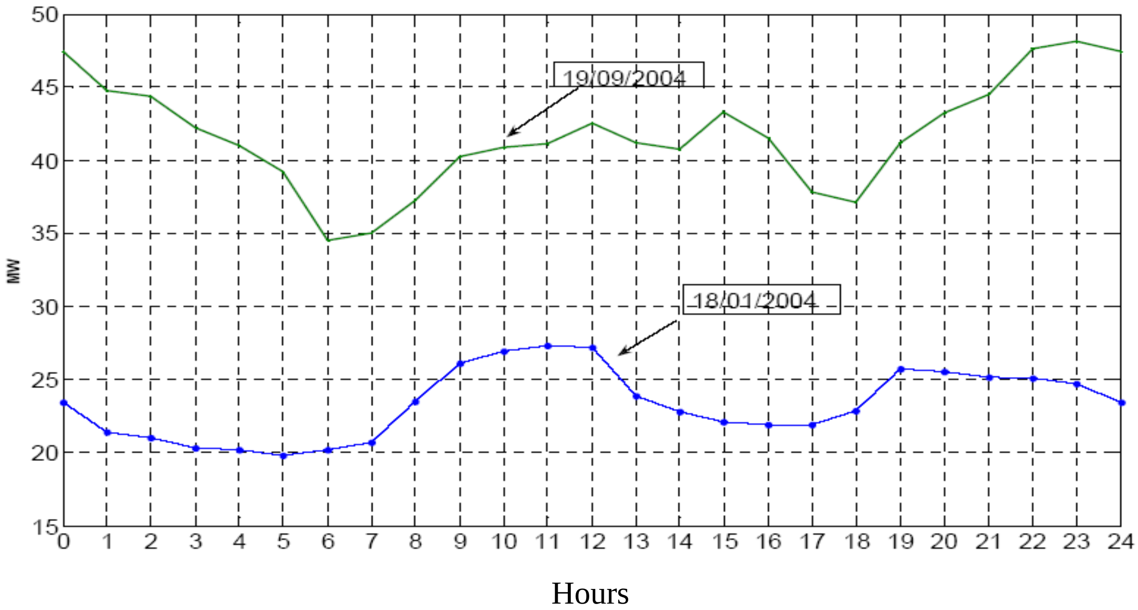

Figure 1: daily load curves for a summer day and a "cold" season day

An undergoing survey that we are conducting shows that the average energy demand of air conditioners for a typical Djiboutian home is around 80 kWh/m^2/year and can be as high as 100 kWh/m^2/year in some cases. Those high values of energy demand are a consequence of the lack of any thermal consideration in the construction in Djibouti. In fact, despite very severe and hot summers, there's no thermal building code at this moment. Most of the homes use only one air conditioner for a typical cooling area of 30 m^2.

The energy consumption for building cooling is linked to three main parameters which are climatic conditions, the building characteristics (architecture, building materials) and the behaviour of the occupants. Among those three parameters we can only control the building characteristics and the behaviour of the occupants. In this work, we have tried to reduce energy consumption of a typical Djiboutian construction by changing the building characteristics. This can be done by changing the orientation of the building in order to receive the minimum of solar heat gain or by changing or upgrading the materials used for the construction. In this work we report how the using of a layer of a 3 cm polystyrene insulation and a layer of 13 mm gypsum board can drastically reduce energy demand of air conditioners in the summer climatic conditions in the city of Djibouti.

METHOD

In order to investigate the impact of thermal insulation on the electrical consumption of air-conditioners, two experimental rooms were built in the Renewable Energy Laboratory. We have compared experimentally the energy performance of the two rooms in the same climatic conditions and at the same time. Figure 2 shows a picture of one of the two rooms.

Figure 2: photo of one of the two rooms

The first room is a widely used kind of construction in the city of Djibouti consisting of a cement brick wall and corrugated iron as a roof. Plywood is used as a roof ceiling. This type of construction does not have any kind of insulation. The second room is exactly the same as the first one described above but it has an insulation material consisting of a 3 cm layer of expanded polystyrene and a 13 mm layer of gypsum board for internal walls and 5 cm tick glass wool for roof. The two rooms are 4m*4m*2.5 m. For cooling purpose, each room has been equipped with a 1.2 KW rated window type air conditioner.

The two rooms were well instrumented. Each room temperatures (K type temperature sensor) and heat fluxes (with HFP01 sensor) of the eastern and western walls have been monitored. Temperature of the internal air has been recorded. External air temperature and global solar irradiation were recorded in order to determine the variation of the electrical consumption with variable climatic conditions. Global solar irradiation was monitored with a LP02 sensor. In order to determine the energy performance, ABB energy meters have been used to record the cumulated electrical consumption of each air-conditioner. An Agilent 34970A data acquisition system was used for sensors readings, storing and monitoring. The goal assigned to the two air-conditioners was to maintain a set temperature of 25°C inside the rooms. For several days, experiments have been done and some of the obtained results are reported here.

RESULTS

Results concerning the response of the two rooms and the air conditioners to the variation of external climatic conditions are reported in this section. Figure 3 shows the evolution of the external ambient temperature and the global solar irradiation received on a horizontal surface (the roof of the rooms) on a typical experiment day (on august 07, 2008). The graph (a) shows that external temperature can reaches challenging level for human bodies. We can see in fact that this temperature is higher than 40°C for more than 6 hours in the day. In the graph (b) the global solar irradiation plot shows a pattern typically obtained with a partially cloudy day in the city of Djibouti.

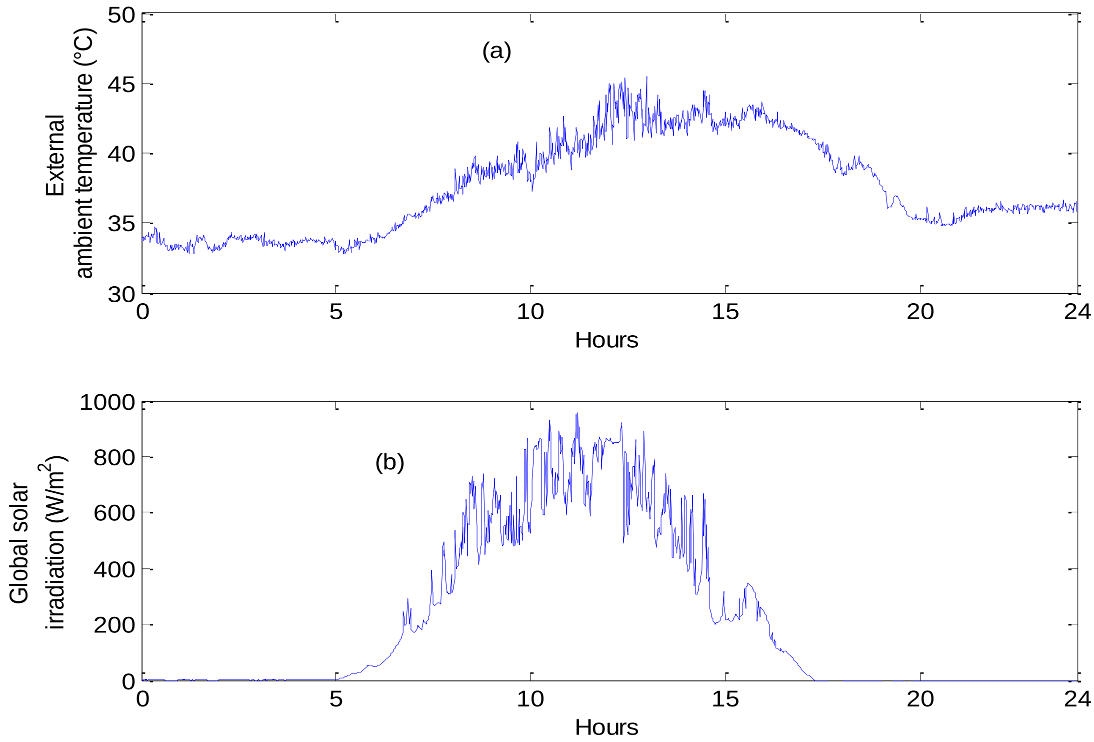

Figure 3: External ambient temperature (a) and global solar irradiation (b)

The external temperature and the solar irradiation are the two driving parameters for heat gaining of a building trough heat transfer by convection with external air and heat transfer by radiation.

Figure 4 shows the response of the walls of the rooms to the variation of the external conditions. Eastern (a, d) and western (b, c) wall heat fluxes are plotted in this figure. It is clear from this figure that the walls of the two rooms have different responses. The walls of the non insulated rooms transmit more heat than the insulated one. It is a quite normal result since the quantity of heat transmitted is proportional to the thermal conductivity and the polystyrene is a thermal insulator.

The most important expectation that we was looking for was whether adding a thermal insulator would lead to a reduction of electrical energy consumption. The table 1 shows the energy consumption of the two rooms for twelve days experiments. The specific energy saving and the relative efficiency are defined as following:

$$\text{Specific energy saving} = \frac{\text{Non Insulated room energy demand - Insulated room energy demand}}{\text{surface of the room}} \quad (1)$$

$$\text{Relative efficiency} = \frac{\text{Non Insulated room energy demand - Insulated room energy demand}}{\text{Non insulated room energy demand}} \quad (2)$$

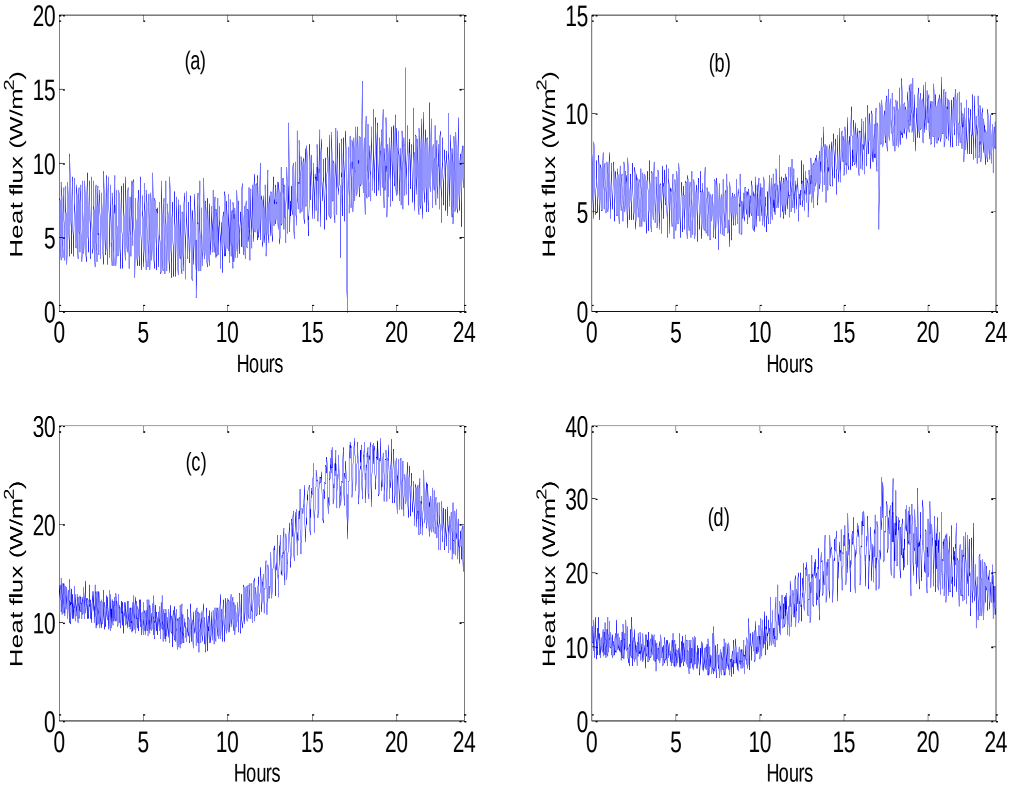

Figure 4: Eastern and western walls heat fluxes, (a), (b) for insulated room, (c), (d) for non insulated room

Depending of the external conditions, the energy consumption is not the same for each room. But for all of the days of the experiments, we can see clearly that the insulated room has lower energy demand than the non insulated one. The average energy saving for the twelve days is equal to 0.33 kWh/m^2/day and the average relative efficiency is equal to 27%. That means that thermally insulated room can save energy up to 27% compared to non-insulated room and in the specific summer climatic conditions of the city of Djibouti.

	Insulated room (kWh**)**	Non insulated room (kWh)	Specific energy saving kWh/m^2/day
05/08/08	16	21	0.31
06/08/08	12	15	0.19
07/08/08	14	19	0.31
08/08/08	15	22	0.44
09/08/08	14	20	0.38
10/08/08	15	21	0.38
11/08/08	12	17	0.31
12/08/08	15	22	0.44

13/08/08	15	20	0.31
14/08/08	14	20	0.38
15/08/08	14	18	0.25
17/08/08	15	20	0.31

Table 1: energy consumed by the two air- conditioners (set temperature 25°C)

This result is quite important for continuously cooled buildings like hospitals and supermarkets for example, which use a huge amount of energy for this purpose.

DISCUSSION

In this work, the importance of using thermal insulator in the construction as an electrical energy consumption reduction tool has been assessed. The tick of the insulator used here is not large (3 cm only) but it can already provide up 27% energy saving compared to classical non insulated buildings of Djibouti. In the future, other configurations should be tested such an increase of the insulator tick. This project was a part of a demonstration project dedicated for engineers and architects of Djibouti in order to aware them of the importance of thermal insulation. The final goal is to make buildings that would satisfy all of their energy demand by solar energy. Limiting the heat gain trough walls and roof is the first step on this way.

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THEORETICAL SOLUTION OF NON-VENTILATED COLLECTOR BUILDING FAÇADE.

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ABSTRACT

The presented work is devoted to estimating the effects of anexternal partition with inter-space on the thermal behaviour of the adjacent building zone. Heat absorbed in the space and exchange processes between element as well as heat storage potential play a significant role in the energy balance between building and environment. The analysed wall consists of an external skin, non-ventilated air space and an inner part. The external part consists of several components: visual, daylight, solar, opaque, airflow. Some of these are individual elements but some can play two or more functions. The inner part consists of the same area of transparent and opaque parts as the outer one.

All analyses have been conducted using computational numerical techniques based on the dynamic heat transfer model and advanced simulation software. The façade was defined as a single zone with inter-space. The façade space was assumed to be disconnected from the airflow duct. This means that only air flow between external environment and inner zone is consider in the model. Additionally, the heat exchange processes, absorption emission and convection inside the façade are taking into account.

The paper presents and discusses the results of several solutions of external building façade. The following changeable magnitudes of the outer components were considered in the presented work: solar collector area, opaque area and inflow air area. Others such as daylight area and visual area were assumed to be constant. The part of the wall under consideration was assumed to play the role of solar collectors, stimulating heat gains according to required internal conditions. The inner part of the building façade was assumed to be made of transparent, low thermal mass components. The optimisation criterion considered here is energy absorbed and utilized together with stable thermal conditions inside a wall space. The results were obtained for a particular building location and climate. The weather parameters correspond to moderate European conditions with cold winters and warm summers.

INTRODUCTION

An optimal solution of inter-space between outer and inner parts of a building envelope are currently well described for some particular practical applications [1,3,5]. The rules how to provide the requiredconditions and optimise the systems from a thermal point of view were investigated e.g. for solar walls, solar spaces, double-skin facades etc. The first two of them are limited to a small scale building application. The third is rather used in modern, huge and tall buildings and has a wide range of options to control the effects between external and internal environment. In the majority of climatic conditions, the main exploitation problem is summer overheating, not only in the gap of the façade but also in the adjoining room. On the other hand, the limitation of sun access (e.g. by vertical shading) results in deterioration in illuminance. The worst side effect is a decrease in both: thermal and/or visual indoor comfort parameters.

The results of a whole building dynamic simulation [2,4] give not only energy efficiency of buffer space but also precise temperature distribution inside each part of the external partition. Recent works showed many different strategies in the design of a buffer zone and solutions to optimise the control strategy of shading systems, air flows or both. It means that the previous strategies were devoted rather to eliminate or protect against environmental effects, based on additional elements like blinds or a ventilation system. The presented work shows possible storage potential of each façade component and the potential of controlled heat exchange between air in inter-space and external and internal skin.

FAÇADE SOLUTIONS

For the case studied herein the envelope is considered as an outer and inner partition. The lowest part of the façade (10%) is permeable and dedicated to ventilating a building space. In the presented part of the study the influence of that part is omitted. The rest of the façade is divided into three parts:

- transparent – glass U=5.40 W/(m^{2}K) – 40%,
- translucent – insulation material U=0.72 W/(m^{2}K) – 20%,
- opaque – insulated panel U=0.30 W/(m^{2}K) – 30%.

The space gap is 0.6 m wide and represents a separate space on each floor. No additional shading system was applied in an inter-space. The inner part is almost all made from double glazing panels (80%). The rest, 20% of surface area is assumed to be opaque but permeable.

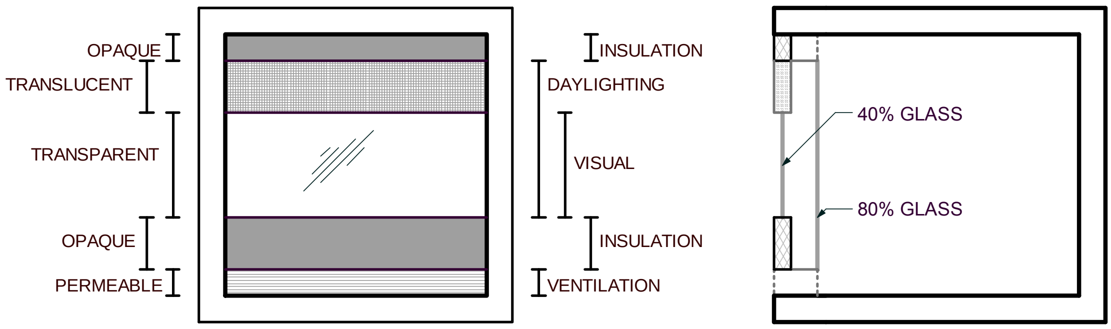


Figure 1. Geometry and construction solution of analysed façade – base case.

The analysis has been done for various proportions between a transparent and translucent part. Both elements fill up 80% of the outer part. In the base case the assumed proportions of transparent and translucent area are 2/1. In Case 1 there is no translucent part, and in Case B the ratio is 1/2. It means that the heat loss coefficient of the external façade differs while the daylight permeable area is constant. The set of main parameters is presented in Table 1.

	Base Case	**1**	**2**
Percent of transparent in outer surface	40%	60%	20%
Percent of translucent in outer surface	20%	0%	40%
Heat lost coefficient [W/(m^{2}K)]	21.5	30.0	13.1

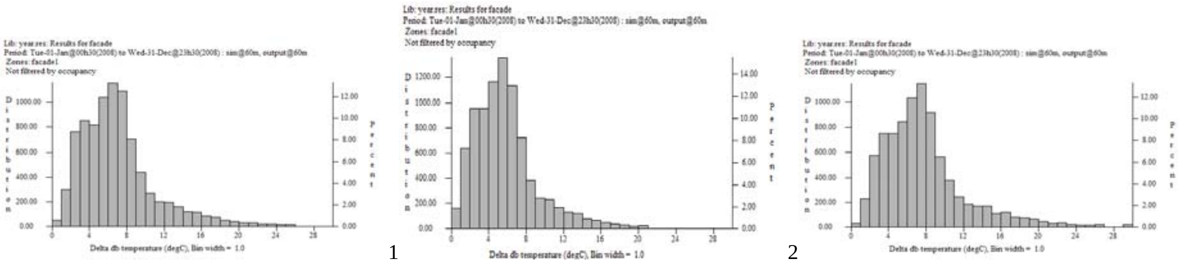
Table 1: Percentage of external daylighting area distribution.

RESULTS

Temperature statistics

The solar gains distribution during the year has been analysed for weather conditions in the moderate climate of Central Europe. The indoor parameters have been changed without any controls. The frequency distribution of $\Delta T=T_f-T_e$ for three cases is presented in Figure 2. Delta T increases for the cases when transparent insulations improved thermal characteristics during the whole year. Extreme temperatures presented in Table 2 do not show significant differences. However, extreme temperature differs more than 60deg in all three cases. On the other hand the difference between internal (zone) and façade temperature is much higher during summer. For winter (case 1) $\Delta T=T_i-T_f=20-(-7.1)=27.1$deg, while for summer (Case 2) $\Delta T=T_i-T_f=61.6-24=37.6$deg. It means that in the hottest time in summer the heat gains from façade to building zone trigger off higher overheating more than they help to protect against overcooling during the coldest days in winter.

The minimum external temperature in winter is $T_e=-11.6$°C, while in summer it is $T_e=30.7$°C. Temperature differences between T_f and T_e are respectively 30.9deg for summer and 4.5deg in winter. For the best case in winter (Case 2) the temperature difference is 1.8deg higher but the relative benefits in winter are still at the level of 20%.



BC 1 2

Figure 2. Comparison of temperature differences distribution (T_i-T_e) in façade space for base case, and Cases 1 & 2.

	Base Case	1	2
Minimum temperature [°C]	-6.0	-7.1	-5.3
Maximum temperature [°C]	59.6	55.9	61.6

Table 2: Percentage of external daylighting area distribution.

Solar gains

	Total	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
solar gains entering [kWh]													
BC	2 622	195	152	277	239	298	262	269	284	222	226	107	91
1	2 989	216	169	314	275	346	303	311	327	253	254	119	102
2	2 436	185	143	259	221	273	241	247	262	206	212	101	86
solar gains absorbed [kWh]													
BC	1 018	75	58	107	93	116	103	105	111	86	87	41	36
1	1 071	76	60	111	99	124	110	112	118	91	90	43	37
2	971	73	57	103	88	109	97	99	105	82	84	40	34

Table 3: Solar radiation entering and solar energy stored in façade zone for selected months.

The gains from sun radiation, global and diffuse were also calculated for each month. Results for each case are compared in Table 3. The highest amount of energy during the whole year is collected in Case 1 (2 989 kWh), when there is no TIM elements.

	heating season			**cooling season**		
solar gains [kWh]	entering	stored	s/e	entering	stored	s/e
BC	1287	497	0.39	1335	521	0.39
1	1449	516	0.36	1540	555	0.36
2	1207	479	0.40	1229	492	0.40

Table 4: Solar radiation entering and solar energy stored in façade zone for the seasons.

However, comparing absorbed and utilised part of the energy, almost 2/3 are lost and a maximum of 40% is utilized in Case 2. On the other hand a similar amount of energy is stored in a façade during winter and summer.

Conclusions

The presented study is part of a multi-criteria optimisation of a building façade in moderate climatic conditions. These analyses were devoted to estimating the effect of different proportions between transparent and translucent parts of outer skin in a double façade.

The presented solutions reveal significant overheating during summer and insufficient protection against solar radiation in the hottest periods. On the other hand during winter the heat gain in the façade allows to store about 500 kWh of solar thermal energy and reduced heat loss in the coldest period by about 20%.

Comparing three presented solutions the differences seem to be negligible. The façade in Case 2, with a 40% of translucent and better insulated material (TIM) allowed to keep 4% of collected energy more than façade done according to Case 1 (only 60% of transparent glass).

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TOWARDS THE DEVELOPMENT OF A SIMPLIFIED LCA-BASED MODEL FOR BUILDINGS: RECYCLING ASPECTS

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ABSTRACT

The building sector identified as a main contributor of energy and resources consumption contributes to many environmental impacts such as resources depletion or climate change. The identification, quantification and analysis of the main flows of matter, energy and pollution through the building system by means of appropriate methods can help to provide knowledge and tools for decision making.

The Life Cycle Assessment (LCA) is, in this context, a method which can be applied to study the environmental impacts of buildings. Several LCA-based environmental analysis tools have been developed over the past few years. However, the relevance of such tools is often questioned. The methodological choices seriously influence the results of the analysis particularly in terms of data quality, type and number of environmental indicators, recycling take-account, modelling of the end of life (EOL) and more widely the chosen system boundaries. As a result of all of these shortcomings, the LCA studies are often seen as being too complex for application in the design process.

In this article, we present the current LCA models characteristics for buildings. Then, we focus the analysis on the recycling and EOL of products by presenting the current practices.

It has been found that current LCA models do account for material, recycling and end of life aspects but in a way so that it is not an easy task to evaluate the design choices for these aspects. Through the adopted methodology, main recycling criteria of LCA models were identified and consequences of defining a proper boundary system for a LCA model are discussed.

We conclude by discussing the challenges of improving the LCA methodology for buildings.

INTRODUCTION

The environmental impacts of buildings have become an issue of interest since the building sector is identified as a major contributor to the environmental impacts resulting in many pollution, energy consumption and waste generation among others. Even if much work has been done in this area, there is still a major way for research to improve the methodology of LCA tools for buildings. The detailed analysis of some hidden flows in current LCA model such as the material and recycling flows and end of life aspects become relevant as the use phase of a LCA of buildings is of less magnitude in new types of buildings (green buildings, low energy, and passive buildings). By reviewing the literature about environmental assessment tools for buildings, several tools were identified. However, even if state-of-the-arts are available [1], no proper detailed analysis on the LCA model characteristics is proposed. Dealing with the recycling and end-of-life (EOL) aspects, they are often poorly addressed even if some authors tried to propose improved methodology in this field [2]. The objectives of the work underlining the article are to first present the basis of LCA models for buildings. Based on the current limitations, we discuss the recycling aspects and the relevant criteria to account for.

METHOD: SURVEY OF CURRENT LIFE CYCLE ASSESSMENT MODELS

The construction of a LCA-based model of buildings refers to a systemic approach of mass flow balance. It enables the quantification of diverse environmental impacts of a system (material, product or building) from the extraction of raw materials until the end of life and possible reuse or recycling [3, 4]. As a result and contrary to other environment assessment tools such as Mass Flow Analysis (MFA) or Environmental Impact Assessment (EIA) which model the flows within a given period of time (*e.g.* a year), intrinsic key parameters in a LCA are the evaluation of a function across a certain period of time. It means that the scope of usual LCA study encompasses different periods of time between the extraction of raw materials until the end of life inevitably resulting in using scenarios. This argument is especially justified for long-lived system such as buildings where the life cycle is generally model within 50 to 100 years depending on its use [5]. These key parameters enable to distinguish the LCA of buildings (resp. building products) from the LCA of other manufactured products with short life cycle.

The survey literature on recycling aspects is taken both in current LCA models description [1] and some from the existing literature [2, 9].

RESULTS OF THE ANALYSIS

Table 1 presents five different models currently implemented in LCA models except the construction product model [9]. The analysis of recycling modelling is split between different criteria as shown in table 1 and in the following paragraph.

Existing recycling approaches	**Type of evaluation**	**Type of recycling model**	**Type of recycling allocation / characteristics**	**Recycling process allocated in FAB**	**EOL included?**	**EOL activities included**	**Recycling process allocated in EOL**
Cut-off [1]	Comparative	Open or closed loop	Full bonus of recycling at the fabrication phase	x			
Metallic recycling methodology [1]	comparative	Open or closed loop	Full bonus of recycling at the fabrication phase	x	x	x	x
Bonus method (avoided impact) [1]	comparative	Open or closed loop	Half bonus at the fabrication phase and half at EOL	x	x	x	x
Value substitution [1]	comparative	Closed loop only	Decrease of the quantity of matter in entry and quantity	x			
Construction products model [9]	Absolute (flow)	Open or closed loop	Bonus for using SRM** in the life cycle system studied	x	x	x	
Stock flow [11]	Absolute (flow)	Open loop only	Assessment of an effective flow	x	x	x	

**: *secondary raw materials*

Table 1. Criteria of existing recycling approaches.

- **INTRODUCTION IN EOL MANAGEMENT AND RECYCLING TYPE:**

Considering the building sector specificity, we differentiate closed-loop which corresponds to a recycling within the same system and for the same function *e.g.* recovered steel in a steel production plant from open-loop recycling which deals with different life cycles upstream and downstream the life cycle of interest. The last type of recycling is usually encountered in the building sector [10]. Whereas the closed-loop recycling allocates the recycling process within its boundary, in open-loop recycling, the recycling process is not readily allocating, remains unclear and lead to define boundary conditions depending of the objectives the model should follow.
As mentioned previously, one key assumption in every LCA model is the time parameter. Usually no time differentiation is considered and it is assumed that the impacts occurring at the end of life are the ones occurring at the time the assessment is carried out by lack of having forecasted data on end of life.

- **USUAL PARAMETERS TO CONSIDER:**

In the recycling modelling, usual parameters are the incorporation (at fabrication), recycling (at EOL) rates and the distances of transport between recycling facilities and the building site.

- **ALLOCATION OF RECYCLING PROCESSES:**

Current bonus method, as shown in table 1, credits a material being recycled with half of the bonus (impacts of recycling minus impacts of the avoided fabrication thanks to recycling) at the fabrication and the other half at the EOL phase, often resulting in negative values at this stage (see for instance results from figure 2). Yet, crediting a bonus at the EOL phase is actually relying on a major assumption which can lead to a major drawback: one may credit a product for a recycling that may not happen. On the other hand, 90% of steel elements are recycled at EOL whereas this proportion is only around 40% during fabrication, so that the bonus method may be more appropriate for such materials.
As a result, the stock flow model, currently implemented in the French environmental data, enables to be in accordance with environmental product declaration (EPD) and databases specific to construction products [7]. The main criteria for this model are to date: the allocation of the recycling process at the fabrication phase which enables to always evaluate current recycling technologies. This type of allocation in a recycling model adapted to the LCA of buildings has been little discussed in the literature. Vieira et *al.* proposes a similar method to take into account the end of life impacts of buildings (and as a result the recycling aspects) by allocating the recycling process at the fabrication stage [2]. Besides, this model does not consider the EOL treatment and draws the system boundary until the EOL activities *i.e.* selective dismantling and transportation to the end of life (with specific distances according to the assumed end of life scenario: landfill, incineration or recycling). As a result, one key point of this recycling model is that it decreases uncertainty due to technological forecasting by always assessing effective recycling flows at the fabrication stage.

- **EVALUATION OF THE RECYCLING BENEFIT:**

One aim of every LCA study or LCA-model is to be as transparent as possible that is to clearly show the methodological hypothesis taken in the model. In the recycling issue, a LCA practitioner would straightforward apply the recycling at the inventory step whereas the output of the LCA model is very often expressed as environmental indicator.

In the different recycling models analysed, it has been noticed a difference between all the models as some calculate the recycling benefit as a function of the current flows *e.g.* incorporation of secondary raw materials (SRM), recycled waste generated whereas others do it by means of a difference between a virgin material compared to a recycled material.

To make clearer the situation, there is a need to explore more the relationship between the input (environmental data representing inventory of several flows), the methodological choices (does the building's LCA model include a recycling model) and the environmental indicators as an output (which indicator is suitable and affected by the integration of the recycling flows).

It is every time possible to consider three scenarios of recycling rates (null, current, maximal rates). For example, the incorporation of the steel as secondary raw material (SRM) is currently in France about 40% whereas the recycling rates are still high, around 90%. This discrepancy may be explained by the fact that there is not obvious correlation between these two recycling parameters because they rely on technological processes for the recycling, material structure after a life cycle which may lead to use more process to incorporate it as a SRM in a new life cycle, and a last parameter which we define as the degree of separability. It means that even if a material is potentially recyclable at the end of life, due to its incorporation within other materials and as a whole within a building will not automatically ensure its recycling at the end of life due to its 'degree of separability'. By taking again the example of steel, it is stated that a steel product entirely made by steel material will be more recyclable than another product incorporating steel linked to other materials. As a result, incoming work should define precisely the concept of the degree of separability by identifying for different building products a value of this innovative parameter. Current recycling models either define a bonus (difference between recycled and non recycled product) or a flow with an effective recycling (at fabrication and EOL phases). Generally the recycling rates at EOL do not properly address this degree of separability as data may not always be available.

By emphasis on this last parameter, it enables to identify one of the major differences between product specific LCA databases [7, 11] and generic LCA databases.

- **RECYCLING PARAMETERS INFLUENCE:**

The different models were tested in order to see how they influence the results of the analysis. A simplified application on a reinforced concrete building enables to emphasis the importance of the production phase. Its influence decreases if the incorporation rates are maximized except in the bonus method where negative values occurred when assessing the EOL impacts which significantly differentiate this model from the other ones under study. It has been also found that the transportation distances are usually of less relevance than key parameters such as the recycling rates. Yet, these transportation distances can play a key rule at the EOL. As some models *e.g.* stock flow do not account of recycling processes at EOL, the only parameters of recycling at EOL are the dismantling impact and transportation distances. As a consequence, it may result in assessing a better environmental impact for landfilling or incinerating scenario compare to the recycling scenario as the transportation distances to recycling facilities are often higher than the distances to landfill scenario due to the presence of local landfill opportunities [12].

This is illustrated in figure 1 where a distance of transport to recycling facilities ranging from 0 to 500 km was assessed. Results show the increasing discrepancy between the allocations approaches depending on the inclusion of the recycling process and the associated recycling rates. Data were taken in the LCI database ecoinvent [6] and the impacts are expressed in cumulative energy demand [6] for a functional unit of 1000 kg. The default scenario was considered as landfilling of concrete by taking a 30 km distance according to the french EPD database [11]

The impacts for recycling at EOL are for the 'no recycling process' scenario only the dismantling and the transportation distances corresponding to an increased function of transportation distances whereas the other scenario do include the recycling process, it results in having negative values (recycling offsets) up until a critical distance about 400 km. The offsets for the stock flow approach are of less magnitude as the model does not include the recycling process and the critical distance is thus shorter and about 80 km.

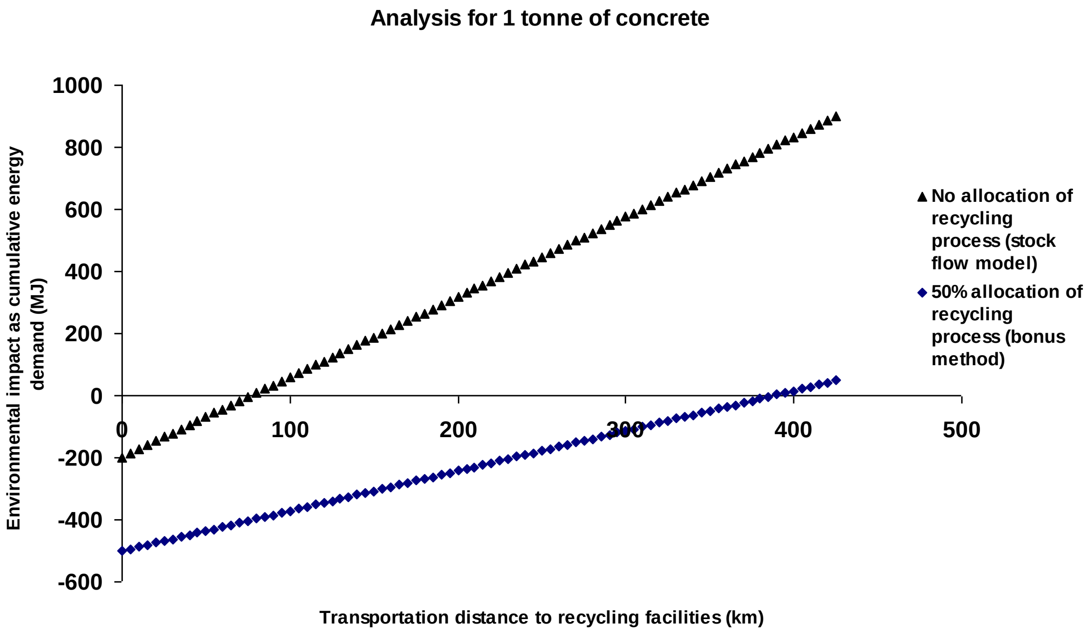

Figure 1. Analysis of EOL impacts as a function of transportation distances

DISCUSSION IN RECYCLING MODELING WITHIN LCA MODEL OF BUILDINGS

The recycling and end-of-life inclusion is currently modelled in different manner leading to possible high differences especially if the assessment is done phase by phase (*e.g.* production, transport, on-site… EOL). As a result, we recommend that the inclusion of recycling at the EOL should be first guided by the objective of the study. If the goal is to favour building design for recycling, then the EOL recycling processes should be taken in the analysis. The concept behind is the precautionary principle and the incentive to influence the building design as early as possible to take into account of recyclability at the EOL.

However, the study of the stock flow model revealed another way about dealing with recycling. First, this model does not deal with recyclability but only effective recycling. By allocating the recycling process at the new product (fabrication stage), it ensures to always assess current technologies which deals only with an effective recycling flow. From a LCA methodology point of view, it enables the reduction of uncertainties due to technological forecasting. The other approaches reported in the table either are closed loop approaches (value substitution) and then not properly deals with the effective recycling in the building sector or do not account for the EOL (cut-off approach) meaning that the material flows leave the system without any environmental impacts. In a view of developing a simplified LCA model for building, it would be interesting to study some probabilistic scenarios at the EOL as it would encompass some of the shortcomings of the different current models namely account for the uncertainty and include the recycling process at EOL.

CONCLUSION

Different recycling approaches were assessed according to different criteria. Current limitations are of many magnitudes and it was not in the aim of this article to present all of them in details. The recycling and end-of-life inclusion seems to be either portly handled or in different manner leading to possible high differences especially if the assessment is done phase by phase (*e.g.* production, transport, on-site… EOL impacts). A sensitivity analysis would be needed in the incoming work in order to estimate the main parameters of a LCA of buildings as we only isolate the recycling parameters from the rest of the LCA model. However, for the purpose of defining proper boundary conditions in a LCA model for buildings, the purpose of the model needs to be defined first in an attempt to assess an effective flow in a way of decreasing uncertainty of impacts that are far from the time the assessment is conducted. The other possibility is to include EOL recycling process in a way of designing building for recycling.

ACKNOWLEDGEMENTS

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MINERGIE-ECO SYSTEM VERIFICATION

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ABSTRACT

In the MINERGIE-ECO system verification project, methods and software libraries were created which allow operating energy consumption, environmental impacts caused by construction materials and energy consumption, and health aspects of buildings in a single easy-to-use and user-friendly software tool. This integrated computer tool will help professionals to easily optimize building designs without switching between different software. This is an important step towards a holistic view of building projects with sustainability in mind.

INTRODUCTION

An instrument has been developed which will serve as the platform for the Swiss building label MINERGIE-ECO [1] and allows verification of various other standards (SIA norms 380/1 [2], 380/4 [3], SIA fact sheet 2031 [4], MINERGIE and MINERGIE-P). This creates synergies with the official energy verification process and creates the basis for a wide acceptance among professionals.

To achieve this high degree of acceptance, the project has been built in large part on existing, recognized bases (see chapter "References" at the end of this paper).

The project has been divided into different work packages, which were all completed in a first phase. In a second phase, an additional number of case studies and the introduction as a certification tool are planned.

Figure 1 shows the methodology structure. In each of the three areas Construction Materials/Construction Methods, Operating Energy and Well-Being/Health, there are quantitative evaluation methods: eco-footprint, energy verification and room module. Questionnaires supplement the methodology for non-quantitative aspects. The qualitative and semi-qualitative evaluation procedures currently used in the MINERGIE-ECO process are thereby partially replaced by quantitative evaluation methods.

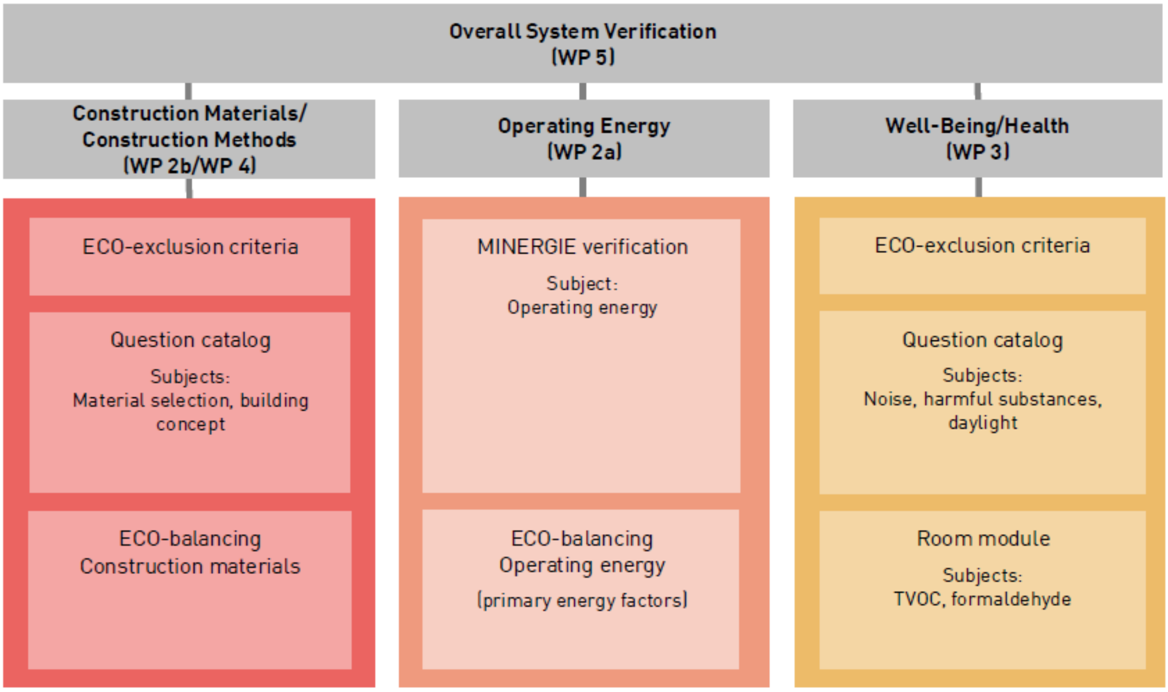

Figure 1: Structure and components of system verification

CALCULATION OF ENVIRONMENTAL IMPACT

In LESOSAI [5], the operating energy can be calculated according to the current SIA Norm 380/1. New in this project is the integration of the method proposed in SIA fact sheet 2031. This allows a rating of the building in energy efficiency classes A to G.

The environmental impact is calculated based on the LCA data published by the associations eco-bau and KBOB [6]. This can be done with a pre-defined construction component catalogue [7] (which also contains the U-values for energy calculations) or with self-defined components. The calculation method is compatible with the SIA fact sheet 2032 [8]. The results display the ecological impact of operating energy, building materials and both together.

Up to now, the integration of technical installations was not possible because reliable LCA data was not available. In the next project phase, the latest LCA data, containing installations as well, will be incorporated.

ASSESSMENT METHOD FOR INDOOR AIR QUALITY

With the room module, it is possible to evaluate the indoor air quality in an early planning phase. At its core is an emissions database, which contains emission rates for total volatile organic compounds (TVOC) and formaldehyde for typical construction materials (Figure 2).

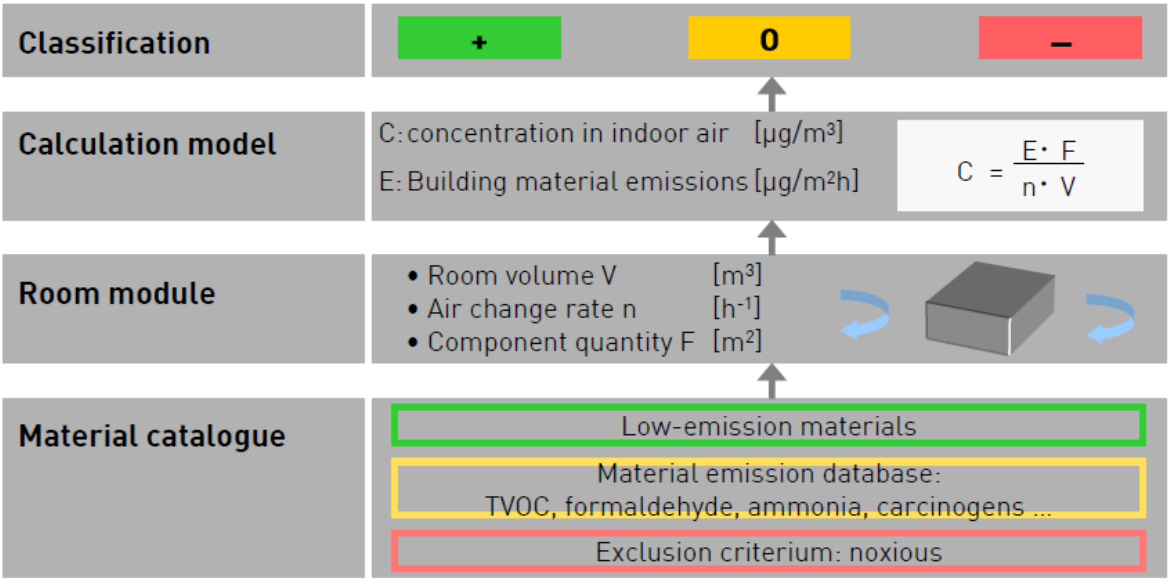

Figure 2: Overview room module

The room module is based on an existing approach for the calculation of concentration. The additional criteria comfort, daylight, noise protection and building material labels are evaluated using a questionnaire based on the existing building label MINERGIE-ECO and can also used for existing buildings.

At last there is a questionnaire which contains all aspects which have not been treated so far.

EVALUATION METHOD

The evaluation system allows the aggregation of partial results on several levels: first within the LCA calculation and the energy footprint, the room module and the question catalog, then for the three areas Construction Materials/Construction Methods, Operating Energy and Well-Being/Health, and finally for Overall Evaluation. The system is based on a “traffic light” metaphor that is easy to understand for users and allows an equal weighting of qualitative and quantitative results.

METHODOLOGICAL ADAPTATIONS FOR RENOVATIONS

In contrast to newly constructed buildings, existing buildings require a different methodical approach. So far, there is no method in Switzerland that allows the ecological assessment of renovated buildings, and the current version of the Label MINERGIE-ECO is only applicable for new buildings. In this project, the methodological adaptations for renovations have been developed.The first step of the process is a check of the existing building regarding waste deposits or pollutants in the remaining building materials.

In a second step, a life-cycle assessment (LCA) has to be calculated. This can be done either by using pre-defined building components (a collection is provided in a building component catalogue) or by defining own elements. Existing or deconstructed elements are disregarded in the calculation, because for new materials, the whole lifespan is taken into account, and a change of system boundaries had to be avoided. For the definition of boundary values, a check of the actual state of the building and the depth of engagement has to be done. Additionally, a small questionnaire has to be completed for renovations also.

The Requirements for Renovations regarding operating energy are already defined for the current MINERGIE-Label and will remain unaltered.

The boundary values for the LCA have to be confirmed within the next phase of this project. For this purpose, about 15 case studies with main focus on renovations are planned.

CASE STUDIES

The system verification has been tested based on ten case studies of new constructions and three case studies of renovations. Figure 3 shows a comparison regarding embodied energy between the case studies of new constructions.

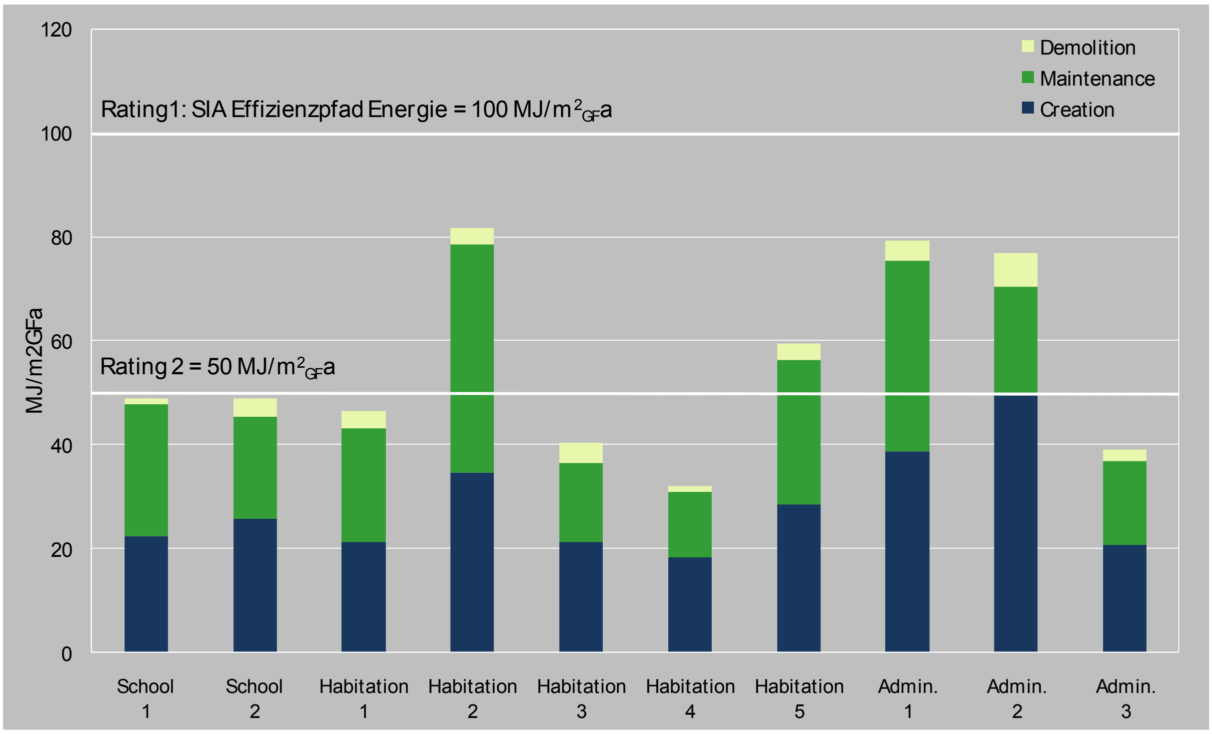

Figure 3: Analysis of new construction case studies: Comparison of embodied energy

Data was entered in Lesosai [2], an energy evaluation software, which was extended with the software libraries developed within this project. The results of the evaluation were used to test the plausibility of the methodology and to define boundary values. Regarding embodied energy of construction materials, this process was successful. For the evaluation of the room module and for renovations, it was possible to determine the general magnitude of the boundary values. Further evaluation based on additional case studies is planned to define the values more exactly. It became apparent that the evaluation method is relatively strict. Since none of the investigated buildings were directly optimized for the new requirements of the system verification process, we assume that the requirements can realistically be met in future, if the criteria are already taken into consideration during early planning phases.

RESULTS

The most important results of this project are the development of the methodology, including its documentation, and the implementation of the methodology in software libraries, as well as their integration into an existing simulation evaluation software (Lesosai 6.0).

NEXT STEPS

These Software libraries (DLL, dynamic link library) will be made available at no cost to other program developers for implementation. Additionally, questionnaires and checklists were developed for the subjects Construction Materials/Construction Methods, Well-Being/Health and demolition as a supplement to the methodology.

The next steps in this project are an extended trial phase with additional case studies (emphasis on renovations), the preparation of the tools and documents needed for the certification process, development of quality assurance processes and the integration of latest lifecycle assessment and lifespan data.

PROJECT PARTNERS

- Swiss Federal Office of Energy SFOE
- Association eco-bau
- Association MINERGIE
- Association of excavation, deconstruction– and Recyling- firms
- Swiss Federal office of Public Health FOPH

WORKGROUP

- Intep— Integrale Planung GmbH, Zürich (Lead)
- E4tech Sàrl, Lausanne
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- Laboratory for solar energy and building sciences of Swiss Federal Technical Highschool Lausanne (LESO)
- Holliger Consult GmbH, Epsach
- Amstein&Walthert AG, Zürich

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ELECTRICALLY CONTROLLED WINDOWS: PERFORMANCE OF NEW PRODUCTS

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ABSTRACT

A new generation of electrically controllable architectural insulating glasses is currently becoming commercially available. The advantages of these smart windows compared to standard glazings are the possibility to control the transmittance of solar radiation and hence the opportunity to avoid additional shading systems.

In order to get detailed information about two new products (SAGE Glass, SAGE Electrochromics inc. and EControl-Glas, EControl-Glas GmbH & Co. KG) we performed a full analysis of the performance by applying our set-up presented in a former CISBAT conference [1, 2]. Our measurements include a full optical characterisation by studying the spectral and angular dependent transmittance and reflectance that yield all relevant one-figure parameters such as solar direct transmittance τ_e, solar direct reflectance ρ_e, solar direct absorptance α_e, light transmittance τ_v, light reflectance ρ_v, and complete colour information of the transmitted and reflected light as well as the general colour rendering index R_a (all parameters as a function of the angle of the incident light). Furthermore, the g-factor has been determined as a function of the incident light by using a solar simulator [2, 3]. All these measurements have been performed for switching steps defined by the manufacturer's control units (two controlling states, bright-dark for the SAGE glass and five discrete states for the EControl glass).

The switching dynamics of smart windows is an important issue and therefore has been analysed by recording transmittance spectra over an extended time period. Furthermore, the consumption of electrical energy for switching and holding a transmittance state has been analysed.

Though we cannot assess the life cycle, the performance of the two product analysed in the present study indicate a clear improvement over former smart windows in several respects.

INTRODUCTION

Overheating of buildings due to extreme heat loads by solar radiation has become a well known phenomenon caused essentially by architectural preferences for highly glazed façades on one hand and by climatic changes on the other hand. Measures to avoid overheating could be appropriate architectural design, variable shading and blinds, sun protection windows, and switchable window glazings. The advantage of switchable windows by using electrochromic phenomena is the dynamic control of solar energy and visible light. Electrochromic windows therefore can contribute to the reduction of the energy needed for cooling and with it increase the comfort of occupants in the building.

For switchable windows two coating types are used, the all-ceramic coatings and coatings containing a polymer foil. In both cases the multilayer stack consists of two transparent conductors, an electrochromic tungsten oxide (WO_3) film, an ion conductor, and a counter electrode. The tungsten oxide layer changes its transmittance when a voltage is applied between the two transparent conductors. The ions needed for the charge transfer are provided by the counter electrode. The electrochromic layer and the counter electrode are separated by the ion conductor, the layer that is different in the two coating types. It can either be another ceramic thin film deposited directly on the electrochromic layer, or a polymer foil which will be sandwiched between two glass panes both containing parts of the layer stack [4 - 9]. When a voltage is applied ions will be transferred from the ion storage film to the electrochromic film or vice versa and alters the optical absorption properties of the electrochromic film [7]. As ions usually protons (H^+) or lithium ions (Li^+) are used.

METHOD

For the investigation of insulating glass units two measuring setups are used. The optical properties like transmittance and reflectance are measured angle dependently with the window stand developed at the University of Basel [1]. With it the transmittance and the reflectance can be investigated angle dependent from 0° to 75° angle of incidence over a wavelength range from 350 nm to 2150 nm. The g-factor is also determined with a home made set-up [3].

The required power for switching and holding a transmittance state was investigated with a METRA Hit 29S from the Gossen-Metrawatt GmbH. Two types of measurements have been performed: (1) the total power consumption of the system measured at the power line of the control unit and (2) the power consumption of the glass unit itself.

RESULTS

The investigated smart windows consist of the glass unit and a power supply with an integrated control unit, all provided by the producer. The dimensions of the invested EControl glass are 1200 x 600 x 29 mm^3 and 1400 x 785 x 25 mm^3 for the SAGE glass. The active area is 0.72 m^2 and 1.1 m^2 for the EControl and the SAGE glass, respectively. Further the SAGE glass has a middle electrode dividing the total area of 1.1 m^2 into two areas of 0.55 m^2.

The spectral transmittance for the five discrete states of the EControl glass for perpendicular light incidence is shown in figure 1. In figure 2 the spectral transmittance for the SAGE glass is shown which only has two states. As the transmittance for the dark state is very small the values of the spectral transmittance were multiplied by a factor of 20 for clearer presentation.

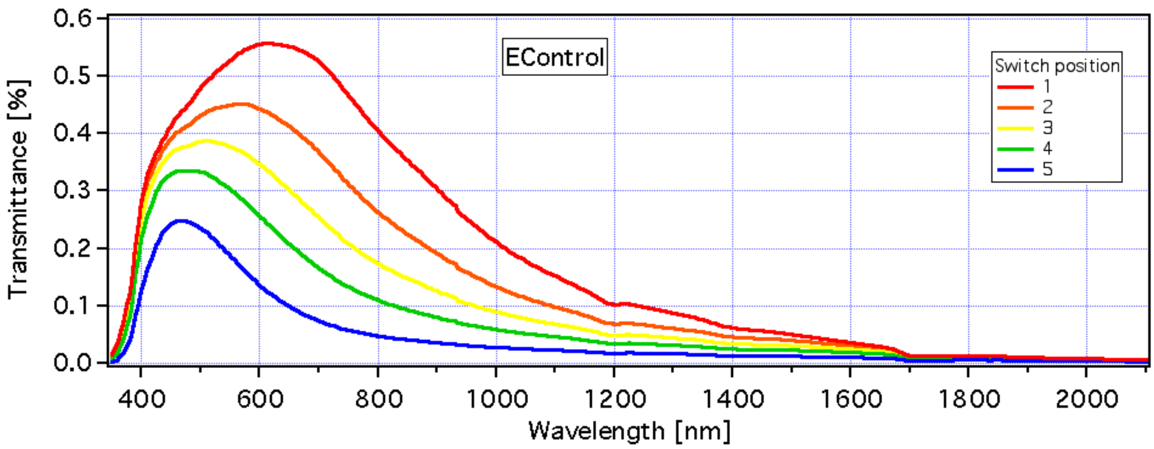

Figure 1: The spectral transmittance of the EControl glass for the five different switch positions, where 1 corresponds to the uncoloured and 5 to the darkest coloured state.

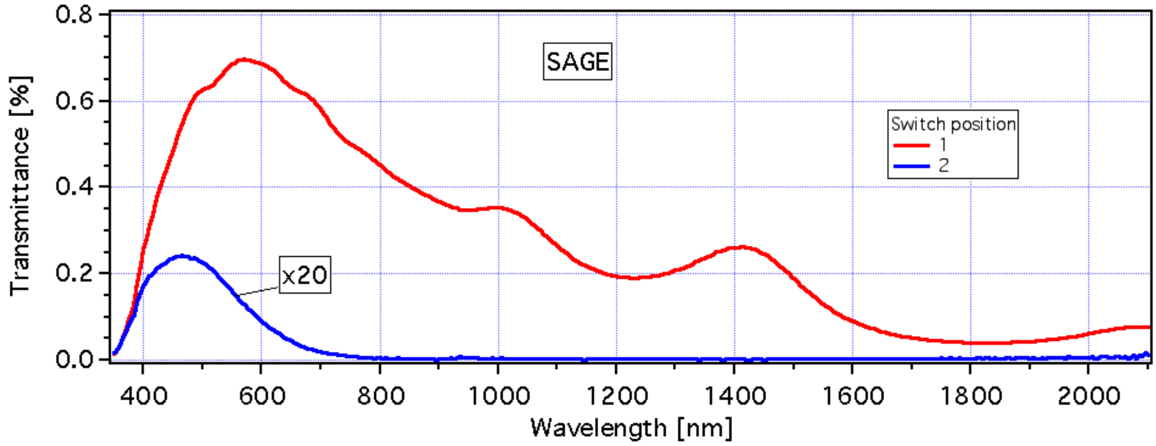

Figure 2: The spectral transmittance of the SAGE glass for the two different switch positions, where 1 corresponds to the uncoloured and 2 to the dark coloured state. The transmittance of the dark state is magnified with a factor of 20.

Comparing the transmittance of the bright state of the two glasses shows that the SAGE glass has a remarkably higher transmittance between 1100 nm and 1600 nm than the EControl glass. In the dark states of both glasses the reduction of the amount of incoming radiation having wavelengths greater 800 nm is greater than the reduction of the visible light (350 nm – 800 nm). Further the switching characteristic of the two products is different. The shape of the transmittance of the EControl glass is more or less constant for all states, whereas the shape for the SAGE glass changes.

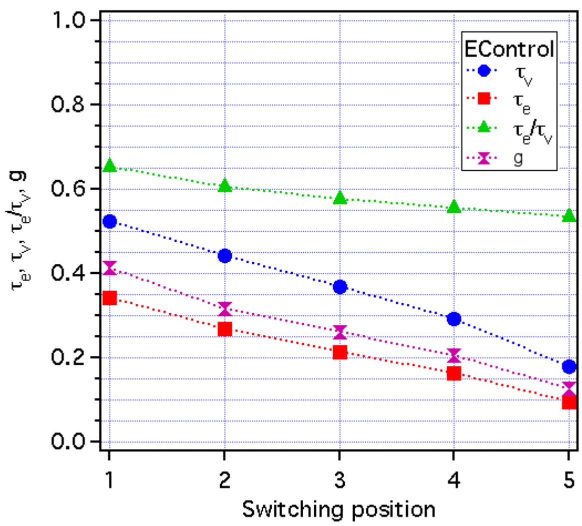

Figure 3: Light transmittance τ_v, solar direct transmittance τ_e, energy load coefficient τ_e/τ_v, and g-factor for the EControl glass depending on the colouring state. The markers give the values where as the lines are guides for the eyes.

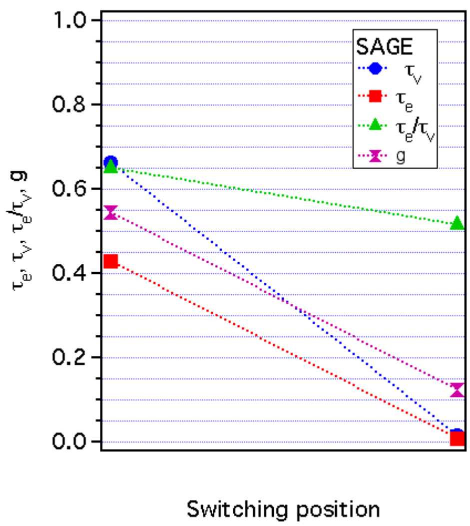

Figure 4: Light transmittance τ_v, solar direct transmittance τ_e, energy load coefficient τ_e/τ_v, and g-factor for the SAGE glass depending on the colouring state. The markers give the values where as the lines are guides for the eyes.

Light transmittance τ_v, solar direct transmittance τ_e, energy load coefficient τ_e/τ_v, and the total solar energy transmittance or *g*-factor are shown in figure 3 and 4 for the different switching states of the two glasses under investigation. In both cases the values decrease when switching to darker states and in the case of the five states of the EControl glass they posses a linear change. In table 1 the values for the bright and the darkest state are given.

	τ_v		τ_e		τ_e/τ_v		g-factor	
EControl	0.53	0.18	0.34	0.10	0.65	0.53	0.41	0.13
SAGE	0.66	0.02	0.43	0.01	0.65	0.52	0.54	0.13

Table 1: The value obtained for the bright and the darkest state of the two windows under investigation.

Comparing the values for the two glasses shows, that the energy load coefficient τ_e/τ_v is for the bright state of both glasses the same and nearly the same in the case of the darkest state. This means, although the solar direct transmittance τ_e at the bright state of the SAGE glass is higher it has the same selectivity (τ_v/τ_e) as the EControl, as its light transmittance τ_v is also higher. For the dark states it is the other way around. The g-factor is 0.13 for the darkest states of both and for the bright state 0.54 for the SAGE and 0.41 for the EControl glass. The g-factor of the SAGE glass in its dark state is with g = 0.13 unexpectedly high in view of the extremely low $\tau_e = 0.01$ value. The reason for this is the high direct solar absorptance $\alpha_e = 0.89$ of the active coating combined with a high heat conductance towards the interior glass pane leading eventually to a high secondary internal heat transfer factor $q_i = 0.12$.

The switching dynamics of smart windows is an important issue for usage and comfort. The evolution of light transmittance τ_v, solar direct transmittance τ_e, and energy load coefficient τ_e/τ_v versus time for the two glasses under investigation are given in figure 5 and 6. As can be seen in fig. 5 bleaching of the EControl glass goes faster than fully colouring it to state 5. For the SAGE glass the time needed to go from one state to the other is independent of the direction. The duration for a complete colour change for the two glasses is different. The EControl glass needs 700 s to change from state 1 to 5. This corresponds very good with the 12 min given by the manufacturer for a 1m x 1m window [8]. The time given by SAGE is 5-10 min for changing, for the investigated unit the time obtained in our experiment is around 15 min [9].

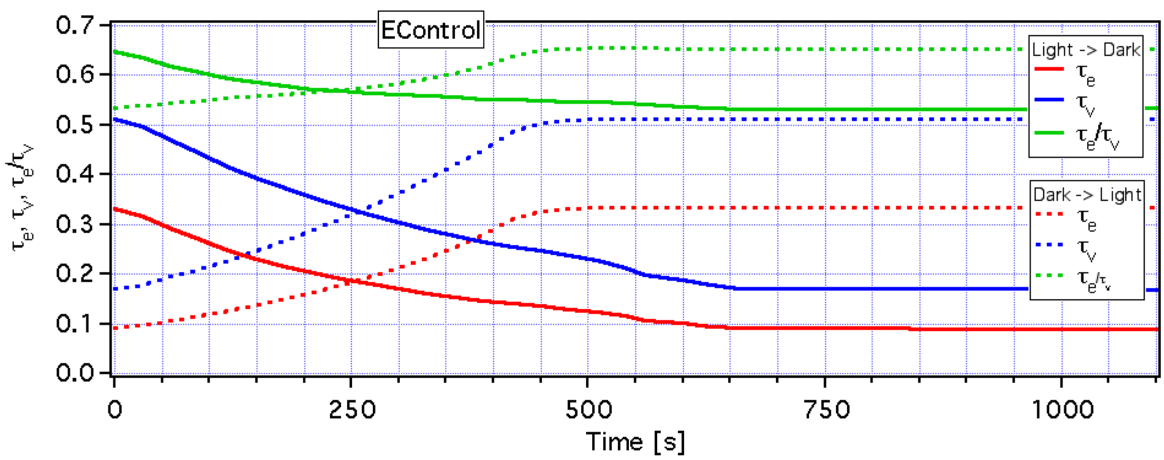

Figure 5: The evolution of the light transmittance τ_v, the solar direct transmittance τ_e, and the energy load coefficient τ_e/τ_v for the EControl glass, when switching from brightest (1) to darkest (5) transmittance.

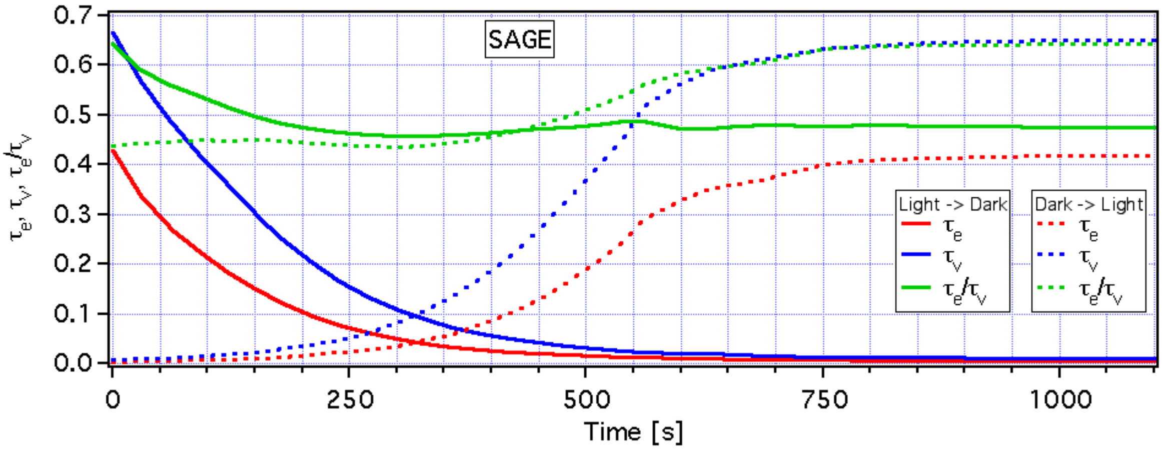

Figure 6: The evolution of the light transmittance τ_v, the solar direct transmittance τ_e, and the energy load coefficient τ_e/τ_v for the SAGE glass, when switching from bright (1) to dark (2).

The power consumption by the glass and by the system during changing and keeping the optical properties of the coating for the two investigated windows are shown in figure 7 and 8. In both graphs the yellow und blue lines represent the power needed by the glass unit, whereas the red and green give the total power of the system. The power consumption for the system and the glass are determined in individual measurements. For comparing the two graphs one has to keep in mind that the scale of the power axis is not the same.

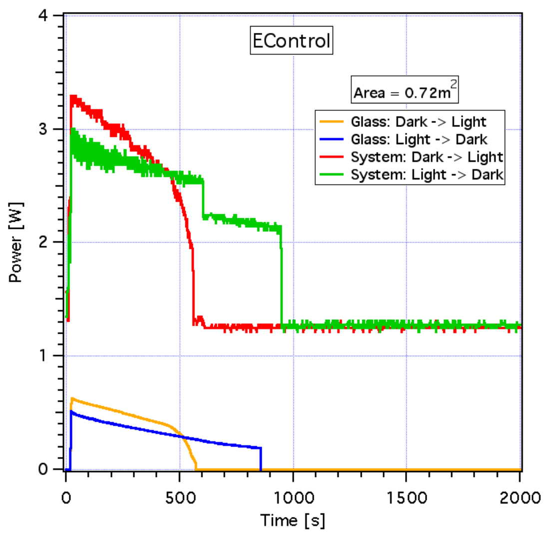

Figure 7: Power consumption of the EControl glass during the switching from the bright (1) state to the darkest (5) state or vice versa and afterwards keeping this status.

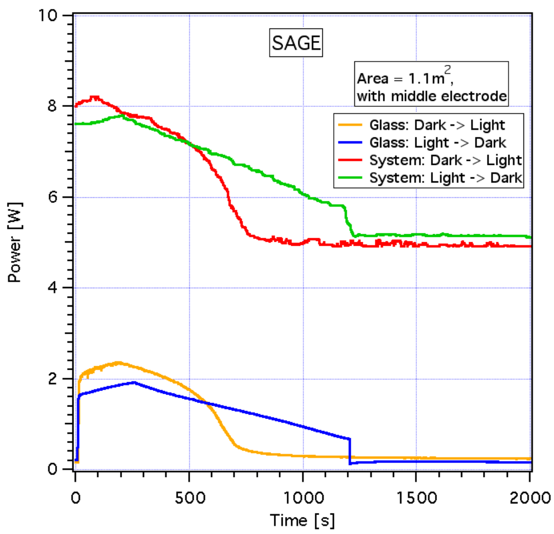

Figure 8: Power consumption of the SAGE glass during the switching of one colour state to the other and afterwards keeping this status.

Comparing the power usage of the coating of the SAGE and the EControl glass shows that the peak power needed for the EControl glass is 0.63 W (0.9W/m^2) whereas it is for the SAGE glass with 2.37 W (2.2W/m^2) much higher. The main difference is the SAGE glass needs 0.23 W (0.2W/m^2) to keep the transmittance state where as the EControl glass here for needs no power. Taking also the losses of the power supplies in to account the power consumption during constant transmittance is 8.2 W (7.5W/m^2) and 3.3 W (4.5W/m^2) for the SAGE and the

EControl, respectively. If the units are disconnected the EControl glass stays in its current state, whereas the SAGE bleaches to a state that is nearly equal to its bright state.

DISCUSSION

From these investigations, not taking the life cycle performance into account, we can conclude that both smart windows can increase the comfort in the building as they reduce the light transmittance without using blinds. Further they reduce the solar transmittance in the dark states and therefore reduce the heating up of buildings. To fully profit from those properties it is of great importance to choose the right glass for a specific usage. For example it would make sense to use the SAGE glass for overhead windows (skylights) as the transmittance can be reduced drastically down to only 2%. Using the SAGE glass in glass façade would increase the need of electrical lightening in the rooms and by the daylight reduction the comfort of the occupants is also reduced. Here the usage of the EControl glass would be advisable as the transmittance can be adapted to the light needed in the building.

Things that would need further improvement is the power consumption of the power supplies, especially during constant transmittance, as during this time the glasses need little or even nothing to keep it. Further a reduction of switching time would increase the comfort for occupants. Changing the coatings to receive a better selectivity would be another improvement, although they can already contribute to smaller cooling loads needed in buildings with the selectivity they posses now.

ACKNOWLEDGEMENTS

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DEVELOPMENT OF A RENEWABLE AND ENVIRONMENTAL FRIENDLY THERMAL INSULATION MATERIAL FROM OIL PALM EMPTY FRUIT BUNCH (OPEFB) FIBRE

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ABSTRACT

A study was done to develop a thermal insulation material from fibres derived from Oil Palm Empty Fruit Bunch(OPEFB). Suitable processes were identified to produce an insulation material for roof applications. In the production of the insulation material, cellulosic materials derived from recycled papers, were mixed with the OPEFB fibers. For the purpose of thermal insulation, the best material property was found to be at a density of around 120 kg/m^3 at 60:40 OPEFB to recycled-paper ratio. Based on ASTM standards, the insulation material was found to be semi-rigid and has a degree of suppleness, and could be categorised as board insulation. The insulation material can be categorised as semi-rigid and is not flexible. Using 'Rockwool' as a reference, it was found that the EFB insulation has an apparent k-value of around 0.043 W/mK, at an average temperature of 55^{o}C. Compression and flexural tests were also carried out; and the physical properties of the insulation material were found to be satisfactory. The insulation material developed from OPEFB fiber, which is plant based, will offer a more environmental friendly and renewable alternative to existing insulation materials.

Keywords: Oil Palm Empty Fruit Bunch, Thermal Insulation, sustainable materials

INTRODUCTION

According to 2005 statistics (Wahid, 2006), more than 74 million metric tonnes of fresh Oil Palm fruit bunches were processed yearly in Malaysia to produce palm oil. The Oil Palm empty fruit bunch (OPEFB) has a high fibre content, and potentially more than 4.8 million metric tonnes of usable fibres can be produced per year in Malaysia alone.

The cost of extracting usable OPEFB fibre was reported by Zain (1994) to be nearly Malaysia Ringgit (RM) 79 per metric tonne. In processed form the fibres are in the form of fiber bundles, not unlike coir. Some attempts have been made to process OPEFB into various products such as paper (Law, 2001) and composites (Ramli,2002; Kalam, 2004; and Shaji, 2006). At present, a large portion of OPEFB is still burnt as fuel or used for mulching purposes. Further development of OPEFB based products should be encouraged to ensure that it would be more commercially utilized.

Many agriculture based material has been studied to determine their useability in building applications. Cellulose insulation from recycled newsprint has been studied (Yarbrough,1996, Ewadinger, 2000) and is available in the US market. Hemp shiv mixed with lime has also been shown to be viable to be used as building material in the UK(Woolley,2008). Varlovita (2002) studied loose fill and matt form of hemp insulation. Other agricultural fibers are also available such as kenaf (Ardente et al, 2006), linseed, and straw, and the feasibility of using them were also investigated (Kymäläinen, 2002). Whilst kenaf and hemp are non-food crops; straw and the OPEFB fibre being reported in this paper, are low-cost by-products from the processing of food-based crops.

The study shows that a thermal insulation material, suitable for tropical roof applications, could be produced based on the OPEFB fibre. The novel insulation material would be renewable and also environmental friendly. The new insulation material should have a low environmental impact to the environment and of sustainable material.

MATERIALS AND METHOD

Figure 1: Raw OPEFB Fibre

The raw EFB fiber, commercially obtained, has been processed to reduce its oil content and broken up into long fibers. The raw fibers are initially further refined to loosen the fibers using a Sprout-Waldron single disk refiner. The process further separate and loosen the fibers and makes it easier for further processing.

The refined fibers are then centrifuged for 2 minutes to remove excess water and then either immediately used or refrigerated for later processing.

Table 1 summarises the length and width distribution of two 5 g fiber samples (FS1 and FS2) of the refined OPEFB fibers. Before measurement, the samples are oven-dried and are left to cool to room temperature. Moisture content of the fibers were found to be around 10%. They are then measured for their width and length.

	Fiber Sample 1		Fiber Sample 2	
	Length(mm)	**Thickness(mm)**	**Length(mm)**	**Thickness(mm)**
Average	60.01	0.18	67.52	0.17
Minimum	19.12	0.04	16.33	0.02
Maximum	201.27	0.55	264.80	0.68
Standard deviation	31.92	0.08	40.89	0.08

Table 1: The Average, minimum, maximum and standard deviations value of length and thickness of refined OPEFB

In the production of the insulation material, cellulosic materials derived from recycled papers, such as old newspapers, magazines or other paper wastes are added to the OPEFB fibers. The paper pulp is prepared by soaking old newspaper overnight and then passing it through the Sprout-Waldron single disk refiner. Normally, newsprint paper contains calcined or aggregate clay as filler and starch, which is added to enhance strength. In addition, some coatings and chemical additives may also be present in the paper. The refining process is simply to turn the paper into pulp and there is no deinking process involved. Thus, the pulp may contain some ink, filler and starch materials. The cellulosic pulp materials and the refined OPEFB fibers are then added together and wet-mixed using an electric mixer. The mixture is then vacuum dried for 1 hour until the mixture is drip-dry and the resulting damp fiber sheet is then transferred into an oven for further drying. The fiber sheet is heated and dried in the oven at a temperature range of 60°C for approximately 4h. After drying, the moisture content of the fiber sheet is found to range from 8% to 12% by weight.

The dried insulation sheets are then coated with single-pack foaming polyurethane adhesive and cold pressed to a number of sheets to form a layered insulation of desired thickness. Polyurethane is used since it is water and chemical proof and capable of withstanding moderately high temperature. The foaming of the polyurethane during curing maintains the insulative properties of the fiber sheet. The amount of adhesive used is 15% to 20% by weight of the insulation sheet.

RESULTS

The insulation material is tested for its physical properties based on several accepted methods.

Based on ASTM standards C168-05a, the material could be categorised as board insulation as it is semi-rigid and having a degree of suppleness. When using tests laid out in ASTM C 1101/C 1101M-00, the insulation can only be categorised as semi-rigid and not flexible. A visible break occurs when the material is bent more than 45^o compared to the 90^o bending as stated in the standard. When tested for rigidity, the sag was found to be more than 13 mm. The material was also tested at a maximum service temperature of 80^oC for 96 hour and no visible cracking, charring or smoking was found. The apparent thermal conductivity of the material was measured using a guarded hot-plate apparatus using Rockwool insulation as a reference, at an average temperature of 55^oC, and the result is as shown in table 2.

SAMPLE	k_a-value (W/mK)	Thickness (mm)
S3 (20% recycled-paper)	0.048	27.95
S4 (30% recycled-paper)	0.043	26.27
S5 (40% recycled-paper)	0.043	25.02
S6 (50% recycled-paper)	0.042	24.00

Table 2: Apparent thermal conductivity value (k_a-value) and thickness of different fiber to recycled-paper composition at average temperature of 55^{o}C.

The apparent thermal conductivity value was found to stabilise from 30 % paper content onwards at around 0.043 W/mK. The thickness of the sheets however decreases slightly with increasing recycled-paper content.

Since the authors did not manage to find any standard specification for bio-fiber based insulation, ASTM C612 -04 (2006) was used as a reference. The compressive properties of the material was tested for different fiber to recycled-paper content and the result is as shown in Table 3.

SAMPLE	Maximum Load (kN)	Compressive Strength (Mpa)
S2 (10% recycled-paper)	0.86	0.08
S3 (20% recycled-paper)	0.88	0.08
S4 (30% recycled-paper)	1.21	0.11
S5 (40% recycled-paper)	2.37	0.23

Table 3: The maximum load and compressive strength of various sample.

Table 3 above shows that the compressive strength increases significantly at 30% paper content onwards.

Although the standards does not specify any flexural property requirement, the flexural property was studied to investigate the physical properties of the material; and the values of modulus of rupture (MOR) and modulus of elasticity (MOE) are as in table 4 below.

SAMPLE	MOR (Mpa)	MOE (Mpa)
S2 (10% recycled-paper)	0.159	1.971
S3 (20% recycled-paper)	0.244	7.168
S4 (30% recycled-paper)	0.249	7.869
S5 (40% recycled-paper)	0.347	21.048

Table 4: The values of Modulus of Rupture (MOR) and Modulus of elasticity (MOE) for various samples.

Table 4 shows that as recycled-paper content increases, the bending strength of the insulation board also increases. A substantial increase in strength occur as the ratio of recycled-paper is increased from 30 % to 40 %.

DISCUSSIONS

The tests carried out showed that the material has properties suitable for insulation purposes for use at a maximum service temperature of 80^{o}C and average temperature of 55^{o}C, for application in the tropical region. The best OPEFB fiber to recycled-paper ratio was found to be around 60:40. At lesser recycled-paper ratios, the strength of the insulation board is compromised and a higher apparent k-value is recorded. At the suggested content ratio, the apparent k-value is comparable to existing insulation material available in the market.

The recycled-paper fibers probably acted as binder or adhesive for the OPEFB fibres and help to trap and block air flow in the insulation sheet. Since air is a good insulator, the more air is trapped in enclosed cells or sheets, the better the insulation effect. The residual starch may also still play a role in the adhesion between the OPEFB fibres and the recycled-paper fibres.

Further development has to be carried out before the OPEFB insulation material could be marketed. Studies will have to be done to satisfy requirements such as linear shrinkage, water sorption, moulding and burning characteristics. Suitable chemicals can be incorporated into the insulation sheets for providing properties, such as fire retardation, insect repellence and others. Mechanical strength may also be improved by adding other types of adhesives or materials for special applications.

Other potential applications of the EFB fiber product includes uses as sound absorbing material. The material could also be applied between wall panels and a more rigid form could be suitable for use as ceiling material.

The study showed that it is possible to produce insulation materials from OPEFB and recycled paper. Since both the OPEFB fibre and recycled paper are plant derived, the product is renewable. Naturally, it has a very low impact on the environment and it is also not known to present any form of health hazard.

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THE FUTURE BUILDING – A DYNAMIC HUMANE SOLAR SHELL

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SUMMARY

The paper deals with the development of a dynamic concept for the future design of buildings. It proposes that the design of buildings should have dynamic characteristics to achieve maximum human well being, comfort and health with maximal utilization of daylight, solar heat and natural ventilation. This should be done with highly efficient energy systems and at a reasonable cost. The anticipated future building envelope will not have separate transparent windows and opaque walls. The goal is to develop a dynamic controllable system, which allows for changes of the visual, thermal and acoustic properties of the envelope. The separation between window and opaque wall will not exist anymore. It is proposed to call this combination of wall-window **-** the WALLDOW.

INTRODUCTION

A perspective is suggested for the design of buildings so that their characteristics will be dynamically controlled to achieve maximum human well being, comfort and health with highly efficient utilization of solar heat, daylight and natural ventilation, and at a reasonable cost.

Variable transmitting and glazing materials like the "electrochromic" and "electrothermal" materials have already been developed. However, so far attempts at developing controllable thermal properties for opaque parts of the building envelope have not yet been successful. It is believed that the emerging new material technologies in combination with advanced controls will bring about the development of systems with the desirable properties. These goals may be achieved by developing buildings in which there will be no division between opaque walls and transparent windows. We call these wall-window envelopes WALLDOW which will have bi-directional controlled dynamic properties.

It is important to indicate that this is an on-going research, and further progress will be reported in the future. For publications on earlier stage on the study see [1] and [2]. See also Ne'eman, Yarmolinsky et al, 2007)

CURRENT TRENDS IN ENERGY SAVING

Modern life styles have led to the situation that most people do their daytime work indoors. In result, the energy consumed for electrical lighting has dramatically increased. There are well known energy saving solutions for indoor lighting. Thus many kinds of internal as well as external shading devices are installed. Apparently, that the hassle of closing and opening shadings is a major reason for using electrical lighting as a substitute for daylight even when it is available. However, due to the current rise of energy prices, we are forced to carefully reconsider saving energy in general, and energy spent for the electrical lighting in particular.

At present efficient light sources like compact fluorescent and T5 lamps are widely used, which are clearly more efficient than incandescent and halogen lamps. However, some studies currently carried out, indicate that a health risk may be associated with long exposure to this type of lighting.

SUN PATH

Exposure to sunlight mainly depends on geographical latitude, location and weather. Evidently, local sun paths in the northern hemisphere determine that eastern facades are exposed to direct sunlight in the morning hours, while western facades are exposed during the afternoon. Obviously, southern facades are exposed to direct sunlight during most hours of the day, unless the sun is obscured by clouds. The opposite applies to the southern hemisphere. Therefore, it is clear that the utilization of daylight must be suited to the local geographical and climatic conditions.

In most workplaces inside buildings, direct sunlight is a cause of unwanted glare and overheating during the hot seasons. Without the application of shading devices direct sunlight can reach different locations of the interior. As a result, in most such situations the tendency is to lower the shading devices, which are unfortunately left closed throughout the working day. As a consequence, workstations near the windows are protected by the sun shade, but in many cases work stations further away from the windows may become under-illuminated.

SURVEY OF AN OFFICE BUILDING

A typical office building has been examined to figure out the way occupants protect themselves against the glare and overheating by direct solar radiation. An office building in the center of Tel-Aviv, Israel (32.1^0 north latitude) has been surveyed, Figure 1. The figure demonstrates a typical situation where a large number of the windows have their blinds down to avoid the undesirable effect of direct sunlight. Moreover, the survey showed that the application of sunshades throughout the whole day is widely spread. Inevitably, at the same time, electric lighting is switched on during all daytime working hours. As a result, electric energy is wasted while daylight is not used. It should be stated that typically in the Tel-Aviv climate, and similar locations, daylight can be utilized during most day hours for at least 300 days of the year.

Fig. 1: The South Facing facade of the surveyed building, partly shaded by a high-rise adjacent building.

Fig. 2: An interior view of a window in one of the offices of Figure 1. The shades are almost completely closed. Occupant has left a narrow opening to allow some daylight get in and have a limited view out. The Electrical lighting is made of 8 Fluorescent luminaires, switched on all day.

Figure 2 shows an interior of an office in the same building where the sunshades have been almost totally closed and only the very lowest part of the window permits a limited view out and admission of some daylight. It is estimated that lighting consumes about 25-30% of the energy in office and public buildings, while air conditioning and other energy uses account for the rest. In recent years, a lot of publicity and effort have been made to use the most efficient electric lighting sources like compact fluorescent lamps and LEDs.

SAVING BY CONTROLS

Furthermore, currently, many efforts are made in order to save energy by using sophisticated lighting control systems like DALI and others. Moreover, combined electrical and mechanical systems have been recently developed, like central units that control and adjust dynamic mechanical shades and the electrical lighting. We claim that proper utilization of daylight can bring about much higher saving of energy in these buildings during daytime.

CHANGING THE APPROACH TO THE BUILDING OUTSIDE SHELL

The traditional outer shell of all buildings is made of opaque walls into which openings - windows - are made for the admission of daylight and ventilation. At present, the opaque part of the shell cannot be dynamically controlled. On the other hand, as mentioned earlier, there are already dynamically controlled materials like low-E and electrochromic glazing. We suggest here to eliminate the distinction between walls and windows and create a new shell for the building, which will have bidirectional dynamic properties. Because of the integration of windows and walls we call this type of shell WALLDOW, meaning a hybrid of WALLs and winDOWs. The building shell will be divided into arbitrary units, Figure 3, controlled by a sophisticated preprogrammed system according to the desirable protection of each workstation, with an option for individual control by each occupant.

The control system will be made of 4 subsystems as described below. The system will allow variable light, heat, air and sound transmission according to indoor requirements, weather conditions, time of day, orientation and location of various workstations inside the space. The bidirectional control will allow admission of daylight, as well as exchange of heat, ventilation and sound between outdoor and indoor.

Fig. 3: The WALLDOW outer shell is divided into arbitrary units which will be individually controlled according to the desired needs of each workstation. Occupants will have an option to individually control the shading of their space.

A. Daylight admission.

Suitably located light sensors will interact with the preprogrammed control system to allow optimal utilization of daylight for all workstations and other parts of the interior space, as described later on.

B. Heat exchange between inside and outside

The system will be bidirectional. It will control the heat flow, solar radiation and heat conduction through the WALLDOW envelop in both directions. It will have a direct connection by internet to the nearest weather station to allow advance changes in the interior climate, according to weather forecasts. In clear cold winter days, solar heat will be admitted to reduce the electric energy consumed by the heating system.

C. Ventilation

Openable units in the WALLDOW shell will allow natural ventilation during suitable outdoor weather conditions.

D. Acoustic control

Ultimately, this system will be capable of controlling the sound exchange. On an early nice morning it will be possible to hear the birds singing in the nearby park, while avoiding heavy traffic noise later in the day. Furthermore, the system will avoid any undesirable leak of sound information to the nearby outdoor world.

SIMULATIONS

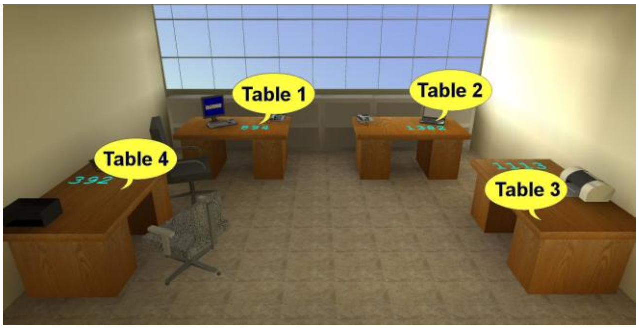

Fig. 4: The simulated office, with 4 individual workstations, with a glazed wall facing south.

The illuminance on each work station has been simulated at different hours of the 22nd day of each month. The simulation was carried out for the latitude of Tel-Aviv, (32.1^0 North). Four of these simulations are presented below:

Figures 5, 6, 7 and 8, show graphs of illuminances on the desktops of Figure 4. These simulations show the illuminances during the whole day. Figure 5 demonstrates the hourly illuminance values on the four desktops on the 22nd of February. It obviously shows that at various hours of the day, desks 1 and 2 will receive very high illuminances which will inevitably cause discomfort for the occupants of these locations. On the other hand desks 3 and 4 receive much lower daylight illuminance. Still, the illuminance may be sufficient for their visual requirements.

The current practice of lowering the window shades will improve the visual and thermal conditions of the occupants of desk 1 and 2, while occupants of desks 3 and 4 will most likely not get enough daylight to carry out their work duties. The unavoidable dilemma is that lowering the window shades will improve the conditions of the occupants of desk 1 and 2, while the occupants of desks 3 and 4 will most probably have to switch on the electric lighting during the whole day, thus unnecessarily consuming energy.

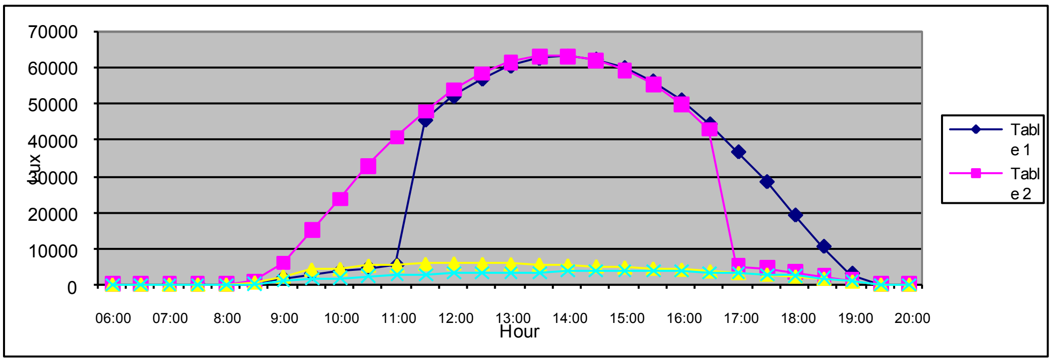

Fig.5: Hourly illuminance values for 22nd of February

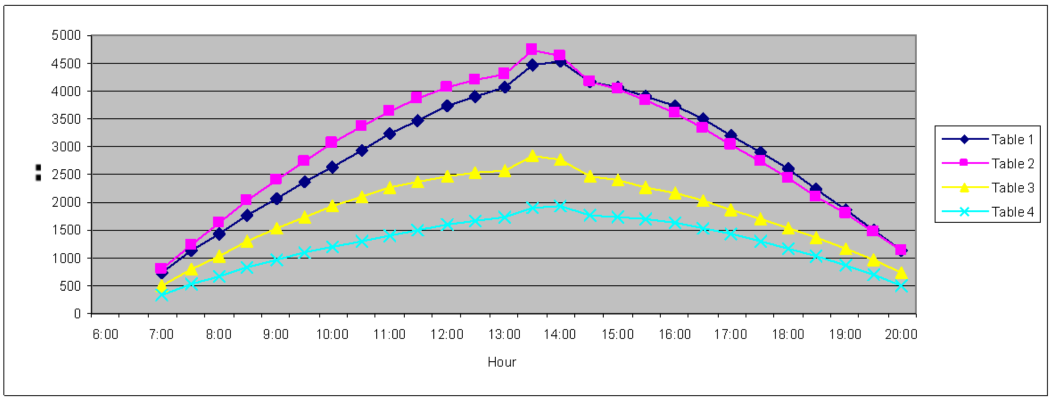

Fig. 6: Hourly illuminance values for 22nd of June

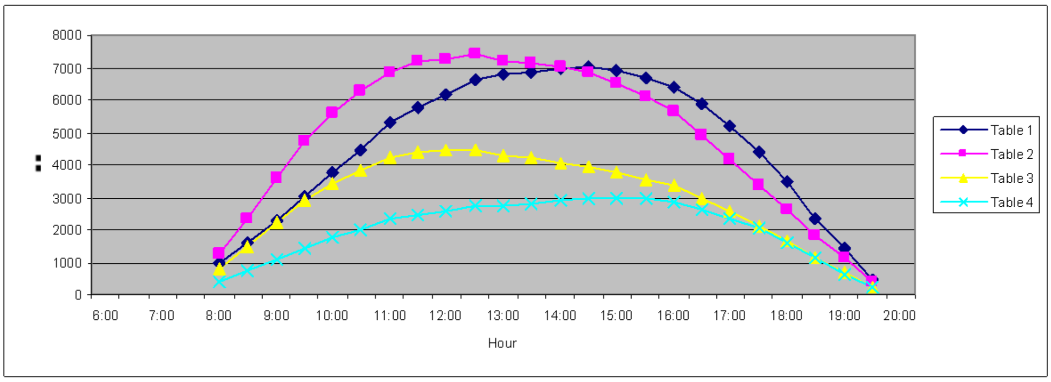

Fig.7: Hourly illuminance values for 22nd of September

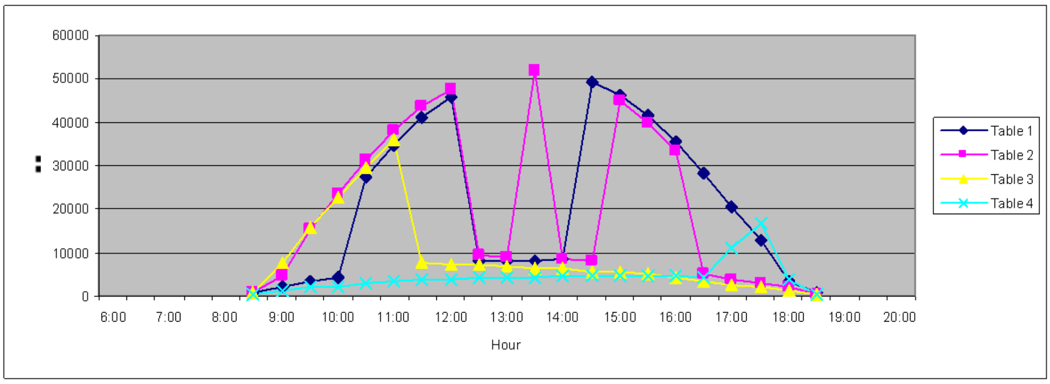

Fig. 8: Hourly illuminance values for 22nd of November

WALLDOW AS A FEASIBLE SOLUTION

As clearly seen in the above simulations. there is a considerable variance in daylight illuminance values during the day hours and in particular between different desk locations inside the examined space. Obviously, there is no simple solution to achieve acceptable illuminance levels on all desks. The illustration in Figure 9 below shows high illuminance values on three of the desktops caused by direct sunlight. The traditional solution for similar situations has been lowering the sun shades and switching on the electric lighting.

Fig. 9: Sunlight penetration into the simulated room on November 22nd, at 11:00 AM

Figure 10 shows the WALLDOW solution which brings about an optimal solution. While the WALLDOW shading blocks direct glare on desks 1, 2 and 3, it admits enough illuminance on desk 4. It is important to indicate that the WALLDOW shading algorithm is not trivial. For example, here we have employed WALLDOW's units with different light transmission values, in order to achieve similar illuminances on all desktops.

Fig. 10: Sunlight penetration utilizing WALLDOW in the simulated room on November 22nd, at 11:00 AM

Clearly, the Walldow pre-programmed configuration depends on geographical location, orientation of the opening, weather and time of the day. Below, is another sample of the same workspace, but with a north facing opening. The graph in Figure 11 shows illuminance values on the desktops during the day hours at on June22nd. It suggests that north facing windows may not need a full WALLDOW protection and a different pre-programmed WALLDOW approach might be taken.

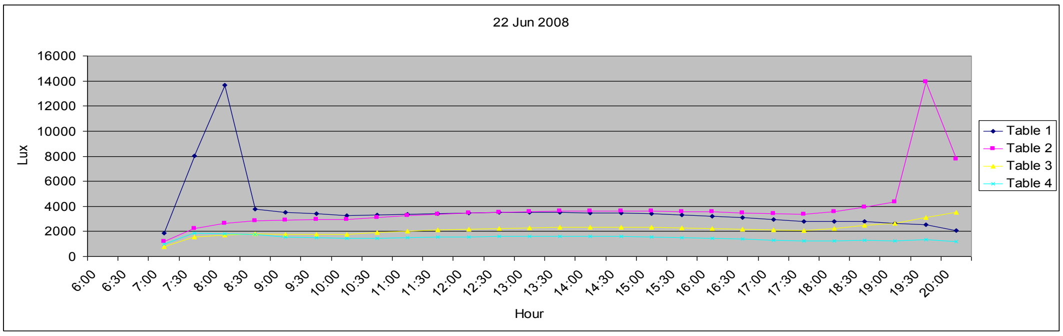

Fig. 11: Hourly illuminance values for a north facing opening on June 22nd

ON SITE MEASUREMENTS

On site lighting levels measurements were carried out in order to estimate current situation in typical office. Following are room details:

Room Description:
Typical office, north facing, 4th floor, dark glazed windows.
Dimensions: 4.76x2.88m, height – 2.6m.
Installed lighting fixtures:
4x18W T8 FL – 4 luminaires

Measurement point No.1: (0.2m from window, height – 1.1m)

Closed window, lighting is ON – 240 Lux	Closed window, lighting is OFF – 210 Lux.
Opened window, lighting is ON – 572 Lux	Open window, lighting is OFF – 540 Lux

Measurement point No.2: (0.5m from window on the desk, height – 0.75m)

Closed window, lighting is ON – 159 Lux	Closed window, lighting is OFF – 107 Lux
Opened window, lighting is ON – 245 Lux	Open window, lighting is OFF – 198 Lux

Measurements show, as follows: Window glaze transmission – approx. 50%. Comparatively poor electrical lighting.
In case of possible daylight utilization using lighting controls , much better results might be achieved as follows: Measurements point No.1: Additional 30% of glazing transparency will provide 273 Lux (210 Lux+30%) of daylight compared to the current 240 Lux, that includes daylight and electric lighting.
It is evident that by means of controllable glazing transmission considerable energy saving can be achieved in the tested room.

CONCLUSIONS

This study indicates that the WALLDOW system may bring about a substantial improvement in energy savings on electric lighting inside workspaces. As mentioned above, the WALLDOW system is under intensive development. Quantitative analyses of potential energy savings and additional algorithms will be available in further publication.

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CREDITS

Computer simulations were made with AGI32 software by Lighting Analysts, Inc

SUSTAINABILITY FOR THE DIALOGUE BETWEEN TRADITIONAL BUILDINGS AND NEW TECHNOLOGIES

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ABSTRACT

Renovation of existing residential buildings is an important field in Italy, where the building maintenance market is estimated to be in the near future about the 70% of the total construction market. [1] More and more often building maintenance is aimed to improve the energetic behavior of the building envelopes, and, consequently, to reduce the operating energy consumption. From this point of view a sustainability oriented approach can be considered the key-word for the dialogue between tradition and innovation. So, building envelopes are a suitable place for the dialogue between traditional buildings and new technologies. Using sustainability as a starting point for the renovation of existing buildings the traditional envelopes can be morphed into innovative (sustainable) envelopes, also by using energy production technologies suitable for envelope integration, such as Photovoltaics. [2 and 3]

The paper presents some architectural proposals developed by students (architects and engineers) of the 5th edition of the post graduate master “Designer of sustainable architectures” at InArch (Italian Institute of Architecture) in Rome, for the urban renovation of the historical (about 1930) Roman peripheral area “Pigneto”.

The general theme of the Master is the investigation of contemporary housing in large cities, such as Rome. Students are asked to design the renovation of an existing building improving its performances from energetic, architectural and social points of view. Main focuses of the theme are the energetic strategies and the complex relationships between private and public spaces (also in terms of energetic behaviors). The approach is to propose an innovative use of new technologies in Architecture, aimed to re-think buildings as “living beings” that can generate the energy they consume, having their own balanced metabolism, so that the city can be seen as an “urban ecosystem”. [4]

THEORETICAL APPROACH

The theoretical frame of the Master is rooted in the will to overcome the contradictions of which we have experience nowadays, due to the huge change produced by the digital revolution on one hand, and to the deep ecological crisis, on the other hand. These two opposite tensions can be considered as a kind of general context (field of forces), which we have to “work in” and to “work with”. As a consequence, the main issue at stake can be regarded as “how can we use technique to sustain life?”

Some appropriate answers to this issue can be given by investigating the ways buildings work (traditional buildings) or can work (eco-buildings). If we look at the way the most of our traditional buildings work, we can observe they are a kind of “black box” where several different resources (at least energy, mainly in terms of electricity and gas, water and food) have to be carried (often from far away), to be used and thrown away as waste, in a blind line of growing entropy.

In order to overcome this vision of the building as a “black box” generating entropy, it is necessary to propose a new vision of the building as a “living being”, characterized by a proper “metabolism”. This metabolism is the link between the building, and the way it can positively or negatively work in the general context described above. A consequence of this vision is that the building can be designed so that its metabolism works positively, by orienting its performance on desired behaviors (mainly energetic). As well as the building performance, also the performance of a group of buildings, located in the same urban area, can be oriented and controlled.

The traditional tools of Architecture are not sufficient to investigate such a kind of building (eco-buildings), and, in particular, the “shape” these buildings can have; but we can learn how to get used to it, if we look at the buildings and their shape from the cybernetic perspective. In fact, as is well known, Cybernetics investigates the structure of regulatory systems. In particular, according to a common definition, Cybernetics is preeminent when the investigated system is involved in a closed signal loop, where action by the system in an environment causes some change in the environment and that change is manifest to the system via information/feedback that causes the system to adapt to new conditions. This "circular causal" (eco-systemic) relationship is necessary and sufficient for a cybernetic perspective.

From the Cybernetics perspective, it is indeed surprising that our concern with shape is still so far from our interest in performance, since it is well known that the ecological crisis we live in is due exactly to the increase of entropy (in terms of CO_2 emission, global heating, oil, soil and water consumption, and so on) connected to our metropolis footprints.

So, taking a step further, the issue of how to use technique to sustain life, means how to use technique to improve our metropolis performances, in order to reduce their weight, on our common planet. From this point of view our built environment has to touch the ground gently, leaving on it what we could call a really ecological footprint (in a positive sense). In order to succeed in this goal, a shift is necessary, and, even though many other issues have to be considered, energy, food and water are anyway the three main not typically architectural concerns we should learn to take care of in designing, or re-designing, at the small and the large scale, the building itself as well as a system of buildings and public space.

The proposed theoretical approach, is the way to move towards what we can think of as an “urban ecosystem”: definitely something hybrid of concrete, nature and information. A built environment able to host man but to breathe as well, generating its own energy as well as growing food and vegetation, recycling and regenerating its waste water and exchanging resources and information in the global web of connections. According to this vision, the buildings in the urban ecosystem are, of course, “eco-buildings”. In particular, their envelope is conceived as an interface generating positive actions and reactions, by achieving a good performance in terms of energy balance for the whole life cycle.

DESIGN APPROACH

The theme of the Master is experimenting with the ideas illustrated above, by considering existing buildings and the district they are part of, as a complex system of relationships. In particular, the study focuses on quite small, existing housing buildings (three/four storied buildings) located in the historical district of Rome, named Pigneto. This is a largely self developed area, grown between the beginning of the 20th century and the 70s, and now characterized by a quite strong gentrification trend.

According to the above illustrated new architectural perspective, some traditional architectural issues have to be re-thought. In particular, the idea of “shape”, since in the case of an eco-building, the shape of the envelope has new meanings with regard to the traditional architectural ones. In fact, the focus is not on the shape itself, but on the relationships this shape has to mediate. So, the shape is no longer conceived only as an occurrence, but rather as an active device able to generate performances. These performances are desired behaviors, in relation with the environment at large and man, which means people living inside the building as well as people living in that urban area.

With regard to the envelope, and the shape(s) it can assume, boundaries are still the place where all the aspects taken into account in the design process come together; but, of course, the boundary is conceived as an “interface”, able to mediate for example between the solar radiation and the energy needs of a building. So, the boundary is not just the limit where the building ends, but rather the surface where sensibility starts. As a consequence, geometry (that means also shape) is still a tool of design, but in terms of the processes it has to mediate.

TEACHING APPROACH

Once illustrated the theoretical approach of the Master, and the way the design process is conceived in its frame, we will illustrate how this new perspective can be taught the students (architects and engineer), so as to generate new Architecture. In order to succeed in such a goal, a teaching method has been organized by teachers with different specific backgrounds.

The teaching method is aimed to develop all the issues of the project the students are faced with, according to an unifying point of view, joining together the environmental context, the urban context, the building. Since the single elements of the urban ecosystems influence each other, and, since from the variation of a single element can be derived variations on the other ones, this kind of environment can be defined as a “parametric domain”. The single parameters are the design variables which influence the reciprocal dynamic behaviour of the elements. Simulation of parametric codes can be used to predict how the relation between the elements happens. In particular, these codes are helpful in all the phases of the design process, such as the analysis of the real context, the concept development, and the final evaluation of the project. For the analysis of the context the codes are useful, for example, in exploiting the potentialities of both site and buildings in terms of use of natural resources, such as wind, water, Sun, etc.. Furthermore, in the phase of the concept development, these codes allow to investigate the shape the buildings can assume in order to maximize the use of the natural resources. The changes in shape are evaluated with regard to the single building and also to a group of buildings. Some variables of the project, such as dimensions, materials, shape, are analyzed to predict the general behaviour of the system; the performance evaluation is based both on energetic aspects, and architectural aspects, in order to achieve the optimal balance between them, allowing a high quality for the project.

From the application point of view the students are asked to improve the energetic performance of the building selected as the case study, so that it could be labelled with the highest energy standard in Italy for residential buildings (energy class A; energy consumption $<30kWh/m^2$ year, that is oil energy consumption $<3l/m^2$ year).

The architectural theme of the project focuses on a metaphorical figure, that is called “parasite”, according to its Greek etymology (*parasitos*, from *para-* + *sitos* grain, food), which means something close to the food. So, despite the common negative accepted meaning, in the architectural context a parasite can be conceived as something positive. In fact a parasite is an organism close to the food (the food that is the “living” part of the metabolism of the urban ecosystem), that can manage the fluxes of food inside and outside the building. So, from an energetic point of view, it can be thought of as a sort of energetic headquarters, able to use the natural resources and manage their fluxes. At the same time, from an architectural/spatial point of view, it can be considered the place where many strategies to promote and enhance the architectural and social quality can take place.

RESULTS

Two buildings have been chosen as case studies for the 5th edition of the Master. The first one has been named “Brunaus” (figure 1a); the second one has been named “Fravalaus” (figure 1b).

Brunaus is a four storied building, built in the 50s. The framework is made of concrete; its foundations and the ground floor are made of a local stone (tuff), and the other two floors are made of concrete. The building faces a square (not used by the inhabitants of the district) on the South side, and a traffic street on the North side. Each floor houses a residential unit (about 90m^2). Some constraints have been given to the students for the retrofitting project. In particular: facades can be transformed, but the maximum distance between the original position has to be 1,5m maximum.

Fravalaus is a four storied building, built in the 30s; the massive framework is made of framing walls made of tuff and bricks. The building faces on the South side a public space, now used as a parking area, which is becoming (according to a municipal project) the access for a new metro-station. On the North side it faces a private courtyard, where two houses in very poor conditions are located. Also for this case study some constraints have been given for the project. In particular: the North façade is not to be modified; the South façade can be modified in terms of windows; the two blind West and East facades can be modified.

Figure 1: the two buildings chosen as case studies. On the left Brunaus (1a), on the right Fravalaus (1b).

For both cases a volume bonus for the energetic renovation of the building has been established, in order to make room for the “parasite”. It is about the 20% of the whole volume of the building (new spatial boots that can be positioned on flat roofs and facades). New greenhouses and terraces are not taken into account for the calculation of the volume bonus.

Among the projects carried out by the students, we selected two of them, named “Captazioni” and “Free-Stay”, for Fravalaus, and Brunaus, respectively.

Captazioni (P. Composto, D. Dispoto, M. Pisano) focuses on the importance of the social relationships in the context of the multi-ethnic district Pigneto. This approach is adopted both for the external (public) and the internal spaces of the building (private). In particular, a new square is designed to be an open laboratory for children, who can learn from the exhibits hand-on how to use the ground. The parasite (that is the 20% new volume) is aimed to be used by disadvantaged people (Figure 2).

The stair case is moved outside the building, on the North side, and it is conceived as an occasion to design a green protection from the cold winds. The stair case covering integrates a thermal system (25m^2) for the DHW of the building.

Figure 2: Captazioni, the building and the public spaces.

The social house (the parasite) is self-sufficient, and it has been designed so that it can be replicated in the case of other similar buildings of the district. The South façade integrates greenhouses, and also a thermal system for DHW. The solar gains due to the use of these greenhouses are helpful in reducing the energy consumption in the heating season. A thin film silicon photovoltaic generator (65m^2), is integrated into the surface of the covering (65m^2); it feeds the parasite, and it also powers the energy consumption related to common functions of the building (such as lighting). Due to the careful attention paid to the use of a good insulation and good materials for the envelope, the energy consumption of the building is reduced from 136kWh/m^2 year (before the renovation) to 22kWh/m^2 year (after the renovation).

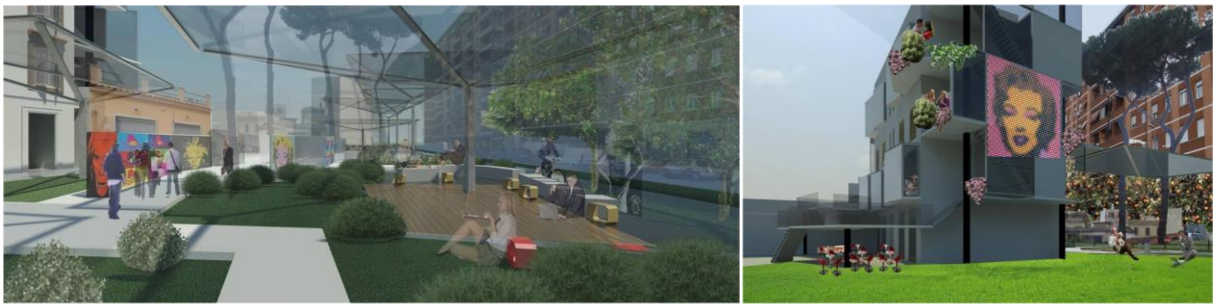

Figure 3: Free-Stay, the "public" coverings (left) and the building (right).

Free-Stay (D. Miccolis, F. De Napoli, P.) focuses on the public space, due to the relevance of the future opening of a new metro-station, which can be relevant with regard to the gentrification trend. As a consequence, the design team focused on the public space transforming it into a place appealing to take a rest. The main design "mark" and "tool", is a system of "public" translucent coverings, able to offer shadow in summer and shelter from raining in winter time. Still, the use of vegetation, water, and sitting place, make of this area a kind of urban living room, with a good level of comfort and environmental control.

In particular, the “public” covering system is structured to be environmentally sensible; it is subdivided into parts that, depending on the solar capitation and on the wind exposition, can vary in materials, textures and transparency degree (such as photovoltaic, glazed, opaque).

The framework of the building is not modified, the service spaces have been arranged outside the building, in order to allow a new distribution of functional spaces inside the building. The North façade has been modified to improve its winter performance. In particular, some small buffers are the protection from cold winds, working as solar gain capitation systems. A greenhouse placed on the roof of the building, gains thermal energy from the sun, to improve the winter comfort of the spaces shared by the inhabitants of the building. The building is equipped with a new covering, integrating a solar collector (7,5m^2), and a photovoltaic silicon thin film generator (100m^2).

All the projects have been supported by parametric simulations to predict the energetic behavior of the eco-buildings, and the technological systems taken into account have been investigated in detail by means of technical drawings.

DISCUSSION

The results of the Master are respectable from various points of view; in particular from the point of view of the diffusion of a new sustainable approach to Architecture, and also from the point of view of the architectural use of energy generation technologies.

Students are educated to an innovative multidisciplinary approach to the theme of the renovation of existing buildings. Furthermore, since the projects they develop are shown to the inhabitants of the district during a public event at the end of the Master, the Master usefully contributes to improve the knowledge about sustainability and the way architects can deal with it.

The Master laboratory represents a good occasion to experiment with both standard and not-standard solutions for sustainable technologies, useful to define new demands of Architecture for sustainable technologies, and, in some cases, also useful to introduce new components on the market. With regard to the technologies, Photovoltaics has an eminent role, since it can be advantageously used to reduce the energy bill of the buildings, and it can also transform ordinary buildings into innovative, sustainable, recognizable, buildings. Repeatability of the solutions for new technologies and design approaches, and their compatibility with the specific features of the users, are taken into account as a key for the success of the project, as well as maintenance costs, and easiness of use.

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ENERGY SAVING IN BUILDING SECTOR IN LATVIA

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ABSTRACT

The household in Latvia is the most energy capacious sector – 40 % of the final total energy consumption has been consumed by households in 2007. According to that the energy demands in household as well as the energy conservation potential are very important parts of the management and development of the energy sector.

Energy demand and also efficiency in the housing sector generally depends on various circumstances: social sphere and state or municipal regulations, infrastructure of living area and energy supply, building envelope conditions, population's consumption habits, thinking manner (ownership) and climate conditions.

Heat energy saving arrangements are the main reason for the refurbishment of prefabricated housing because thermal insulation is paramount to both heat energy savings and to repairing facade damage. The advantages of heat energy saving measures, particularly with respect to prefabricated housing, are undeniably evident:

- Reducing heat energy consumption by 40 to 50% is easily attained. These reductions are equal to an average reduction of the total energy consumption to 60 kWh - 80 kWh per squire meter of heated floor area per year.
- A thermally insulated facade results in dry, warm exterior walls and stops weathering damage to the facade.

The paper presents potential for energy saving in the building sector in Latvia and the results from the realized projects of building refurbishment when building envelope element U-values have been reduced significantly by external insulation measures, and internal heating systems have been rebuilt. The projects illustrate the typical housing energy consumption and optimal energy saving measures for different types of buildings.

INTRODUCTION

The Republic of Latvia has a territory of 64,589 km2 with a population of 2.295 million, out of whom 69.1 percent are city dwellers and the remaining 30.9 percent live in rural areas.
Latvia does not own energy resources except renewable energy resources (mostly biomas) and our dependence on fuel import is up to 65%. Reduction of relative and absolute consumption of energy by increasing of energy efficiency is a way to decrease the dependence on fuel import. Rational energy use in the household sector is very important for Latvia because the energy consumption in the household sector makes up a significant part of primary energy consumption (36 %).

The structure of energy consumption in the housing sector is as follows: 77 % - heating, 9% - meal preparation, 8 % - hot water, 6 % electrical appliance.

STRUCTURE OF THE LATVIAN BUILDING SECTOR

The ownership structure in the Building sector has changed strongly in the 20th century as a result of the privatization process in Latvia and this process continued in the last year also. Private ownership structure's dynamic is shown in Table 1.

	2000	2005	2006	2007
Housing stock - TOTAL	**53,5**	**57,0**	**58,7**	**60,1**
public	12,9	8,1	7,8	7,6
private	40,6	48,9	50,9	52,5
Per capita, m^2	22,6	24,8	25,7	26,4

Table 1: Housing stock at the end of the year (total floor space; mln m²)

To a large extent residential buildings in the Latvia are old (erected before 1990). The figures (Figure 1 & 2) below present the age structure of dwellings and the age structure of individual houses and multi-family houses respectively.

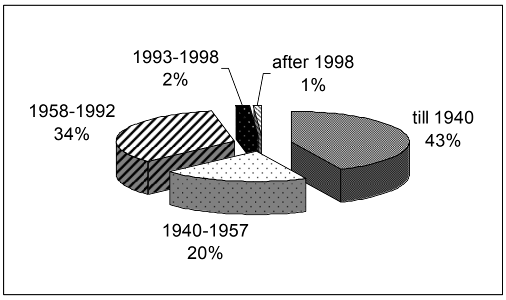

Figure 1: The age structure of individual houses.

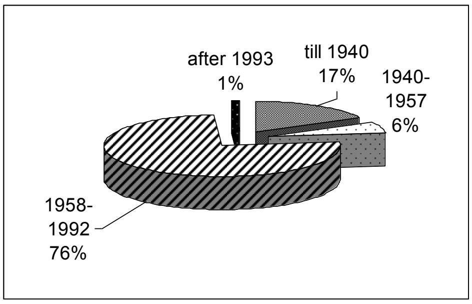

Figure 2: The age structure of multi-family houses.

Due to the age of the buildings and mild standards for building heat protection that were in force in 1958-1992, heat consumption in most of the buildings is high.

Table 2 presents heat consumption per unit in kWh/m^2 for a number of typical serial number buildings in Latvia.

Building serial number	**Number of tested buildings**	**Heat consumption per year kWh/m^2**		
		min	**average**	**max**
103	37	124,18	174,22	224,30
104	10	134,96	198,85	218,69
467	14	155,79	176,06	193,39
602	27	155,76	181,00	212,62
2-6 floor buildings after year1945*)	6	187,52	199,38	211,53

*) – heat consumption for this type of buildings is not typical because the number of tested buildings is too small.

Table 2: Heat consumption per m^2 in residential buildings in year 2004/2005.

LEGAL CONTEXT

The Parliament of Latvia (Saeima) adopted the Law on Building Energy Efficiency in March 2008 and this law is in force from 1st January 2009. The Law stipulates that responsibility of the overall supervision and co-ordination in building energy efficiency is the responsibility of the Ministry of Economics, but the Construction, Energy and Housing State Agency is responsible for the building energy efficiency policy implementation.

Some positive changes took place in the financing of Energy Efficiency Projects in the Housing Sector last year – The Cabinet of Ministers approved a Law on the Energy Performance of Buildings and Regulations Nr. 59 in February 2008 ("State Budget co financing of energy efficiency activities in dwellings") on the amount of cofinancing and the rules of procedure. In this Regulation is noted that:

- 284,6 EUR for multifamily house auditing and
- 20% from total investments for the multifamily house renovation project.

This co-financing is available from this year (2009). From this year also is it enough to have 51% of apartment owner's agreement to take a loan in Latvian Banks. Realised Project applicants faced a problem to reach at least 75% apartment owners agreement to take a loan and to start the whole renovation of a dwelling (required by the bank in case there is no additional security provided).

According to the Latvian Energy Efficiency Strategy for the years 2008 - 2010 (2007) the following goals should be achieved:

- Energy audit in multi - family houses;
- Energy audit in public and municipal buildings;
- Reducing average energy demand in buildings from 220 – 250 kWh/m²/year to 150 kWh/m²/year in 2020.

The process of Building renovation for Energy Efficiency actively started only in the last 5 years in Latvia and unfortunately this process is going rather slowly especially in comparison with the other EU states.

RENOVATION APPROACHES

Basically, there are two approaches for building renovation projects implementation in Latvia: step-by-step renovation and complex renovation
Both approaches were analyzed from point of view of:

- technical measures taken;
- energy saving effects achieved – based on monitoring results;
- barriers for project implementation.

Some renovation projects have been implemented within the framework agreement between the Federal Ministry for the Environment, Nature Protection and Nuclear Safety of Germany and the Ministry of Environment of the Republic of Latvia. The projects are located in 4 regions of Latvia – Riga, Saldus (Broceni), Liepaja and Limbazi (Salacgriva). The project owner in Riga and Salacgriva projects case are associations of apartment owners, but in the case of Broceni and Liepaja – municipalities.

The projects owners in realised projects were:

- Associations of apartment owners – in this case association took a loan and accordingly they went through all the formalities including all administrative, technical and financial actions (projects –Riga, Cesis, Sigulda).
- Municipalities (Broceni, Liepaja, Riga) – in this case municipalities are responsible for all payments and all actions.

EXAMPLE OF BUILDING RENOVATION

Project – Broceni, Skolas Street 21.

The building was constructed in 1983. It is located in Broceni town of the Saldus region. It is a type 104 prefab building. The building has an attic and below the whole area of the building there is basement.
Main parameters of the building: number of floors – 5, number of apartments – 70, number of tenants – 200, heating area – 3820 m^2, hot water – provided all year around.

Figure 3: During and after insulation of the building.

Measures implemented: windows changed, m^2 – 620, walls insulated, m^2 – 2264, top floor ceiling insulated, m^2 – 650, new radiators with thermoregulation installed, pieces – 180, heat energy meters installed on each radiator, pieces – 180, basement ceiling insulated, m^2 – 975
Investments: total – 297 420.17 €.
Implemented measures allowed to achieve a very substantial reduction of heat energy consumption – up to 49% in the heating season of 2004/2005, compared to the heating season before the project. Although the winter (2005/2006) was colder than the previous one, the reduction of heat energy consumption is higher up to 54%, perhaps the reduction was due to the fact that the October and November were warmer. In the 2006/2007 heating season the reduction of heat energy consumption reached up to 60% in comparison to before project situation, it can be explained with a bit higher average temperature in 2006/2007 heating season, because winter was warmer than usually. Although the average temperature was lower than the average temperature in 2006/2007, in the 2007/2008 heating season the reduction of heat energy consumption reached up to 60% in comparison to the pre-project situation; the reason for this result is a longer heating season in 2007/2008.

Before project (2003/2004)	**After project (2004/2005)**	**After project (2005/2006)**	**After project (2006/2007)**	**After project (2007/2008)**
117,83 kWh/m^2	60,12 kWh/m^2	54,29 kWh/m^2	46,96 kWh/m^2	46,81 kWh/m^2

Table 3: Specific heat energy consumption.

Heat is provided by the “Brocēnu siltums” Ltd (fuel – woodchip).

	€/MWh	**Total costs, €**	**Costs, €/m^2**
Before project (2003/2004)	29,37	13215,71	3,46
After project (2004/2005)	31,42	7095,76	1,86
After project (2005/2006)	32,44	6728,37	1,76
After project (2006/2007)	36,62	6570,15	1,72
After project (2007/2008)	43,73	7819,20	2,04

Table 4: Heat costs.

	t
Before project (2003/2004)	200,62
After project (2004/2005)	102,36
After project (2005/2006)	92,46
After project (2006/2007)	79,78
After project (2007/2008)	79,71

Table 5: CO_2 emission.

CONCLUSIONS

Total emission reduction achieved in the first heating season (2004/2005) after the implementation of 2 housing renovation projects is **143 t of CO_2**, but after the heating season 2005/2006 (including 2 more projects) the total emission reduction reached**281 t of CO_2**. In the next heating season (2006/2007) all 4 housing renovation projects show total emission reduction of **322 t of CO_2** in comparison to pre-project data. In the heating season 2007/2008 the total emission reduction reached **297 t of CO_2** in comparison to pre-project data.

Total heat energy consumption reduction in the first heating season was **399 MWh**, but after the second heat season (2005/2006) it was **776 MWh** (including 2 new projects), but after the third (all 4 projects) it is **909 MWh.** After fourth heating season (2007/2008) the total heat energy consumption reduction was **857 MWh**.

The reduction of necessary energy resources for heat generation, during 4 heating seasons, reached:

- ~ 187 500 m^3 of natural gas;
- ~ 309,26 of woodchips.

Despite the fact that the 2005/2006 heating season was colder than the previous season, the heat energy consumption has decreased. Obviously, people have started to use the opportunity to change the consumption themselves according to their needs. October and November in this heating season were warmer than in the previous year. The least heating season (2006/2007) was warmer on the whole, that's why all indices show high improvement. The heating season 2007/2008 was warmer than previous season so the heat energy consumption has decreased. In all projects after renovation of buildings specific heat consumption of buildings is below 70 kWh/m^2 as originally planned, with the exception of the building on Tirgus str. 3, where the top floor and basement ceiling insulation had not been done and therefore the specific heat consumption of the building after heat insulation is 102,3 kWh/m^2.

Almost in all projects heat costs per m^2 have been reduced substantially – from 11 % up to 50%, but in comparison with previous heating season the costs per m^2 in the heating season 2007/2008 have been increased. In Tirgus Str.3 heat costs per m^2 has increased to 8% because also the total heat cost has increased in comparison to the previous heating season 2006/2007.

MAIN PROBLEMS AND CHALLENGES

- Project applicants faced a problem to reach at least 75% (now 51 %) apartment owners agreement to take a loan and to start whole renovation of dwelling (it is required by the bank in case there is no any additional security provided);
- It is very difficult for inhabitants to agree to take a loan for investments in common property. There are very different people that are living in the same house – for some the planned payments are acceptable but for some they are too high;

- Inhabitants are not ready to invest in common property and still do not realize that it is their common obligation;
- Projects required complex renovation of dwellings. That is correct from a technical point of view but it requires also high investments. Not all inhabitants are ready for the major credit payments that necessary to finance complex renovation;
- Inhabitants do not have collective borrowing experience therefore are very skeptic to participate and to take out a loan;
- It is a time consuming process – from the project idea to real implementation.

Comparison of approaches:

Step-by-step:
- the role of standard building renovation measures is crucial – to ensure that expectations on energy saving potential will be achieved (in the opposite case it will be very difficult to convince inhabitants to take the next renovation steps);
- easier to convince inhabitants especially in case when total payment will not increase – energy savings fully cover loan principal and interest repayment;
- usually in the long term perspective more costly and more time consuming than complex renovation.

Complex renovation:
- from a technical point of view the more appropriate approach;
- more difficult to convince inhabitants – payments usually increase.

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STUDYING INNOVATIVE CONCEPTS BY COUPLING SIMPLIFIED SIMULATION AND MULTIZONE AIRFLOW MODEL

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ABSTRACT

In order to respond to global warming and natural resources depletion challenges, industrials from the building sector need to propose an adequate offer. Energy simulation tools can support this process. In order to reach high performance level, e.g. primary energy consumption below 50 kWh.m-² per year (including heating, cooling, domestic hot water, lighting and ventilation), various studies and real cases show that, appropriate architecture, high insulation, free cooling and the use of a heat recovery exchanger for ventilation are needed. This last technology will be particularly affected by airflows across the building envelope caused by a low airtightness. Moreover, free cooling ventilation rate will highly depend on temperature difference between outside and inside. Thermal modelling tools need therefore to deal with those two issues precisely.

A multizone model has been developed to compute building airflows in order to evaluate them with a higher degree of precision in the frame of a simplified simulation tool that can be used in early phases of a project. This model is based on well-mixed zones and mass conservation principles. The air flow rate between two zones is expressed as a function of the pressure drop between those two zones. Wind pressure and buoyancy effects are the causes of pressure drops. Several types of connection are implemented: cracks, ventilation inlets, large openings. More types of connection will be added.

This model has been implemented in the thermal building simulation tool COMFIE [1]. The airflow model uses the temperatures of the zones as an entry and the thermal model uses the airflows as an entry as well. Both thermal and airflow model run at each time step until convergence is reached using a synchronous coupling method. An algorithm has been developed to ensure the convergence for each time step (from 1/10 to 1 hour).

Two case studies are presented. First, the case of a residential building, project of Vinci Construction France where the influence of air tightness on heating loads is being studied. Then the case of a concept building, Effibat, being developed by Vinci Construction France and MINES ParisTech. This building is an urban dwelling building including an atrium. Natural ventilation is used to cool the building at night in summer and the model aims at evaluating the resulting comfort level.

INTRODUCTION

In order to respond to global warming and natural resources depletion challenges, industrials from the building sector need to propose an adequate offer. Energy simulation tools can support this process. In order to reach high performance level, e.g. primary energy consumption below 50 kWh.m-² per year (including heating, cooling, domestic hot water, lighting and ventilation), various studies and real cases show that, appropriate architecture, high insulation, free cooling and the use of a heat recovery exchanger for ventilation are needed. This last technology will be particularly affected by airflows across the building envelop caused by a low air tightness.

Moreover it is important to fulfil a satisfactory level of summer comfort, passively or mechanically. Simulation tools have therefore to evaluate this performance precisely, and must be sensitive to the corresponding design parameters (e.g. free cooling). A precise ventilation rate evaluation is then needed to create ventilation strategies that will allow the building to reach his consumption and comfort targets.

Dynamic yearly thermal simulation tools are used to evaluate heating loads and room temperature for different thermal zones in the building. The building envelope is precisely described: architecture, materials thermal properties. Solicitations from inside (occupation, electrical equipment dissipation) and outside (temperature and solar solicitations) are taken also into account.

In a multizone ventilation simulation tool, the building is idealized as a zone network linked by airflow components such as cracks or windows [2, 3]. Airflow rates are calculated as a function of pressure drop between two zones that will depend on wind pressure around the building and temperature difference of the zones.

Those two models are treating complementary issues that are highly inter-dependent. A coupling of those two kinds of models seems therefore needed to design high performance buildings.

METHOD

Airflow Model

The model is based on the assumption of well-mixed zones: each zone is assigned a reference pressure point and a temperature. Driving forces are variable surface pressure caused by wind on the building, stack effect caused by temperature differences and supplied and extracted air by the mechanical ventilation system. Pressure difference between two points i and j located in zones m and n is expressed :

$$\Delta P = Pi - Pj = P_M - P_N + P_T + P_V$$

Wind pressure P_V epend on wind speed at the building site, Vh. Pressure coefficients (Cp) allow a distribution of the wind pressure around the envelope:

$$P_V = \frac{\rho {V_H}^2}{2} C_p$$

Pressure difference P_T due to buoyancy effect between two points I and J located in zones M and N is expressed as a function of zone air densities and relative elevation:

$$P_T = \rho_M g(z_M - z_i) - \rho_N g(z_N - z_j)$$

Air circulates between the zones via different kinds of airflow components. The air flow rate is then expressed as a function of the pressure drop between two zones.

Air infiltration through the building envelope is taken into account by a power law:

$$\dot{m}_{i \to j} = C_{\dot{m}} \Delta P^n$$

$C_{\dot{m}}$ is the flow coefficient ($m^3.h^{-1}.Pa^{-n}$), it is an indication of the size of the crack. n is the flow exponent (0.5 for a turbulent flow and 1 for a laminar one).

Most energy efficiency buildings labels require a minimum degree of air tightness (example: 1 $m^3.h^{-1}.m^{-2}$ per façade under 4Pa for Effinergie, in France). This value is specified by the user. It needs to be distributed around the building. For instance, energy efficient architecture will tend to place more windows on the southern façade of building, this façade will then present more air tightness defaults due to windows than the northern one. Air leakage is distributed from fan pressurization test results according to [4]. n is supposed to be fixed, and the flow coefficient, found in the literature ($C_{Q_{i,lit}}$) is adjusted with the building coefficient given by the test.

$$C_{Q_i} = C_{Q_{i,lit}} \times \frac{\left[C_{Q_{test}}(\Delta P)^{n_{test}}\right]}{\sum C_{Q_{i,lit}}(\Delta P)^{n_{i,lit}}}$$

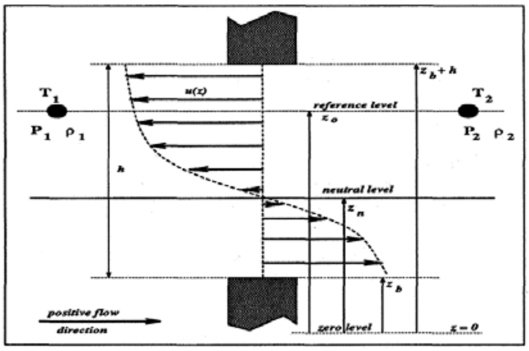

Figure 1: Air flow across a large vertical opening

The model also allows the user to implement vertical large openings. In such openings, multiple way flows are possible (stack effect can cause positive or negative pressure, above or under a neutral level, figure 1). An analytical solution, proposed by [2], has been implemented:

$$\dot{m}_{Z_n,H} = \frac{2}{3} WCd\theta\sqrt{\rho}\left[2g(\rho_{01} - \rho_{02}) - bt\right]^{\frac{1}{2}} \left|H - Z_n\right|^{\frac{3}{2}}$$

And :

$$\dot{m}_{0,Z_n} = \frac{2}{3} WCd\theta\sqrt{\rho}\left[2g(\rho_{01} - \rho_{02}) - bt\right]^{\frac{1}{2}} \left|Z_n\right|^{\frac{3}{2}}$$

W is the area of the opening, Cd a discharge coefficient and the neutral plan is expressed:

$$Z_n = \frac{P_{01} - P_{02} + P_{to}}{g(\rho_{01} - \rho_{02}) - b_t}$$

For each zone, mass conservation principle can be expressed as a function of the pressure:

$$f(P) = 0$$

Eventually, the system is resolved, using the Newton-Raphson Method to find the next approximation of the pressure vector:

$$P^{k+1} = P^k - X^k$$

With $J(P^k)X^k = f(P^k)$ (where J is the Jacobian Matrix)

Coupling with the thermal model COMFIE

COMFIE is a thermal dynamic multizone model. The core of the model simulates a building response to solicitations and can be linked to several objects that were developed independently (heat pumps, air to ground heat exchanger, photovoltaic and thermal solar , etc.).

The airflow model uses the temperatures of the zones as an and the thermal model uses the airflows as an entry as well.

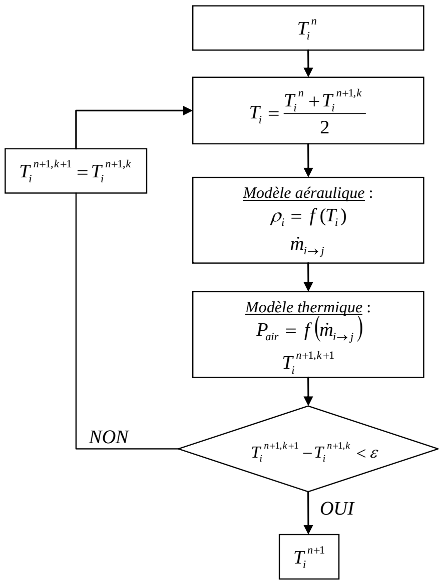

Figure 3: Coupling thermal and airflow simulations

Different approaches are found in the literature to proceed to coupling airflow and thermal models [5, 6]. First, sequential coupling which is an asynchronous method with no feedback between the models. Then synchronous methods where both models interact. Ping-pong (airflow model output is thermal model input for the next time step, this methods requires time steps shorter than 5 minutes) and onions (at each time step, both models iterate until convergence is reached). Onions method is chosen because it allows more freedom to the user who wants to use other modules from the program (e.g. ground heat exchanger).

To avoid convergence problems, temperature that is taken into account is the mean of the current iteration and the previous one (see figure 3).

RESULTS

Presentation of EFFIBAT

EFFIBAT is a dwelling building designed to reach the 50 kWh.m-² consumption target. This performance is made possible by a compact architecture, a high degree of insulation and heat recovery ventilation. Atria allow inhabitants to benefit from day lighting and the air is pre-heated in winter. In summer, atria are cooled by a natural ventilation. The purpose of the study is to evaluate the influence of the air tightness on the building load and the temperature in the atrium in winter and summer.

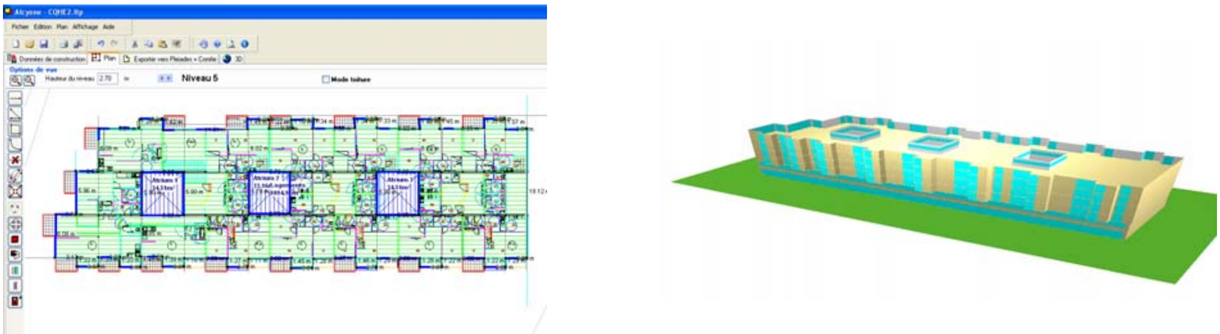

Figure 4: 2D and 3D representation of the project in COMFIE

Influence of air tightness on building heating load

The site meteorological station is Trappes, near Paris. The building envelope is insulated as described in table 1.

	Keynotes		Software presentation
External Wall	3cm fibered concrete +16 cm glass wool insulation+1.3 cm gypsum	Upper Ceiling	20cm concrete+10 cm polyurethane
Dwelling-Atrium Wall	1.3 cm gypsum +10 cm glass wool+1.3 cm gypsum	Floor	20cm concrete+10 cm polystyrene

Table 1: Envelope composition

The building is also equipped with low emissivity double glazing windows (Uwindows=1,3W.m^{-2}.K^{-1})

Dwellings are supposed to be heated at 20°C. Ventilation rate is taken 0,5 vol/h, the heat recovery efficiency is assumed 80%.

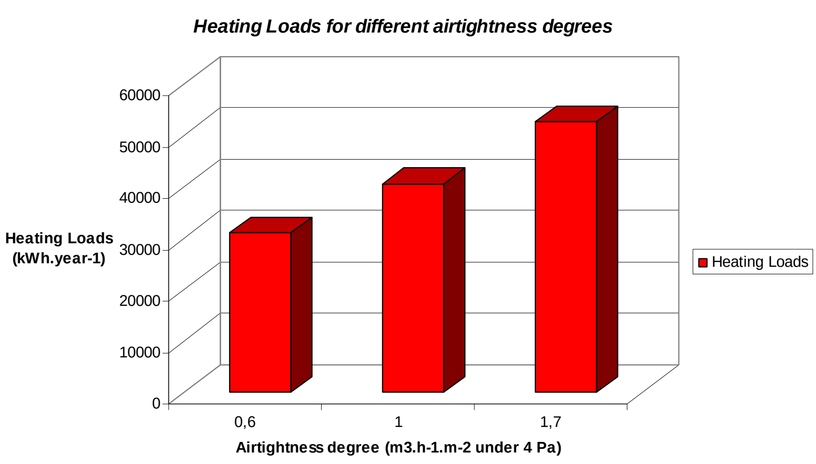

Figure 5: Heating Loads for different air tightness degrees

Three degrees of air tightness are considered: 0,6 m^{3}.h^{-1}.m^{-2} which is the project target, 1 m^{3}.h^{-1}.m^{-2} which is required by Effinergie and 1,7 m^{3}.h^{-1}.m^{-2}, the default value from French regulation which is supposed to be representative French dwellings.

From 0,6 to 1, heating loads vary from 7 to 9 kwh.m^{-2}.year^{-1} (+30%). It goes up to +70%, 12kWh.m^{-2}.year^{-1} for a building with noparticular air tightness preoccupation.

Summer temperature of the atrium

The atrium is a source of heat in winter but it needs to be well ventilated in summer to avoid over-heating problems. In order to evaluate summer comfort, as the building will be equipped by venetian blinds, it is assumed that inhabitants will use them. Windows solar factor is then reduced by 4 during this period. Eventually, 15 m² of facade opened windows is considered for each level (same surface is considered in the atrium).

Figure 6 shows the evolution of the temperature in the atrium and outside temperature during summer time. According to the study, temperature never reaches 26°C. Further work will consist in studying the atrium thermal comfort during the 2003 heat wave.

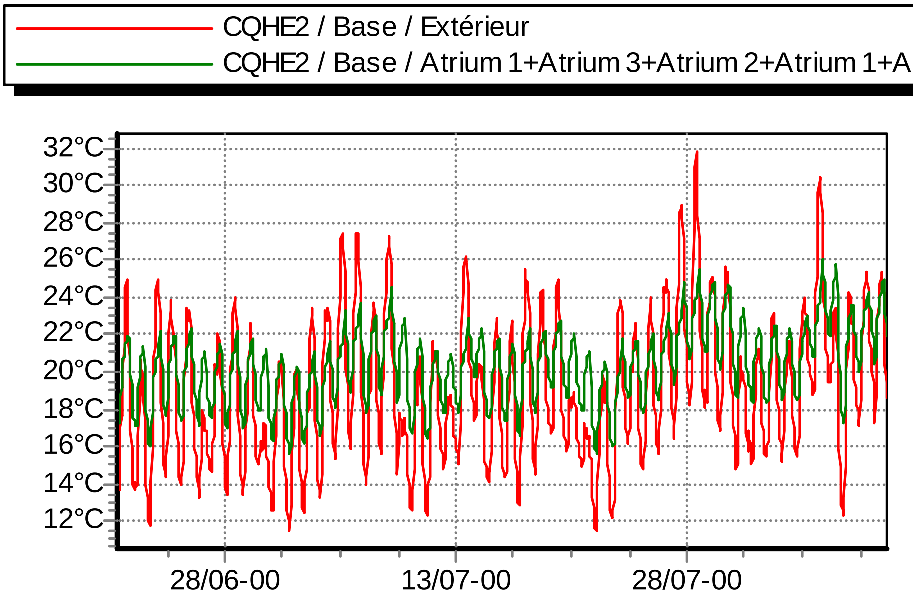

Figure 6: Atrium and outside summer temperatures

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ON THE PARAMETERS CHARACTERIZING THE THERMAL TRANSIENT BEHAVIOR OF THE EXTERNAL WALLS OF BUILDINGS

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ABSTRACT

In the last few years the behavior, under unsteady conditions, of opaque elements within the building envelope has become of outstanding importance, also from the European and National rules point of view, to reduce the energy demand for the summer air-conditioning of buildings in the light of the European Directive 2002/91/CE (EPBD). Assuming the indoor air temperature to be constant, the thermal transient behavior of a building envelope's opaque wall, stressed by external temperature sinusoidal oscillations, is characterized by the following parameters: the decrement factor f, the wall inner surface decrement factor σ, the time lag τ and the dynamic thermal transmittance U_D. Such parameters depending on the wall thermal resistance and thermal capacity, on the period of the external thermal stress and on the stratigraphy of the wall, have been studied by several authors and can be found within the European technical standards (e.g. EN ISO 13786/2007) and Italian national and local rules (e.g. legislative decrees for the implementation of EPBD). In this paper the Author, after deducing by the transmission matrices method the expressions of f, σ, τ and U_D, and discussing in detail their meaning, solve the following problem: to determine (in a lumped-parameter schematization) the stratigraphy of a wall, with given thermal resistance and capacity, minimizing the decrement factor f as well as the stratigraphy of a wall maximizing the time lag τ.

MULTI-LAYER WALLS

Consider a building external wall (Fig. 1); the external temperature $T_{ext}(t)$ is assumed to oscillate in time with amplitude T_e around the mean value T_{e0} (with ω the angular frequency and $P=2\pi/\omega$ the period). Afterwards, complex formalism will be used to represent the oscillating quantities so as to write $T_{ext}=T_{e0}+\mathrm{Re}(T_e e^{i\omega t})$ where $i=\sqrt{-1}$ and Re=real part. With an opportune choice of the time origin t, the amplitude T_e can be assumed to be a real quantity, and the previous expression becomes: $T_{ext}=T_{e0}+T_e\cos\omega t$. Also the indoor air temperature will oscillate with the same angular frequency and with complex amplitude T_i around the mean value T_{i0}. Among the complex amplitudes of the temperature T_i and of the heat flux q_i (W/m^2) on the wall inner face and the analogous quantities T_e and q_e, on the wall outer face, the following linear relation is valid:

$$\begin{pmatrix} T_i \\ q_i \end{pmatrix} = \begin{pmatrix} E & F \\ G & H \end{pmatrix} \begin{pmatrix} T_e \\ q_e \end{pmatrix} = \Gamma \begin{pmatrix} T_e \\ q_e \end{pmatrix} \tag{1}$$

where E, F, G and H are the elements of the wall transmission matrix Γ; this matrix has unitary determinant:

$$EH - FG = 1 \tag{2}$$

For a multi-layer wall, composed of a sequence of m homogeneous layers, Γ will turn out to be the ordinate product, from the inside to the outside, of the transmission matrices Γ_n of the n-th single layers, and will be written as follows:

$$\Gamma = \prod_{n=1}^{m} \Gamma_n \tag{3}$$

The product of matrices, if the case concerning matrices representing purely resistive layers is excluded, is not commutative; in the Eq. (3) the order of layers is then essential. On the other hand, the element F turns out to be invariant under a specular reflection of the whole wall. For the n-th homogeneous layer of thermal resistance r_n (m^2K/W) and thermal capacity c_n (J/m^2K), the elements of Γ_n are given by: $E_n=H_n=\cosh z_n$ and $F_n=(r_n^2/z_n^2)G=(r_n/z_n)\sinh z_n$ with $z_n=\sqrt{(i\omega r_n c_n)}$; in particular Γ_n is symmetric to the secondary diagonal. Generally, in the Eq. (3) the first and the last layer will be purely resistive and it will turn out to be: $r_1=r_i$ and $r_m=r_e$, where r_i and r_e are respectively the inner and the outer thermal resistances. The wall overall thermal resistance R, evaluated from the indoor air to the outdoor one, and the overall thermal capacity C are given by ($c_1=c_m=0$):

$$R=\sum_{n=1}^{m} r_n \qquad C=\sum_{n=1}^{m} c_n$$

Being d_n, ρ_n and c_{pn}, respectively, the thickness (m), the density (kg/m^3) and the specific heat at constant pressure (J/kgK) of the n-th layer results ($n\neq1$, $n\neq m$): $c_n=\rho_n d_n c_{pn}$.

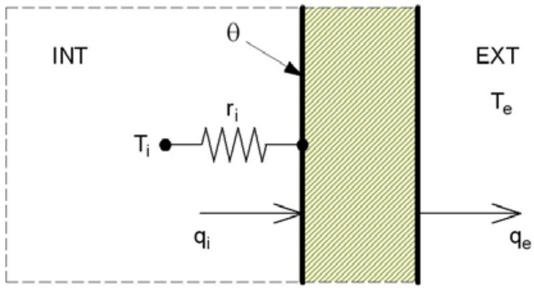

Figure 1 – External wall schematization.

CHARACTERISTIC PARAMETERS

In the case of a room provided with an air-conditioning plant, the indoor air temperature can be considered to be constant. In these conditions, from the Eq. (1) with $T_i=0$, we have:

$$\begin{pmatrix}0\\ q_i\end{pmatrix}=\begin{pmatrix}E & F\\ G & H\end{pmatrix}\begin{pmatrix}T_e\\ q_e\end{pmatrix}$$

hence:

$$0=E\,T_e+F\,q_e \quad q_i=G\,T_e+H\,q_e \tag{4}$$

From the Eqs. (2) and (4) it follows:

$$q_i=-T_e/F \tag{5}$$

that represent the external wall thermal power per surface unit required from the air-conditioning plant to keep the indoor air temperature constant. The Eq. (5) suggests that can be defined the parameter U_D (W/m^2K) as the wall dynamic thermal transmittance [1-2]:

$$U_D=1/|F| \tag{6}$$

Under steady conditions, the heat flux q_0 through the wall (when a constant temperature equalling T_e occurs) is given by:

$$q_0=U\,T_e \tag{7}$$

with U=1/R the wall (static) thermal transmittance. From Eqs. (5) and (7) can be defined the dimensionless parameter f as the decrement factor [1-2]:

$$f=|q_i|/q_0=U_D/U \tag{8}$$

It results: $U_D=f\,U$ and $0\leq f\leq1$; under steady conditions $\omega\rightarrow0$ ($P\rightarrow\infty$), $f\rightarrow1$ and then: $U_D\rightarrow U$. As regards the inner thermal resistance r_i, we have:

$$q_i=-\theta/r_i \tag{9}$$

with θ the wall inner face temperature (Fig. 1). From Eqs. (5) and (9) the following is obtained [1-4]: $\theta = (r_i / F) T_e$, and can be defined the dimensionless parameter σ as the wall inner surface decrement factor [3-6]:

$$\sigma = |\theta / T_e| = r_i / |F|$$

that can be interpreted as the external thermal oscillation attenuation on the wall inner face. According to the Eq. (6), it results: $\sigma = r_i U_D$ and we have:

$$f = (R / r_i)\, \sigma \tag{10}$$

so, in any case, it will result $f > \sigma$. The temperature oscillations θ on the wall inner face will occur with a time lag τ, given by [1-2]:

$$\tau = (P / 2\pi) \arg(F) = -(P / 2\pi) \arg(1 / F) \tag{11}$$

where: $0 \le \arg(F) \le 2\pi$ and $0 \le \tau \le P$, so the Eq. (11) can be written as follows:

$$F = |F| e^{i\omega\tau} \tag{12}$$

The thermal flux flowing out of the room can be expressed as the sum of the mean term:

$$q_{i0} = U (T_{i0} - T_{e0}) \tag{13}$$

and the oscillating term with complex amplitude q_i expressed by the Eq. (5) and hence explicitable with time t as (Eqs. (6) and (12) have been used):

$$\mathrm{Re}[q_i e^{i\omega t}] = -T_e \mathrm{Re}[(1/F) e^{i\omega t}] = -U_D T_e \mathrm{Re}[e^{i\omega(t-\tau)}] \tag{14}$$

Sometimes the thermal load Q(t) (W/m^2), defined as the flux flowing into the room through the wall at the instant t, is introduced; according to the Eqs. (12), (13) and (14), we will so have the following (EN ISO 13786):

$$Q(t) = U (T_{e0} - T_{i0}) + U_D T_e \cos\omega(t - \tau) = U (T_{e0} - T_{i0}) + U_D \left[T_{ext}(t - \tau) - T_{e0}\right]$$

where the term $T_{ext}(t-\tau)$ represents the temperature oscillation at the instant $(t-\tau)$. According to what has been previously said, it follows that the behavior, under thermal transient conditions, of a building envelope's opaque wall, can be characterized, apart from the time lag τ, by the parameters f, σ and U_D; the latter three parameters are related by simple relations. Notice that σ and U_D have to be considered as analogous parameters as they differ in a constant multiplicative factor independent of the wall, the inner thermal resistance r_i has to be considered constant and fixed by technical standards (e.g. EN ISO 6946/2007).

The lower the decrement factor f (σ or U_D) is and the higher the time lag τ, the higher will be the thermal insulation assured by the external wall, i.e. the less the room indoor conditions (internal structures being equal) will be bound to the outdoor ones. The parameters f, σ, τ and U_D are usually referred to P=24 h (EN ISO 13786).

In Italy limit values are fixed as regards the parameters f and τ; e.g. in Ref. [7] the value of the mean value $\overline{\tau}$ (determined as the average of the values of τ relating to the various walls, differently oriented, composing the building envelope) is assumed, for a building, as performance indicator of the thermal inertia requisite. A score p varying from –2 to +5 is assigned to the building comparing the value of $\overline{\tau}$ with a given performance scale; we have p=–2 for $\overline{\tau} < 7$ h and p=5 for $\overline{\tau} > 12$ h. At the moment, in Italy, National guidelines for the Energy certification of buildings [8], which contemplate the use of the parameter U_D, are under approbation process.

The parameter f is often preferred to σ or to U_D, the following should be observed. On the wall inner face, the thermal oscillation amplitude $|\theta|$ and the oscillation amplitude of the thermal flux $|q_i|$, according to the previous relations, can be written as follows:

$$|\theta| = \sigma|T_e| = r_i\, U_D\, |T_e| \qquad |q_i| = U_D\, |T_e| = (\sigma / r_i)|T_e|$$

Such quantities result to be proportional to σ or to U_D. Hence, the usefulness of the parameter σ (U_D), compared to f, seems to be evident. Between two walls, the first with U=0.30 W/m^{2}K, f=0.20 and then U_D=0.060 W/m^{2}K, and the second with U=0.20 W/m^{2}K, f=0.25 and then U_D=0.050 W/m^{2}K, the second, which, even presenting a higher f, is characterized by lower values of |θ| and |q_i| besides presenting a lower value of the transmittance U, is to be preferred. Also notice that the parameter σ (U_D) allows the direct evaluation of the temperature θ of the wall inner face, this temperature is very important on the indoor thermal comfort achievement.
The calculations, whose results are reported and discussed in the following sections, have been carried out in *MAPLE software*.

LUMPED-PARAMETER SCHEMATIZATION

An important problem relating to the thermal transient behavior of walls can be formulated as follows: to determine the stratigraphy of a wall with thermal resistance R (comprehensive of the inner and outer thermal resistances) and with thermal capacity C minimizing the decrement factor f (σ or U_D) given by the Eq. (10), and the stratigraphy maximizing the time lag τ given by the Eq. (11). The analysis will be developed in a lumped-parameter schematization. In this case, as stratigraphy of the wall the number of resistive layers, with thermal resistance r_S, and capacitive ones, with thermal capacity c_S, as well as the sequence of the same layers composing the wall are meant. In such a schematization a 2n+1/layer wall, composed of n capacitive layers and n+1 resistive layers, can be represented as follows [1-4]:

[internal] [r_n] [c_n] [r_{n-1}].......[r_1] [c_1] [r_0] [external]

with R=Σr_s and C=Σc_s. The symmetry property of the element F of the wall transmission matrix implies that the optimal stratigraphies, in the above-specified sense, should be symmetrical. Such problems, even if relating to different contexts, have been studied by the Authors for a long time and have been the subject of several papers [1-4, 9-10]. The stratigraphy minimizing the decrement factor f is demonstrated to be characterized by the dimensionless parameter:

$$\gamma = \omega R C \tag{15}$$

The obtained results can be resumed as follows [1-4]. For γ<18 the symmetric structure with n=1 turns out to be optimal, i.e. three-layer wall with the capacitive layer (C) posed between two equal resistive layers (R/2):

(T_1°) [internal] [R/2] [C] [R/2] [external]

characterized by:

$$F = R(1 + i\gamma / 4)$$

For 18<γ<42 a symmetric structure with n=2 (five-layer wall) turns out to be optimal:

(T_2) [internal] [r_0] [c_1] [r_1] [c_1] [r_0] [external]

while for 42<γ<76 a symmetric structure T_3 with n=3 (seven-layer wall) and for 76<γ<100 a symmetric structure T_4 with n=4 (nine-layer wall). As regards each case with n>1, the optimal values of resistances and capacities of the different layers depend on the value of γ [3-4]; on the other hand, completely symmetric walls T_n°, composed by n capacities and n+1 resistances with all equal values, c_n=C/n and r_n=R/(n+1), approximate very well the behavior of the above-stated optimal configurations T_n, within the respective ranges of γ [3-4]. In this paper only configurations of the type T_n° will be considered. In particular, for the configurations with n=2, 3 and 4, we have, respectively:

(n=2) $\quad F = R[1 + i(2/3)(\gamma/3) - (1/12)(\gamma/3)^2]$

(n=3) $\quad F = R[1 + i(5/6)(\gamma/4)\gamma - (1/6)(\gamma/4)^2 - 1(1/108)(\gamma/4)^3]$

(n=4) $\quad F = R[1 + i(\gamma/5) - (21/80)(\gamma/5)^2 - i(1/40)(\gamma/5)^3 + (1/1280)(\gamma/5)^4]$

For $\gamma \to \infty$ the optimal structure tends to a homogeneous wall $T_\infty°$ (n=∞) with uniformly distributed resistive and capacitive parameters [3-4]; in this case we have:

$$F = R[\sinh(\sqrt{i\gamma})/(\sqrt{i\gamma})]$$

From the Eq. (15), with U=1/R, we have:

$$\gamma = 2\pi(c_p M)/(P U)$$

with c_p the specific heat at constant pressure mean value and M the wall mass per surface unit. Assuming P=24 h, M=230 kg/m^2, c_p=900 J/kgK, and limit value (U_{lim}) fixed in Italian rules [8], we obtain: for U_{lim}=0.62 W/m^{2}K (climatic zone A) γ=24 and for U_{lim}=0.33 W/m^{2}K (climatic zone F) γ=46.

In Fig. 2a for walls of the type $T_n°$, the trends of f with γ are reported for various stratigraphies, each of them identified by the corresponding value of n. From the graph in Fig. 2a the configuration of the type $T_n°$ minimizing the decrement factor f clearly proves to depend on the value of the parameter γ: for γ<19 the best configuration is the $T_1°$ (n=1); for 19<γ<44 is the $T_2°$ (n=2); for γ>44 is the $T_3°$ (n=3), in accordance with what has been previously deduced. For the considered values of γ, the worst wall is the homogeneous one.

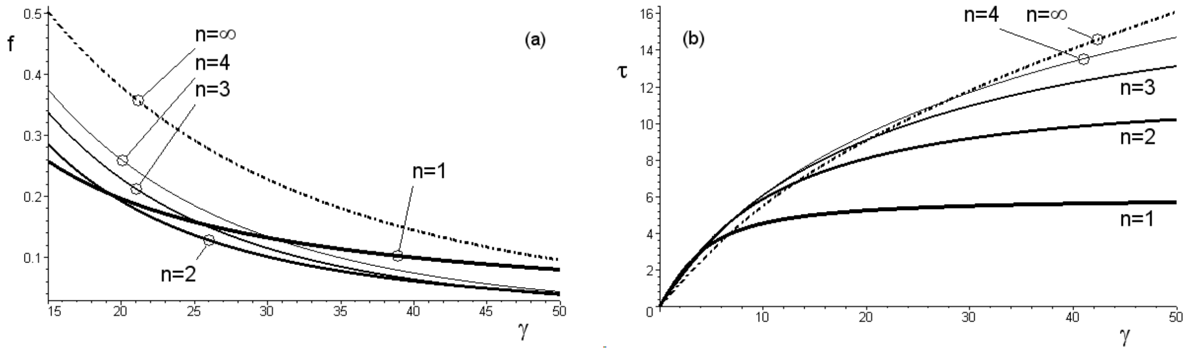

Figure 2 – Trends of the decrement factor f (Fig. 2a) and of the time lag τ (Fig. 2b)with γ for various stratigraphies corresponding to n=1, 2, 3, 4; n=∞ refers to the homogeneous wall.

Also the problem consisting in determining the stratigraphy maximizing the time lag τ is characterized by the parameter γ; results are very similar to those obtained for the minimization of f, unless the transition from an optimal stratigraphy to another occurs for sensibly lower values of γ. The analysis turns out to be very simple, if only walls of the type $T_n°$ are considered. For γ<3.5 a wall of the type $T_1°$ (n=1) turns out to be favourable, with respect to such a wall it can be interesting to notice how for $\gamma \to \infty$ the argument of F tends to $\pi/2$ and then $\tau \to 6$ hours. For 3.5<γ<6.7 a wall of the type $T_2°$ (n=2) results to be favourable, for $\gamma \to \infty$ the argument of F tends to π and then $\tau \to 12$ hours. For 6.7<γ<10.1 a wall of the type $T_3°$ (n=3) turns out to be favourable. Analogously, the various stratigraphies of the type $T_n°$ with n>3 overtakes each other subsequently at moderate values of γ and presenting values of the argument of F tending to $n\pi/2$ and then $\tau \to 6n$ hours. The trends of τ with γ for various stratigraphies (each of them is identified by the corresponding value of n) are reported in Fig. 2b. It is interesting to notice that the τ presented by the homogeneous wall overtakes soon that of structures $T_n°$ with moderate n; for instance, it overtakes the time lag of $T_1°$ already for

$\gamma \approx 6.7$, while overtakes $T_4°$ for $\gamma \approx 28$. In any case, once has been fixed any value of γ, structures $T_n°$, with high n, presenting a higher time lag compared to the homogeneous wall, can be found. From the comparison of the graphs in Figs. 2a and 2b, the homogeneous wall, characterized by very favourable behaviour with regard to the time lag τ, clearly proves to be the worst as for the decrement factor f.
Examples of multi-layer walls, that approximate the optimal behaviour analysed in this work, will be the subject of a companion paper [11].

CONCLUSIONS

The dynamic behaviour of a building envelope opaque wall can be characterized by the following parameters: decrement factor f, wall inner surface decrement factor σ, time lag τ and dynamic thermal transmittance U_D. The parameters f, σ and U_D are not independent, but related by simple proportionality relations.
In a lumped-parameter schematization the stratigraphy of a wall with given thermal resistance and capacity, minimizing f (and, then, also σ and U_D), is characterized by the dimensionless parameter γ. Also the stratigraphy maximizing the time lag τ is characterized by the parameter γ ; results are very similar to those obtained for the minimization of f, unless the transition from an optimal stratigraphy to another occurs for sensibly lower values of γ. Within the values of γ being of some interest, the optimization of the stratigraphy so as to minimize f and, at the same time, to maximize τ, proves to be impossible. If the design choice favours the optimization of f, we will need to realize a three-layer or a five-layer wall, while, if the maximization of τ is privileged, we will need to resort to further divisions so as to approximate a homogeneous wall.
The developed analysis leads to identify the optimal walls as lumped-parameter walls, obviously not realizable in the building practice. However, the obtained results provide useful design guidelines, if we consider that a concrete or limestone layer often approximates quite well a purely capacitive layer, while a low-density thermal insulating layer approximates optimally a purely resistive layer.

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THE USE OF LIGHT WALLS IN BUILDINGS AS A CONSEQUENCE OF THE MOST RECENT EUROPEAN REGULATIONS

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ABSTRACT

The European Directive 2002/91/EC (EPBD) suggests strategies for increasing thermal efficiency of buildings in summer and recommends the use of passive cooling techniques in order to improve the indoor thermal comfort. This involves the design of building envelope's opaque walls not only satisfying the thermal transmittance limit values but also showing a thermal transient behaviour to assure an acceptable indoor comfort level even in absence of an air-conditioning plant. These requirements can be easily met using high-thermal-capacity heavy walls, typical of traditional building; on the other hand, it turns out to be much more difficult to meet these requirements using low-thermal-capacity light walls, widespread in contemporary building. In this case we will need to compensate for the lack of thermal capacity with a reduction in thermal transmittance and an accurate choice of the wall stratigraphy.

Assuming the indoor air temperature to be constant, the thermal behaviour, under unsteady conditions, of an opaque external wall can be characterized by the following parameters: the decrement factor f, defined as the ratio between the wall dynamic thermal transmittance (U_D) and the wall (static) thermal transmittance (U), and the time lag τ, defined as the lag with which the external temperature oscillations are felt on the wall inner face. Such parameters depend on the wall thermal resistance and thermal capacity, on the period of the external temperature oscillations and on the stratigraphy of the wall. In a companion paper, after discussing the meaning of the parameters f and τ, the following problem is solved in a lumped-parameter schematization: to determine the stratigraphy of a wall, with given thermal resistance and capacity, minimizing f as well as the stratigraphy of a wall maximizing τ. In this paper, after a brief discussion of the most recent Italian rules on the building energy performances, the possibility to realize multi-component light walls, characterized by better values of the parameters f and τ, compared to those of heavy walls, is shown.

ITALIAN RULES: STATE OF THE ART

The EPBD has been acknowledged in various European Countries depending, for example, on the peculiar climatic conditions.

In Italy it has been acknowledged with the rules [1-2]. Such rules establish the maximum values (U_{lim}) of the thermal transmittance of the structures (i.e. walls, roofs, windows) composing the building envelope according to the climatic zone. Besides, in order to reduce the energy demand for the summer air-conditioning and to control the indoor air temperature overheating, such rules prescribe that the frontal mass M (obtained from the mass value per surface unit excluding plasters) of the opaque structures of the building envelope should turn out to be not lower than the limit value M_{lim}=230 kg/m^2, if the monthly mean value of the solar radiation intensity results to exceed 290 W/m^2. According to the same rules, the condition concerning the minimum value of M can be even disregarded if the opaque structures with $M<M_{lim}$ are characterized, under unsteady conditions, by values of the parameters f and τ equal or better than those of opaque structures with $M=M_{lim}$.

In addition to the limitations on the opaque structures frontal mass (M), limitations on the dynamic thermal transmittance (U_D) are recently (april 2009) introduced, in particular the following relations shall be satisfied [3]:

- U_D<0.12 W/m^{2}K for the opaque vertical walls (facing south, south-west or south-east);
- U_D<0.20 W/m^{2}K for the opaque horizontal or tilted walls (e.g. roofs).

Later, we will refer to Italian rules, but the obtained results are of general validity and can be also applied, with obvious modifications, to different normative contexts.

TWO-COMPONENT WALLS

Consider a wall composed of two materials, a material C with essentially capacitive properties: k=0.43 W/mK, ρ=1200 kg/m^3, c_p=840 J/kgK, and a material I with essentially resistive properties: k=0.035 W/mK, ρ=35 kg/m^3, c_p=1300 J/kgK. The material C could be brick or concrete, while the material I could be a thermal insulating, such as, for example, the polyurethane. The sake of simplicity, the finish plaster layers are disregarded; therefore, the frontal mass M coincides with the mass per surface unit.

Consider, for example, a site in the climatic zone A and with an insulation exceeding 290 W/m^2, in this case from Ref. [1] result: $M \geq M_{lim}$=230 kg/m^2 and $U \leq U_{lim}$=0.62 W/m^{2}K. Assuming, for the inner and outer external thermal resistances, the standard values (EN ISO 6946/2007 and EN ISO 13792/2005): r_i=0.13 and r_e=0.04 m^{2}K/W and imposing $U=U_{lim}$ and $M=M_{lim}$, we have: $d_C(1) \cong 19.1$ cm and $d_I(1) \cong 3.5$ cm, with $d_C(1)$ the thickness of the material C and $d_I(1)$ the thickness of the material I in the case of $M/M_{lim}=1$. Let us build, with these thicknesses of the materials C and I, two walls with reference stratigraphies:

- EW, two-layer wall with the insulating disposed on the wall outer face (*external insulation*);
- SW, three-layer wall with the insulating disposed between two equal layers of material C (*sandwich-type wall*).

Then, consider two walls W3 and W5 with such stratigraphies as to approximate the optimal lumped-parameter stratigraphies defined in [4]:

- W3, symmetrical three-layer wall composed of a layer of material C disposed between two equal layers of material I;
- W5, symmetrical five-layer wall with the insulating divided into three layers with thickness $d_I/3$ and the material C divided into two layers with thickness $d_C/2$.

Later on, the external temperature oscillations will be always assumed to equal 24 h, as usually required by technical standards (EN ISO 13786/2007).

In Fig. 1a the trend of f with the thickness d of insulating material for the four above-specified walls is shown. For $d=d_I(1)$ to the walls EW and SW correspond, respectively, $f_0(EW)$=0.29 and $f_0(SW)$=0.50; such values are pointed out in Fig. 1a by horizontal lines. Obviously, for $d>d_I(1)$, we have $U<U_{lim}$ and M slightly higher than M_{lim}. From the graph the walls W3 and W5 turn out to be clearly convenient; they show, for each value of d, and then for the same values of M and U, values of f much lower than those corresponding to the walls EW and SW. As d increases, the wall W5 seems to be particularly convenient. Analogously, in Fig. 1b the trend of τ with d is shown. For $d=d_I(1)$ to the walls EW and SW correspond, respectively, $\tau_0(EW)$=7.70 h and $\tau_0(SW)$=7.40 h. Also in this case the convenience of the walls W3 and W5 seems to be evident.

Afterwards, the case of $M=M_{lim}/2$=115 kg/m^2 has been considered, from which, imposing also $U=U_{lim}$, we obtain: $d_C(1/2) \cong 9.5$ cm and $d_I(1/2)$=4.3 cm, with $d_C(1/2)$ the thickness of the material C and $d_I(1/2)$ the thickness of the material I in the case of $M/M_{lim}=1/2$.

In Fig. 2a, analogous to Fig. 1a, horizontal lines are reported for comparison and indicate the values of $f_0(EW)$ and $f_0(SW)$. The curves relating to the walls W5 and W3 intersect the line with $f=f_0(EW)$, respectively for $d \cong 5.5$ cm and $d \cong 6.0$ cm; it means that, as for walls W3 or W5 with $M=M_{lim}/2$, with an overall thickness of the insulating layers exceeding 6 cm, it is possible to obtain values of f lower than those peculiar to reference walls with $M=M_{lim}$. From the trend of the curves relating to the walls EW and SW it follows that, with these stratigraphies, it is impossible to obtain, as for the parameter f, a better performance than that of reference walls with $M=M_{lim}$, unless prohibitive insulating thicknesses are used. In Fig. 2b, analogous to Fig. 1b, horizontal lines are reported for comparison and indicate the values of $\tau_0(EW)$ and $\tau_0(SW)$. The curves relating to the stratigraphies W5 and W3 intersect the line with $\tau=\tau_0(EW)$, respectively for $d \cong 6.5$ cm and $d \cong 17$ cm; it means that with a walls W5 (W3) with $M=M_{lim}/2$, with an overall thickness of the insulating layers exceeding 6.5 cm (17 cm), it is possible to obtain values of τ higher than those peculiar to reference walls with $M=M_{lim}$.

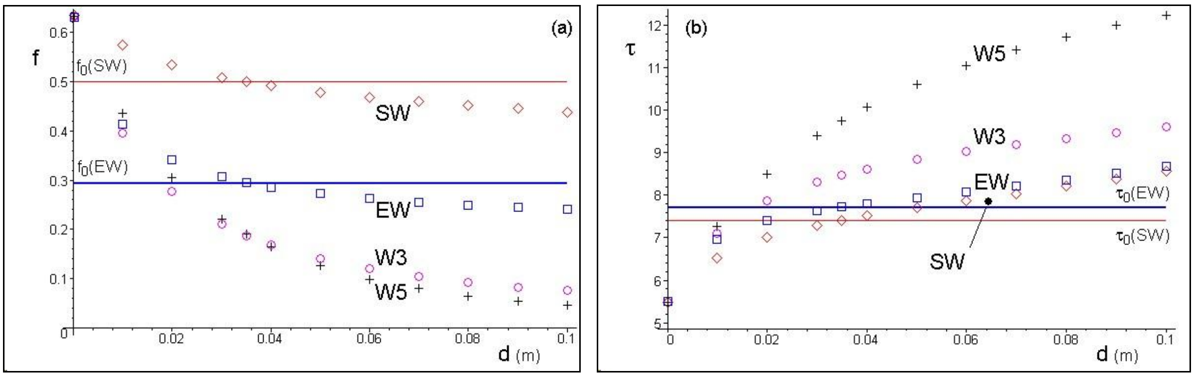

Figure 1 – $M=M_{lim}$, the trend of the decrement factor f (Fig. 1a) and of the time lag τ (Fig. 1b) with the insulating thickness d (m), for the four considered walls.

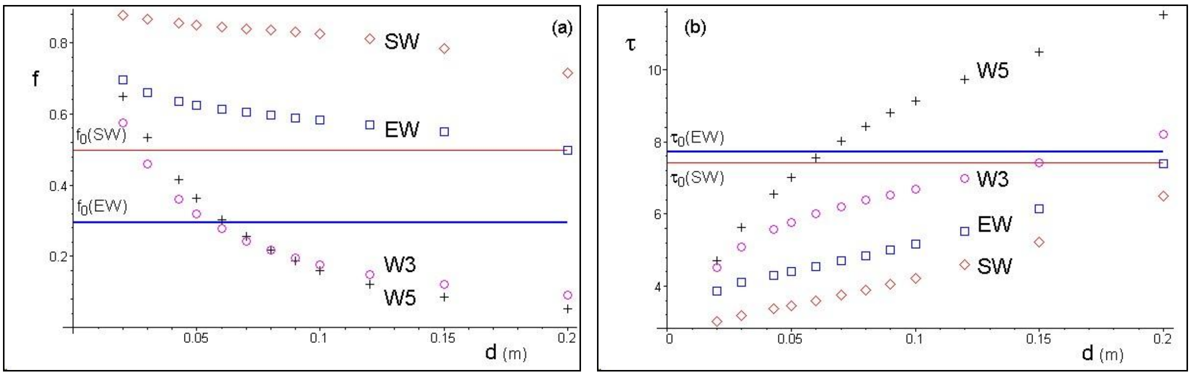

Figure 2 – $M=M_{lim}/2$, the trend of the decrement factor f (Fig. 2a) and of the time lag τ (Fig. 2b) with the insulating thickness d (m), for the four considered walls.

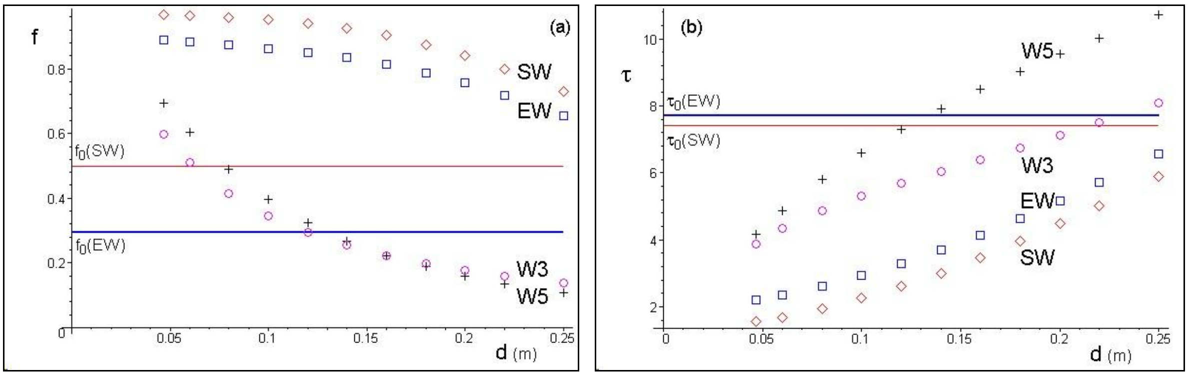

Figure 3 – $M=M_{lim}/4$, the trend of the decrement factor f (Fig. 3a) and of the time lag τ (Fig. 3b) with the insulating thickness d (m), for the four considered walls.

Finally, the case $M=M_{lim}/4=57.5$ kg/m^2 has been considered, from which, imposing also $U=U_{lim}$, we obtain $d_C(1/4) \cong 4.7$ cm and $d_I(1/4)=4.7$ cm, with $d_C(1/4)$ the thickness of the material C and $d_I(1/4)$ the thickness of the material I in the case of $M/M_{lim}=1/4$.

From the graphs reported in Figs. 3a-b it seems to be evident that the use of a wall W5 (W3) with M=57.5 kg/m^2 and with an overall thickness of the insulating layers exceeding 13 cm (23 cm) allows to obtain values of f and τ better than those presented by reference walls with $M=M_{lim}$.

EXAMPLES OF MULTI-COMPONENT LIGHT WALLS

Next four examples of multi-component light walls, indicated by LW1, LW2, LW3 e LW4 are discussed. All the walls considered later on are characterized by thermal transmittance values much lower than the limit values imposed by Italian rules, with effect from the 1st January 2010, as for the different climatic zones [1-3].
The stratigraphies of the walls LW1 (ten-layer), LW2 (seven-layer), LW3 (five-layer) and LW4 (three-layer) are reported respectively in Tab. 1, where the materials composing each layer with the respective thermophysical properties (density ρ, thermal conductivity k, specific heat at constant pressure c_p) as well as the respective thicknesses d are specified; layers are numbered from the outside to the inside. In the same table the values of the overall thickness D and of the overall thermal capacity W, in addition to the values of M and U, are reported for each wall.

Layer	Material	d (cm)	ρ (kg/m^3)	k (W/mK)	c_p (kJ/kgK)
WL1 (D=38 cm; M=68 kg/m^2; U=0.12 W/m^{2}K; W=118 kJ/m^{2}K)					
1	(*outside*) Wood-based panel, cement-bonded particleboard	1.5	1400	0.20	1.60
2	Air space	4.0			
3	Wood-based panel, OSB	2.0	600	0.16	1.70
4	Rock wool panel (semirigid)	10.0	80	0.035	1.00
5	Wood-based panel, OSB	2.0	600	0.16	1.70
6	Expanded polystyrene panel (rigid)	10.0	35	0.034	1.40
7	Expanded polystyrene panel (rigid)	6.0	35	0.034	1.40
8	Wood-based panel, OSB	1.5	600	0.16	1.70
9	(*inside*) Gypsum plasterboard	1.25	1000	0.47	1.00
WL2 (D=43 cm; M=82 kg/m^2; U=0.13 W/m^{2}K; W=101 kJ/m^{2}K)					
1	(*outside*) Composite material panel	3.0	550	0.090	1.40
2	Expanded polystyrene panel (rigid)	6.0	35	0.034	1.40
3	Mineralized plywood panel	5.0	360	0.090	1.55
4	Expanded polystyrene panel (rigid)	12	35	0.034	1.40
5	Rock wool panel (semirigid)	5.0	80	0.035	1.00
6	Air space	8.0			
7	(*inside*) Gypsum plasterboard	3.75	1000	0.47	1.00
WL3 (D=30 cm; M=112 kg/m^2; U=0.27 W/m^{2}K; W=127 kJ/m^{2}K)					
1	(*outside*) Plaster, lime and sand	1.0	1600	0.80	1.00
2	Expanded polystyrene panel (rigid)	3.0	35	0.034	1.40
3	Cellular concrete (low density)	22	500	0.13	0.84
4	Expanded polystyrene panel (rigid)	3.0	35	0.034	1.40
5	(*inside*) Plaster, lime and sand	1.0	1600	0.80	1.00
WL4 (D=58 cm; M=19 kg/m^2; U=0.062 W/m^{2}K; W=90 kJ/m^{2}K)					
1	(*outside*) Plaster, lime and sand	2.0	1600	0.80	1.00
2	Expanded polystyrene panel (rigid)	54.0	35	0.034	1.40
3	(*inside*) Plaster, lime and sand	2.0	1600	0.80	1.00

Table 1: Stratigraphies of the considered walls.

The wall LW1, peculiar to wooden light structures, is widespread in central-northern Europe and privileges the use of light and insulating materials.

The wall LW2 is characterized by a sequence of thermal and acoustic insulating layers. The outer facing is realized with composite-material slabs, made up of a grain expanded-silica matrix combined with epoxide resin, realized using the “complete panel” technique. The air space (towards the inside) is designed for housing the canalizations of some plants.

The wall LW3 is composed of an autoclaved cellular-concrete layer posed between two insulating layers. This kind of wall, whose performance has been studied by the authors in [5-7], is currently widely used in the USA and in Canada; in Italy it is used as panel wall of industrial sheds as well as underground spaces of buildings.

The walls LW4 is composed by expanded polystyrene rigid panels with plaster on both faces; such a wall can be considered as the practical realization of a homogeneous wall. The wall PL4, considering its high thickness, turns out to be of negligible practical importance, and has been taken into account just as a limit case as to “ultralight” wall.

The thermal transient behaviour of the light walls LW1÷4 has been compared with two walls: the wall ETW, with an outdoor external insulation, and the wall STW, with a sandwich-type insulation, typical of traditional building. The walls ETW and STW are characterized by M≥230 kg/m^2 and comply with Italian rules as for all climatic zones and for insolation values even exceeding 290 W/m^2 [1-3] The wall ETW is composed of lightened-brik blocks of 25 cm in thickness (k=0.43 W/mK, ρ=910 kg/m^3, c_p=840 J/kgK) and by expanded polystyrene rigid panels of 8 cm in thickness, posed on the outer side. The wall STW is composed of two slabs in lightened-brick blocks of 12 cm in thickness (k=0.40 W/mK, ρ=1000 kg/m^3, c_p=840 J/kgK) with interposed expanded polystyrene rigid panels of 8 cm in thickness. The walls are plastered on both faces with lime mortar (k=1.0 W/mK, ρ=1600 kg/m^3, c_p=880 J/kgK) of 1.0 cm in thickness. The wall ETW is characterized by: M=230 kg/m^2 and U=0.32 W/m^{2}K; while the wall STW is characterized by: M=243 kg/m^2 and U=0.32 W/m^{2}K.

In Tab. 2 the following values are reported: the frontal mass M, the thermal transmittance U, the decrement factor f, the time lag τ and the dynamic thermal transmittance U_D for the walls LW1÷4 and the walls ETW and STW.

Wall	M (kg/m^2)	U (W/m^{2}K)	f	τ (h)	U_D=f U (W/m^{2}K)
ETW	230	0.32	0.201	9.67	0.064
STW	243	0.32	0.322	10.1	0.102
LW1	80.1	0.12	0.195	11.8	0.0233
LW2	82.3	0.13	0.205	11.3	0.0255
LW3	112	0.27	0.171	11.1	0.0470
LW4	18.9	0.062	0.200	13.8	0.0124

Table 2 – Calculated values for the multi-component light walls (LW) and for the walls ETW and STW.

From the Tab. 2 the walls LW1÷3, even though they show values of M much lower than the limit value of 230 kg/m^2, seem to be clearly characterized by values of the parameters f and τ better than those relating to the walls ETW and STW. Therefore, also in consideration of the low values of the thermal transmittance of the walls LW1÷3, we can state that such walls comply with the limits imposed by Italian rules [1-3] for all climatic zones and for any insulation level. Obviously, also the wall LW4 fully complies with rules requirements, but, owing to its high thickness, it is supposed not to weigh in the building practice.

Observe explicitly that the values of f and τ, presented by the walls LW1÷3, being in use in the current building practice, are quite far from the limit values, determined in [4], for

lumped-parameter walls; with more carefully determined stratigraphies, a performance much better in terms of f and τ could be obtained. For example, for a wall of the type LW1, optimized according to what has been reported in [4], the value of f could be reduced by approximately 90% and the value of τ could be increased by over 30%.
In some cases the dimensionless parameter σ (defined as the ratio between the thermal oscillation amplitude on the wall inner face and that of the external temperature), connected with f by the relation [4]: $\sigma=r_iUf$ ($\sigma<f$), is preferred to the decrement factor f. Notice that the parameter σ explicitly depends also on U; for this reason, for example, the wall ETW, presenting a value of f similar to that of the wall LW2, is characterized by a value of σ almost three times higher than that of LW2.

CONCLUSIONS

Using the decrement factor f and the time lag τ parameters, the behaviour of multi-component light walls has been compared to that of walls typical of traditional building.
The possibility to obtain, with light symmetrical-stratigraphy three-layer or five-layer walls, values of the parameters f and τ better than those of walls with mass per surface unit even 4 times higher, is pointed out. From the analysis of the investigated cases it has clearly turned out that, increasing the thermal insulation of a light wall, it is easier to obtain low values of f than high values of τ. The possibility to obtain acceptable values of f and τ even with "ultralight" walls (mass per surface unit of approximately 20 kg/m^2) has been also highlighted but, in these cases, the insulating high thicknesses required would lead the wall overall thickness to such values as to make their use difficult in the building practice.
Finally, three examples of multi-component light walls (five-layer, seven-layer and ten-layer) whose use is becoming widespread in contemporary building, have been studied; the values of f and τ presented by such walls have been compared to those of brick walls typical of traditional building.
Italian rules, derived from the EPBD, have been assumed as reference ones, but the obtained results have general validity and can be easily extended to different normative contexts.

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NANOTECHNOLOGY FOR SUSTAINABLE BUILDING FACADES

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ABSTRACT

Optimal energy performance is often in contradiction with a comfortable climate. The current façade systems are often a compromise between energy and comfort. To look for new solutions a methodical design method is used. The theoretical design approach let to interesting new façade concepts based on the new possibilities of nanotechnology, which are very prosperous for the comfort as well as for sustainability of the building itself. The result are 7 facade concepts, which are all theoretically capable of suffice the requirements and wishes to innovative facades. Two of these nanotechnology concepts are presented.

INTRODUCTION

The modern façade has multiple functions, for example lighting, shading and view. Most functions of the façade can be assigned to a specific zone of the façade. The zones can be horizontal or/and vertical divisions. The zones concerning the management of light can be defined as three zones; daylight, sight and railing. A preliminary investigation was done to map the existing state-of-art techniques and see where the improvements can be made. The techniques currently available or available in the next 5 years were studied.

METHOD

The design of better functioning façade concepts is a complex process. To support this process the methodical design method is used. The methodical design method is a methodology for structuring and documenting design process steps [1]. The functions to fulfil and features to create are listed in a morphological chart (figure 1).

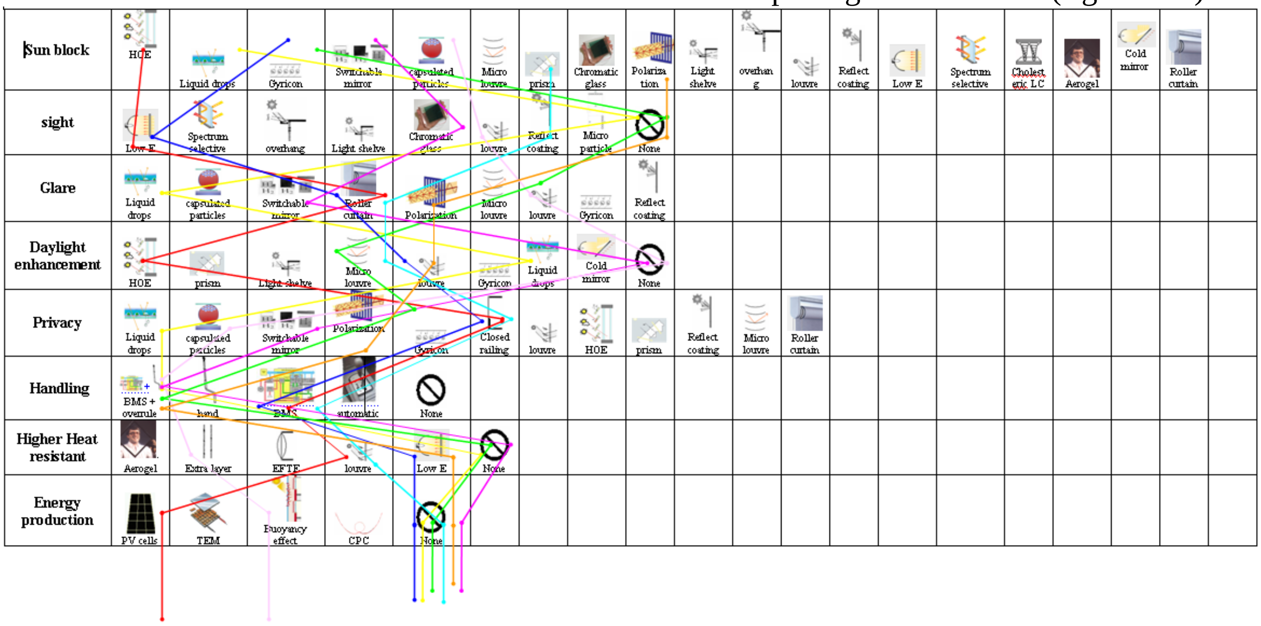


Figure 1: Morphological chart [2].

In a morphological scheme the sub-functions of the façade are listed vertically. The possible solutions for these sub-functions are set out horizontal. This way it becomes clear what the different solution are for each sub-function. This overview of functions and their solutions makes combining different sub solutions to overall solutions easier. This enlarges the possibility that innovative solution occur. Besides the good overview and the easy combination making the scheme also helps the future researchers to follow every step made in the process. It is clear which solutions were available and which were not. All the choices are clear to see and the explanation of the choice can be clearer by referring to the scheme. The most important function is sun block. To get a good indoor climate good sun block is necessary. This way the heat of the light waves stays out and the internal load stays lower. In the scheme the sub-function sun block has a lot of solutions. Some are better than others. The solutions are arranged in order of quality; the best solution is listed first. The most ideal concept can be said that it is the one which includes all the best sub solutions. However it is not always possible to make these combinations and sometimes other combinations are the result.

RESULTS

All combinations formed in the morphological scheme seem to be possible solutions to block the sun were needed and still let light through the façade. The method of VDI 2225 [3] based on the Kesselring method is used to have an indication which solution will function better and which solution is easier to built or both. The VDI 2225 assessment method indicates by means of scores for the functional quality and the easiness of building or implementing a solution. The results are set out in the S-diagram. This diagram shows the solutions' score relative to each other.

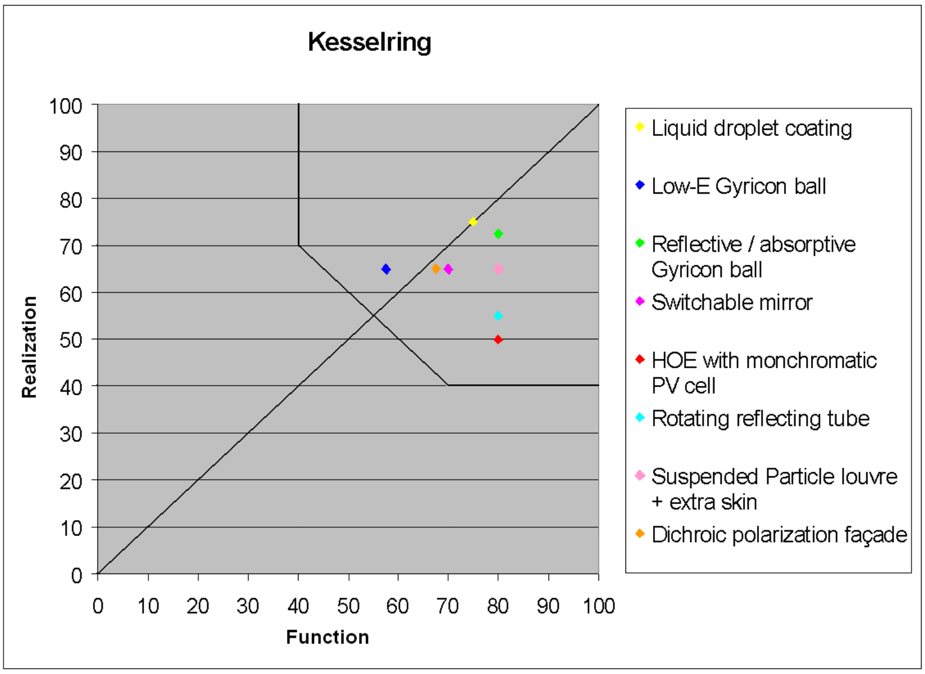


Figure 2: Kesselring diagram of the new façade techniques[2].

The two best solution liquid droplet coating and reflective gyricon ball will be elaborated.

Concept 1: Liquid droplet coating

There is been a lot of research after the electronic paperone of these is the liquid drop technique [4,5]. A pixel element contains a droplet of a dyed polar liquid such as water. The droplet is connected to a wettable electrode. The droplet, positioned on the surface of an insulator layer, does not wet the material of the latter. A lower electrode is placed on the opposite surface of the insulator layer. The display operates upon the basis of the electrocapillary effect (electrowetting). An addressing voltage is applied to each droplet through the wettable electrodes. When the potential difference is applied to the wettable electrode and the lower electrode, the droplet is charged and has a potential opposite to the potential of the lower electrode. A droplet with the opposite charge is driven to the lower electrode. This causes the contact angle of the droplet to decrease. As the contact angle is decreased, the droplet is deformed and spreads over the surface of the insulator layer. When the electrode and the droplet are discharged, the droplet regains its ball-like shape. The deformation of the droplet is substantially rapid, so a change in the surface area occupied by the droplet also occurs in a short period of time.

This display application can also be used as solar protection in the façade of a building. By using a reflective dye in the droplet the coating can reflect the incoming sunlight. This can be total reflection to the outside when the droplet is all spread out. It can also be redirection of the sunlight into the building when it is incoming onto the droplet at the right angle.

Disadvantage is the inability to switch step less. It’s either fully reflective or transitive.

The resulting concept is a coating that can be changed per pixel. The possibilities of the coatings are big. The coating can be applied to new and exiting materials. Different forms are possible. Together with an intelligent computer system the user can create customized shading. The user can program with the computer the rate of shading and even the position form of the darker spots. The coating consists of a grid of electrical circuits. With an advanced computer the electrical devices can be addressed individually. Therefore it’s possible to create different appearances and functionality.

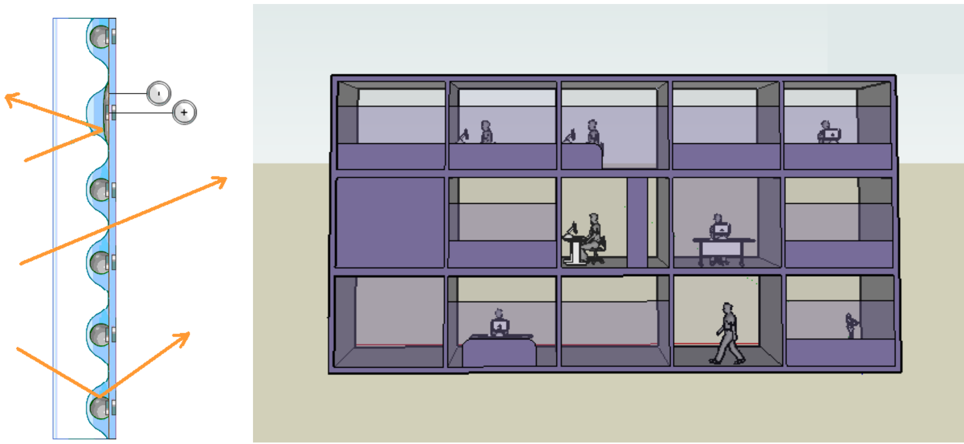


Figure 3: Working principle of the liquid droplet coating and its practical application: the many different possible views of the coating concepts [2].

With a sun tracking device the dark blocks like the vertical block in the middle can move in wintertime along with the position of the sun. The inconvenient direct sunlight can be blocked without closing a whole part of the façade, see figure 4.

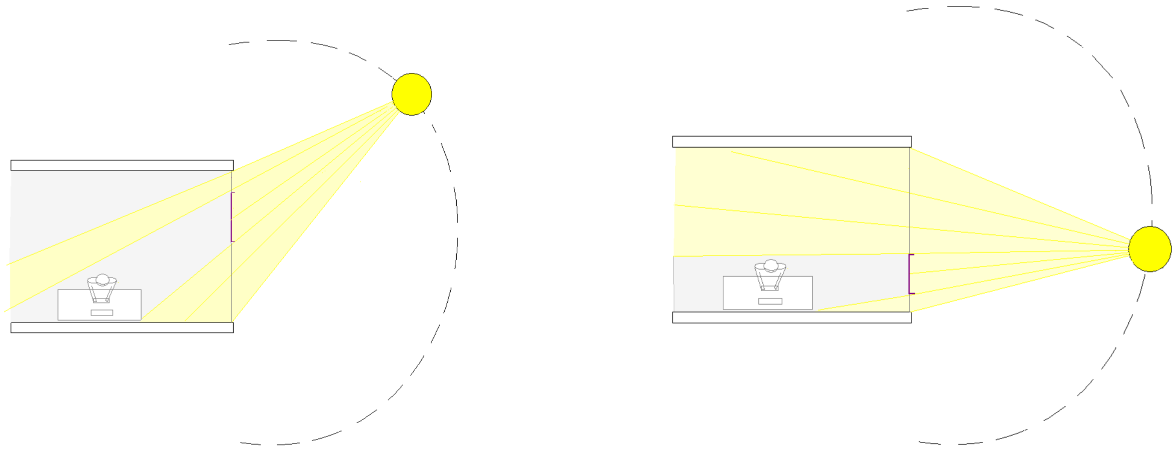
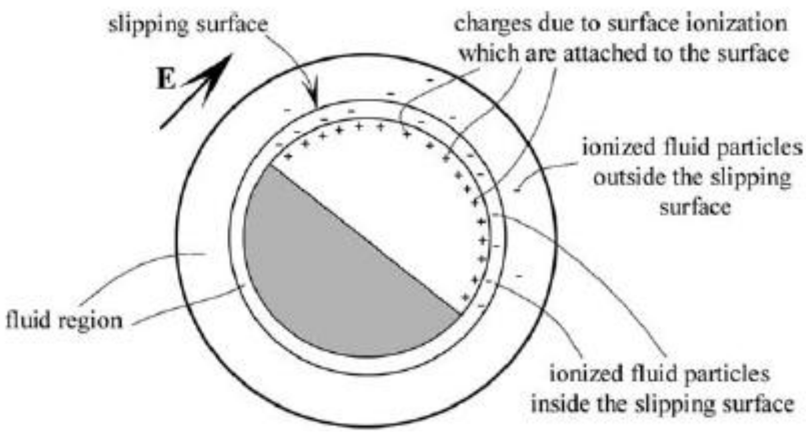


Figure 4: sun tracking coating follows the position of the sun [2].

Concept 2: Reflective Gyricon ball

The Gyricon ball is also invented as a solution for electronic paper. Gyricon balls consist of two hemispheres of different colours and different electrical properties. When immersed in a liquid and exposed to a uniform electrical field, they rotate so that the ball is aligned along the polar axis. The dipole moment of the ball is modelled in terms of a uniform surface charge distribution on each hemisphere, and the predicted motion is obtained from a balance of electrical and viscous torques. The motion shows a long and variable initial decay, followed by a relatively rapid turning and then a long final delay. After switching no power is necessary to keep it's position., see figure 5 [6].



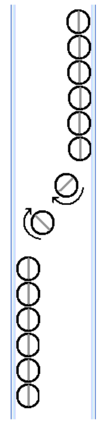


Figure 5: working principle of the Gyricon ball and the concept of a cluster of gyricon balls [2,6]

To make this application suitable for solar protection it's possible to insert a low-E coating between the two hemispheres. The hemispheres are transparent in stead of coloured. This way the advantage of the Low-E coating can be fully exploited. In summer the heat is reflected outside and can't come in the building. In winter the balls turn and the heat reflecting side turns towards the inside. As a result the heat stays inside. The switching of the balls can be very quick so the system can react to changes during the day also.

The Gyricon ball can be fabricated into a coating and require a minimal usage of materials.

This presents an economic advantage over conventional systems which require the construction of a separate structure to support them, and motors to orient them to intercept and properly reflect sunlight. Reflective/ absorptive Gyricon balls

Instead of inserting a low-E coating between the hemispheres it is also an option to put a coating with an absorbing side and a reflective side in between. The absorptive side can be used in wintertime when the sun is causing glare or an unpleasant heat gain. The sunlight is absorbed by the Gyricon balls. The heat that is released by the absorption can be used to decrease the heat loss over the façade.

The reflecting side can either reflect the sun to the outside or can reflect the sunlight deeper into the room. When the light is better distributed to the back of the room the artificial light can be minimized, so the building is consuming less energy. The reflective Gyricon ball coating has electronic control and just like the liquid droplet coating each pixel can be controlled separately. With this coating it's possible to create the same functionality. The appearance is slightly different, because the liquid droplet absorbs more light as the reflective Gyricon ball. The reflective side of the Gyricon ball will give the building a more shiny appearance, see figure 6.

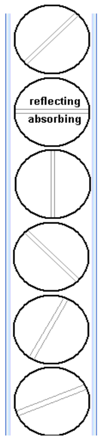


Figure 6: Reflective Gyricon ball [2]

The Gyricon balls don't need electric current to stay in position. Once positioned the balls stay in position. The current needed for switching is very low. By introducing a hand held device with can give the current is becomes possible for the user to draw there own shading. Just like a magic board kids play with. The user can assign tasks to the shading like sun tracking and save the preference into the BMS system. It's also possible for the user to have a quick look through the shading if needed by whipping the shading away. Just like condensation on a window.

DISCUSSION

The world is changing rapidly. The climate changes, more pollution regulations and different user demands make the design of a building more and more complex. With good structure in the design tasks and decomposing the design process into smaller steps it is possible to find new components and techniques.

The coating concepts together with an intelligent computer are really interesting for the future. The computers get better every day and the next generation of office workers are more familiar with computer programs. These two developments together with better production techniques make the liquid droplet coating and the Gyricon ball coating serious candidates for future façade techniques. The coating can easily be applied on existing buildings to. People working at home can make more of an office environment of their homes by applying the coatings on the windows of their study. The future techniques are going to be the strongest, most intelligent and the most adaptable!

New and existing techniques are scale to the size of nanometres (10^{-9} m). This offers new possibilities for the façade. Many research in micro particle techniques in done in display technology and electronic paper. The liquid droplet technology and the Gyricon balls are examples of new and interesting techniques. The techniques aren't transparent but with little adjustments they can be made transparent and suitable for use in façades. The Gyricon balls are currently used for electric paper and offer high contrast and low energy consumption. The liquid droplet technique is a new display technology with rapid switching time and made out of fully sustainable materials. Prototypes of their original purpose are available on the market and commercial exploitation of both techniques is planned in 2008. Many techniques are controlled electrically and can therefore be easily attached to the BMS. Due to the small particle size shading devices can be controlled per pixel. This introduces new possibilities for positioning dark shading spots randomly on a façade. Little adjustments can be made to make prototypes for the use in façades. A more extensive description of these techniques is given in (Verwer 2007).

CONCLUSIONS

Methodical design describes the path from an abstract problem to a solution. The complex design question of creating a new and better adaptable façade solution is managed by decomposing the design question into questions of manageable size. The possible solutions which were generated show the promise of new application of nanotechnology in the domain of facades. It indicates a whole new set of solutions implemented in façade technology in the next decade.

ACKNOWLEDGEMENTS

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Hybrid and Passive Cooling

EXPLOSION OF ENERGY DEMAND FOR AIR COOLING IN SUMMER: PERSPECTIVES AND SOLUTIONS (EEDACS)

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ABSTRACT

The Swiss Federal Office of Energy has published directives in order to limit the increase of electrical energy consumption to a maximum of 5% in 2010 in comparison with 2000. To reach this goal, clear measures have to be taken regarding the installation and the utilization of air conditioning systems. Considering the current growth, the needs of energy related to air conditioning will reach 2'500 GWh/year in 2020 if no action is put in place to limit it. This is even worse as the electrical demand linked to air conditioning explodes in summer when the electricity production with hydraulic sources is the lowest. In order to answer this problem of drastic increase of energy consumption linked to the air conditioning, a research has been undertaken on needs and reasons for air conditioning installations in buildings and the concrete measures to limit these installations or their consumption. The needs for the next 20 years have been predicted, the motivation of these needs have been understood, the air conditioning techniques have been studied as well as the legal framework, and an overheating model has been developed. The result is a list of measures taking into account the application delay (short to long term), categorized by domains, awareness action, information, and organization, technical and legal aspects. For example the measures involve reducing the internal heating load, tuning of the existing installations, supply of photovoltaic power to the air conditioning systems, a better demonstration of the needs and integration of the SIA norm 180 in the law.

INTRODUCTION

The energy consumption of the air conditioning system is increasing constantly since 1990. The Swiss Federal Office of Energy has published directives in order to limit the increase of electrical energy consumption to a maximum of 5% in 2010 in comparison with 2000. To answer this objective, clear measures have to be taken on the air conditioning system. Moreover, the energy demand linked to air conditioning system occurs during the summer period when the hydro-electrical production is at the lowest. One typical example which let us believe that some improvement could be made is the air conditioning system working during the winter when heating is on.

In order to determinate the measures which will allow reducing the energy consumption of the air conditioning systems, a research has been carried out by a group of 3 partners (EPFL-LESO, UNIL, Planair SA). The methodology has consisted of the following steps:

- Determination of the energy consumption of the air conditioning systems in Switzerland and forecast for the next 20 years
- Understand the needs of air conditioning systems

- Inventory of the actual techniques of air conditioning systems and legal framework linked to them
- Development of model predicting the risk of overheating
- Understand the representations underling environmental adaptative behaviors or needs of air conditioning.
- Propose measures to reduce the energy consumption due to air conditioning systems

Determination of the energy consumption of the air conditioning systems in Switzerland and forecast for the next 20 years

A bottom-up approach has been applied to estimate the electricity consumption of the air conditioning systems. The air conditioning surfaces have been estimated and the specific consumption related to them.

In order to estimate the strong increase of energy consumption during the extremely hot summers, the forecasted curve has been corrected based on the increase in the air conditioning systems sales in Switzerland.

Understanding of the needs of air conditioning systems

The objectives of this part of the main project study was:

- Identify the habits and behaviours of workers and home residents in terms of estival temperature regulation
- Identify the attitudes, the understanding/knowledge and beliefs regarding air conditioning
- Identify health related problems with air-conditioning in different groups of users.

3 methods have been used to understand the habits and behaviors of occupants of buildings in term of temperature regulation:

- Surveys: 2 questionnaires have been established with the goal to provide information regarding the importance of psychological variables influencing the need of air conditioning systems. The first questionnaire has been addressed to 500 employees working in administrative offices without air conditioning. The second questionnaire has been addressed to 500 inhabitants of building without air conditioning.
- Semi structured interviews: the goals of these interviews were to deepen aspects revealed by the questionnaires described above. This has allowed understanding the attitude towards overheating.
- Focus group: the goal was to get the point of views of professionals regarding this subject. Architects, air conditioning providers, public bodies, employers, and construction companies have participated and given their inputs regarding solutions to decrease the energy consumption due to air conditioning systems.

Actual techniques of air conditioning systems and legal framework linked to them

The technical division of Planair has provided information regarding the most advanced techniques in terms of air conditioning systems as well as on the legal aspects. This study has been completed with a literature review.

Model to predict the risk of overheating

The principal role of the LESO within this recently completed project was to develop a new model for predicting the risk of summertime overheating in indoor spaces, defined in terms of the probability that occupants would be thermally dissatisfied with the summertime thermal history of an occupied space. The purpose of this work was to enable building designers to determine the acceptability of design proposals with a view to avoiding the use of applied energy for space conditioning, by using the model to post-process results from building simulation programs.

The theoretical basis used to develop a model to predict the risk of overheating are the following the model of Fanger (1970), the adaptive algorithm of Humphreys (1978), the Baker and Standeven study (1996) and the modification of adaptive algorithm proposed by De Dear and Brager (2002) The development of the model has been based on continued measures of thermal conditions in several selected buildings and the filling up of their occupants of electronic questionnaires installed on their computer. These questionnaires have allowed obtaining a range of data regarding the evolution of the thermal perception and the adaptation to overheating. A second questionnaire has been distributed to understand the situation of overheating and their causes.

Proposition of measures to reduce the energy consumption due to air conditioning systems

The studies described above have provided the necessary information to establish a list of measures to reduce the energy consumption induced by the air conditioning systems. The solution proposed has been reviewed with a group of professionals composed by the cantonal services of energy (Neuchâtel), the Swiss society of engineers and architects, Buildings Companies, an architect, a bank.

RESULTS

Forecast of the energy consumption of the air conditioning system over the next 20 years

The graphics below present the forecast of the energy consumption of the air conditioning system over the next 20 years in Switzerland :

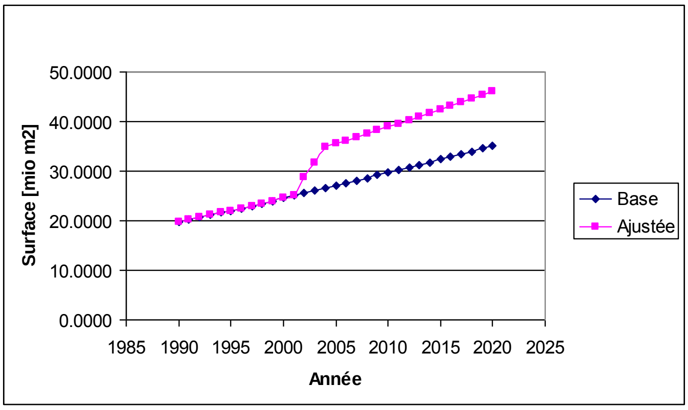

Figure 1: Forecast of the increase of air conditioned square meters in Switzerland until 2020

Understanding of the needs of air conditioning systems

Surveys, interviews and focus group:

The key points which influence the needs for air conditioning are the following:

- The feeling of freedom: The need in terms of thermal comfort is higher at work than at home.

- The feeling of control: the temperature controlling systems are in a room (opening of windows, sun blinds, and so on) the more satisfied the occupants are, and the less air conditioning is requested.
- The need for information regarding the ways of cooling a room with natural actions, employers ask for information regarding the way to cool buildings.
- The individual take responsibilities: employees want to choose their working conditions and to assume them.
- The need to have an integrated solution: the overheating at work has to be considered as a global problematic and not as an isolated problem.
- A better understanding as well as a prevention of the negative consequences related to the summer overheating

Actual techniques of air conditioning systems and legal framework linked to them

Two main categories of air conditioning systems have to be distinguished:

- Refrigerating fluid
- Chilled water production

An appropriated management of the air conditioning systems consists of letting the installations work during the night in order to reduce the delta to be cooled. This allows to have fresh air in the buildings on the morning and to have an acceptable temperature at the end of the day. In general, the management of the installations is a key parameter which influences the energy consumption.

With regards to the Swiss legal point of view, the SIA (Swiss engineer and architect) gives instructions on cooling of buildings, and recommendations regarding acceptable comfort with air conditioning. However the notion of energy consumption with a cooling system is not considered so far. In order to receive an authorization to install an air conditioning system bigger than 20 kW, cantons request building owners to demonstrate the “need”. However, in reality, some buildings owners do not ask for authorization or if the authorization is not received, install a considerable number of air conditioning systems of 20 kW. Another point is that the proof of the need is not based on the same conditions in each canton.

Model to predict the risk of overheating

During the summer of 2006 a field survey was conducted in eight non air-conditioned office buildings, each located within a 50km radius of Lausanne. Their selection was based on a desire for reasonable diversity in terms of their design concept and the adaptive opportunities available to occupants. For each building, volunteers were asked to complete a short electronic questionnaire which was installed on their PC. This questionnaire (below), which appeared at regular participant-defined intervals, asked for evaluations of:

- Clothing and activity level.
- Thermal satisfaction and preference.
- Adaptive opportunities exercised.

The purpose of this dialogue box was to produce time-series data regarding participants’ adaptive actions and their evolving perception of the parameter(s) under examination.

The data from these questionnaires was analyzed and a preliminary form of a new adaptive model for overheating risk assessment was developed (see below). This model:

1. Predicts the probability with which occupants will adapt their personal or local characteristics to improve their thermal satisfaction. Examples include: opening windows and doors, use of blinds, switching on fans, adjusting clothing levels etc.

2. The corresponding temperature results from thermal simulation program are then adjusted according to the effect of a given adaptive action on occupants' neutral temperature (empirical adaptive increments).

3. Finally the new adjusted temperature is input to a model which predicts the probability with which an occupant (or indeed the proportion of a population) will perceive their indoor environment to have overheated.

This model for predicting overheating risk is based on analogy with an electrical capacitor. When we encounter overheating stimuli our thermal tolerance *T* to them is discharged (or overheating probability *P* increases: *P=1-T*). During cool periods our tolerance is then re-charged (for example during winter in readiness for discharging the following summer).

The following hypothetical (step-change) temperature profile illustrates the concept (Figure 2): When the temperature is above 25 °C (an arbitrary reference temperature) overheating probability increases; at 25 °C it is unaffected; below 25 °C overheating probability reduces.

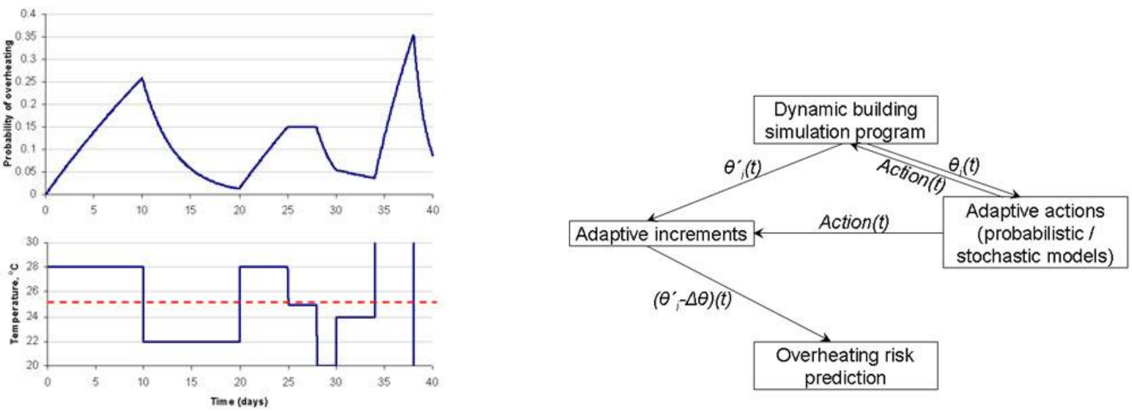

Figure 2: Step changes in indoor air temperature (bottom left) and a hypothetical overheating probability response curve (top left). Suggested model structure: integration of stochastic interaction and dynamic thermal comfort with building simulation models, the results post-processed by an overheating model

PROPOSITION OF MEASURES TO REDUCE THE ENERGY CONSUMPTION DUE TO AIR CONDITIONING SYSTEMS

Based on the results of the studies presented above, measures have been established. These can be classified into three categories:

- Measures of information: one important point coming out of the questionnaire is the need of information regarding the temperature (digital screen in office); the way to decrease the temperature in buildings (instruction to the users of buildings); the cost of the energy needed by air conditioning systems; training for the use of air conditioning systems; management and optimisation of the air conditioning system.

- Consciousness: professionals have to be conscious of the air conditioning energy consumption and the way to diminish it. The internal supply of heat due to appliances also has to be considered.
- Legal aspects: extend the proof of the need to all systems including those with a power of less than 20 kW; link the air conditioning system installations to a renewable source of energy; introduce a tax on air conditioning system; impose the application of the SIA 180.

These measures have been tested on real cases (third sector companies) and have demonstrated the efficiency.

ACKNOWLEDGEMENTS

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HYBRID VERSUS LABYRINTH VENTILATION AND NIGHT COOLING

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ABSTRACT

Building integrated geothermal energy systems promise to reduce the energy consumption of the built environment. The passive building concept is the present trend in energy efficient sustainable dwellings. Within the passive building concept every effort is made to minimize the energy use. The ventilation capacity of many of these passive houses with hybrid ventilation systems is critical. Energy saving and sustainability is very important but not at the risk of endangering health of the occupants. This was the starting point for a new approach inspired the vision to see the building as s tree, which led to an alternative concept: the active house concept. By using ground air collectors, labyrinth foundation, murocauster and hypocauster, the whole building envelope, its construction is thermally activated by natural pre-cooled air in the summer and natural pre-heated air in winter by using the soil. A first design is presented to illustrate the concept.

INTRODUCTION

The built environment uses around 40% of our total energy demands and this leads into environmental problems, global warming and exhaustion of fossil fuels. This has to change and new approaches have to be developed. One such approach is the latest trend on low energy housing: the Passive House. Recently in Germany and Austria already more than 5.000 Passive houses have been built and a lot experience was gained. However designing and building of passive houses in a country is not a matter of straight forward following the experience of the already built examples from Germany or Austria. Each country has its own building tradition, architecture, building technologies, climate and culture (Kaan en de Boer 2005). Analysis of Passive House solutions shows high priority with regard to the performance of the thermal envelope: high insulation of walls, roofs, floors and windows/doors, thermal bridge-free construction and air tightness (Storm et.al 2006). The most common solution ventilation is a hybrid system: natural supply and mechanical exhaust. For good insulated low energy houses the needed heating energy for the ventilation air is around 50 to 65% of the total heat demand (Pottler et.al. 1999). This is the reason that often the ventilation are strongly reduced, there are values mentioned as low as a ventilation rate of 0,4 (Kaan et.al 2005). In the Netherlands a number of Passive houses have been built by Franke IEA 2005) and were investigated (Balvers et.al. 2008). As the passive house concept proved to be critical in relation to adequate ventilation, we started to look at other ways for a building to minimize the need for energy while still maintaining a satisfactory indoor environment. William McDonough (Bond 2004) asks the question: Why can’t a building be designed like a tree! This inspired us to look into the roots: nature and history. There are quite a few lessons to be learned from the natural world (Godfaurd et al. 2005) and also from history (Bellow 2006, Florides et al. 2002, Kenda 2006).

METHOD NATURE: TERMITES

Termites are some of the most ingenious of animal ‘architects’ John et al. 2005). The Barossa termite has perfected the building of massive structures with fully integrated passive temperature control (Bellow 2006). The system controls the temperature in the Queen’s chamber, at the heart of the nest, to within 1ºC throughout the year. The main driving forces for this temperature control are thermal mass and evaporation. Outdoor air is drawn through tunnels which have a large contact surface area with the ground into a subterranean chamber to cool it on a hot day and warm it on a cold day. In extreme heat the the driving force for cooling is supplemented by evaporative cooling. The termites travel down tunnels to the water table to collect minute quantities of water to place into the system (Bellow 2006).

METHOD HISTORY: ACTIVE VERSUS PASSIVE

Sometimes it is good to go back all the way to the beginning, the basis. The basis of conditioning buildings are from the Greek and Romans. The Romans pioneered with heating using double hollow floors through whose core the hot fumes of a fire were passed (Florides et al. 2002). They used with their 'hypocaust' and 'murocaust' the materials of the build construction to condition the building with hot air, see figure 1.

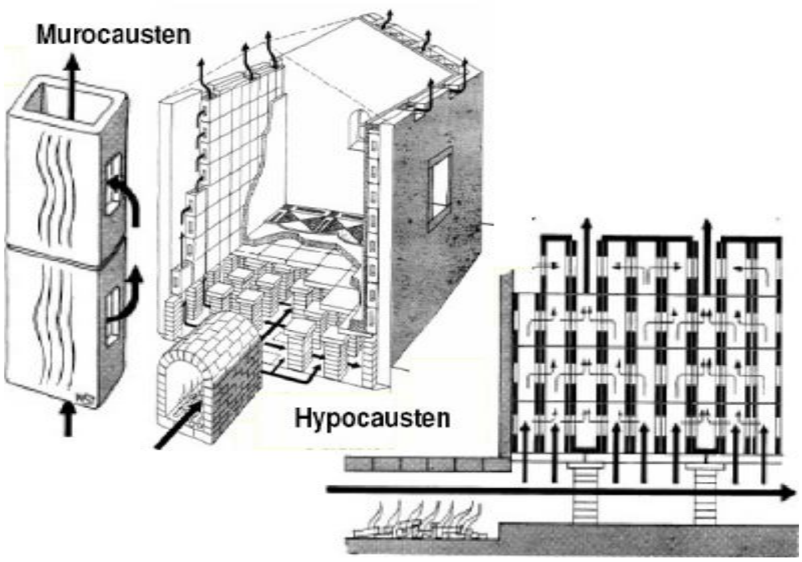

Figure 1: The Roman thermo- and muro-causten system (Florides et al. 2002)

People ruled by Romans assimilated their building techniques and technologies that became one thing with the local ones (Sansone 1999). This was not the only Roman/ Italian influence: Kenda (2006) focused on the beneficial integration of architecture and medicine in Renaissance Italy: Sixteenth century pneumatic architecture, especially the examples of hygienico-pneumatic villas, figure 2.

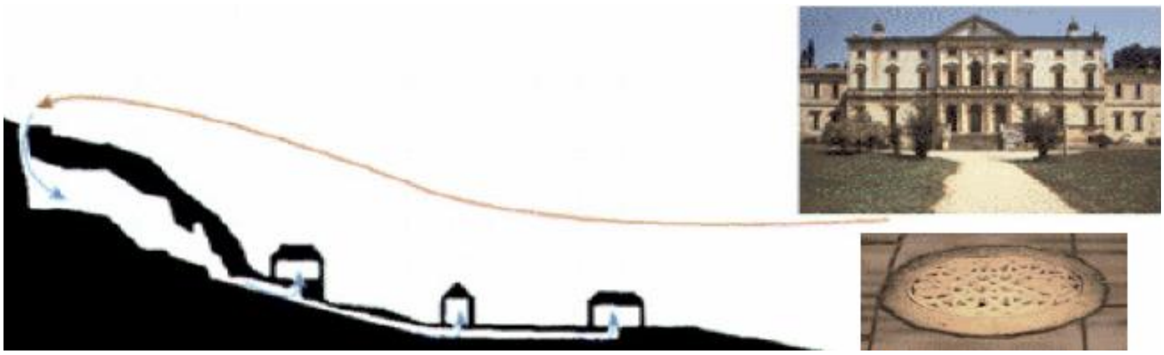

Figure 2: Natural ventilation Villino Garzadori da Schia, Costozza, Italy (Thiene 1998, Bellow 2004).

Lying in a semicircle at the foot of the hills along the Riviera Berica, Costozza is home to an intriguing hygienico-pneumatic buildings: the Villino Garzadori-da Schio. As early as the sixteenth century it was famous for its carefully designed system of air conditioning ante litteram (Thiene 1998). This was achieved by a network of underground pipes which channelled the air from the caves, covoli, into the nearby buildings. This also meant that the cellars were perfect for the storing of fine wines, and indeed the name Costozza is said to derive from the Latin custodia (preservation). The complex consists of three buildings, linked by a dramatic park, which rises upwards towards the former Benedictine church of San Mauro in a series of high, deep terraces. Ca' Molina and the main villa stand on the lower part of the hill, while the Villino Garzadori-da Schio is situated in the upper part of the garden. A little road, lined with box trees and cypresses, leads to the front of the small, simple building. Exceptional feature of this building is the use of the cool air, with its constant temperature, which was channelled from the quarry into the upper rooms for the purposes of air conditioning; in the main room the grilles through which the air flowed are still visible (Thiene 1998). The villas are connected underground by labyrinth caves and wind channels to provide a unique natural ventilation system. Therefore, the integral aim in the making of Renaissance pneumatic architecture was to augment the powers of pneuma so as to foster the art of well-being (Kenda 1998).

SYNERGY OF NATURE AND HISTORY

These examples may seem a far cry from the needs of a contemporary building but the basic physical principals are transferable through many scales, and can be effective in reducing both energy consumption and peak demands on infrastructure (Bellew 2006). A modern variant of the termites architecture is the Alpine House, which houses, a collection of plants at Kew Gardens that in west London enjoys an alpine climate. It has been designed by Stirling Prize winner Wilkinson Eyre and environmental engineer, Atelier Ten, which is devoted to passive controls. To induce cool alpine like breezes to pass over the plants, vents at the top of the 10 m high internal void open to create a natural stack effect - air rising as it warms up, escaping through the vents, and drawing in cool air at the base to replace it. The under croft adds to the process, as its concrete labyrinth cools the air that passes through it. Admittedly, drawing fresh air all the way through the labyrinth was a task too strenuous for the natural stack effect; instead it is pumped up into the glasshouse by mechanical fans, see figure 3.

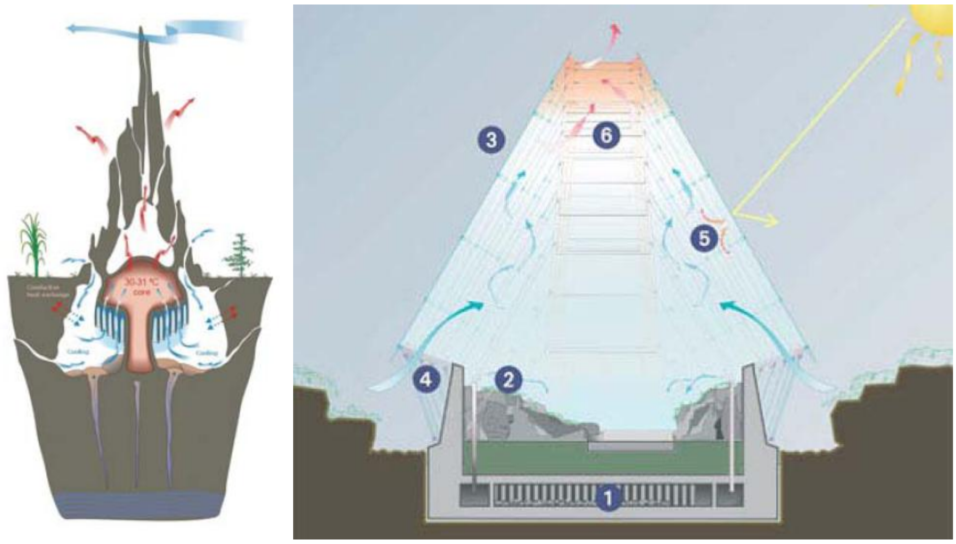

Figure 3: The working principle of the nest of the Barossa termite (Bellew 2006) and climatic principle of the Alpine house (Spring 2006}.

Figure 3 presents the climatic principle of the Alpine house;
1 An underground concrete labyrinth cools air in summer
2 Cool air from labyrinth passes over plants and replaces rising warm air
3 Clear, low-iron single-glazed skin admits maximum daylight
4 Permanent perimeter fresh-air vents draw in fresh air
5 Automatic internal blind shades sunlight during day and blocks radiated heat loss at night
6 Automated roof vents release heated air
When we compare the concept of the Alpine House with that of a nest of Barossa termites there is large similarity. So it is really a good concept to use.
The direct inter-action between the building fabric and the environment in offers many possibilities to reduce the need for additional energy for conditioning in order to achieve the desired comfort and cover the residual demand. It is difficult to categorize the various active systems from true passive systems because they often combine strategies for power generation, passive cooling, passive heating as well as heat storage, heat recovery or avoidance of the various external and internal heat gains (Wachenfeldt and Bell 2003).

A modern variant to use the accumulative capacity of concrete constructions to flatten and damp the effect of fast changing outdoor temperatures by means of a 'thermolabyrinth' was the 1977 Royal Academy of Music complex in London existing of theatres and music studios by Bill Holdsworth (Holdsworth 2005). Also in Germany there are several project with so called 'Thermo labyrinth' systems built, par example Stadttheater Heilbron and Terminal 1 Hamburg Airport. Recently Atelier Ten has enjoyed considerable success with thermal labyrinths on some prestigious projects such as the Federation Square in Melborne project were the outside air is led in a labyrinth under the square and blown into the atrium of the main building (Bellew 2004, AIRAH 2003). Patrick Bellow principal of Atelier Ten has long believe in thermal labyrinhs (Bunn 2004).Other projects a business school designed by Cesar Pelli Architects for the University of Illinois, the Grand Rapids Art Museum in Michigan and the Earth Centre in Doncaster by FeildenClegg Bradley Architects.

In 1988 the IEA task 19 published a manuscript which mentions a solar air system with sun collector connected to murocaust and hypocaust. Such a systems were applied in projects: Lutzstrassen Apartments in Berlin (Hastings and Mørk 1999) and Gardstens Bostäder aparmentscomplex in Gothenburg (SHINE 2006). These are systems which supply the heat of a thermal suncollector to the floors or walls (BINE 2006). Heat from air collectors can be transferred to mass using the room air, or, as in the Lutzstrassed Apartments in Berlin, warmed air can be blown, using fans, through hollow cores in a massive floor, called a hypocaust (Hastings, 1999). The building has a closed loop from collectors in the south facade through tubes embedded in the concrete floor, and back to the collector. Discharge is by radiant transfer through the slab. This has the advantage of keeping the indoor air temperature from rising rapidly when the collector is heated by the sun. In the apartment Block in Gothenburg, Sweden, by Christer Nordstrom ((Hastings and Mørk 1999)) air warmed from rooftop collectors is ducted by mechanical ventilation to a murocaust cavity in the external walls, formed by adding an insulated layer outside the existing not insulated masonry wall.

RESULT: PROPOSED ACTIVE ENVELOPE GEOTHERMAL HOUSE

In the air ducts of the ground-air collectors labyrinth foundation condensation can occur (Koene & Lightart 2001). To avoid the negative effects of this possible bacteria growth in the ground collectors and labyrinth, the choice is made for a separate air cooling system which carries the air through floors and walls and a ventilation system for the building. To improve the heat transfer from the tube to the air, the inner surface was tripled. This system is already used in several German projects (Schröder 2002, Kiefer 2003). With a heat exchanger energy is exchanged between supply air and exhaust air, so there is no direct contact between the air directly blown into the rooms and air which went through the air-ground collector and the labyrint foundation. The air for ventilation is supplied into the rooms through a separate floor duct Concrete Core system. The air for the conditioning is used only to cool or heat the total building envelope. Activating of the buildings' envelope by air supplied concrete core can be done with the ConcreteCool systems in combination of hypocausten and murocausten, see the schematic in figure 4.

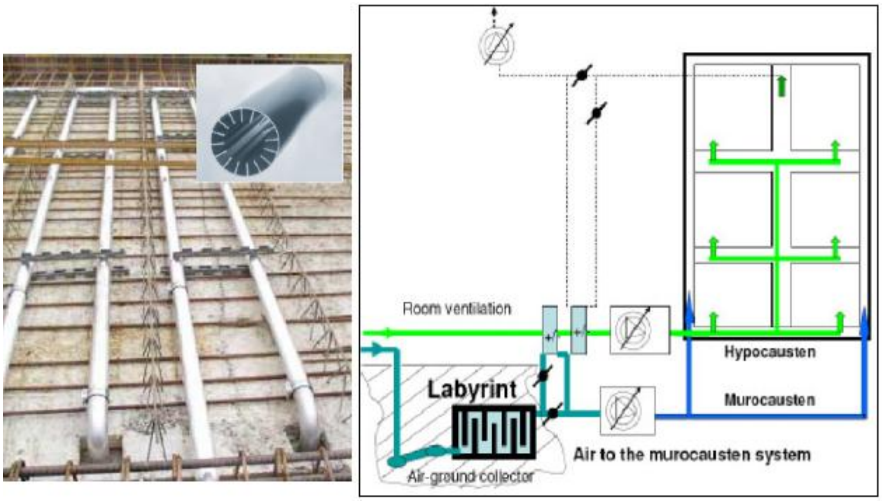

Figure 4: The concrete core activating system and schematic of the hypocausten /murocausten system in combination with air-ground collector and labyrinth foundation.

DISCUSSION

Passive houses are a real hype, but good indoor ventilation is critical. Energy saving and sustainability is very important but not at the risk of endangering health of the occupants. This was the starting point for a new approach, which led to an active house concept. By using a labyrinth ground air collector foundation, murocauster and hypocauster, the whole building envelope and construction is thermally activated by natural pre-cooled air in the summer and natural pre-heated air in winter. This principle could play a significant role in the design of healthy buildings and change the present hype of passive building concepts. It would be a good concept to maximize the effects of night cooling by means of labyrint ventilation. This enables to pre-cool the building during the night and use not only the thermal mass of the building but also use the thermal mass of the labyrinth and the soil around it.

ACKNOWLEDGEMENTS

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Daylighting and Electric Lighting

DEVELOPMENT OF A DAYLIGHT DISCOMFORT DETECTOR FOR CONTROL OF SHADING

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ABSTRACT
Shading control is a key parameter in real energy saving of electricity for lighting in workspaces. Daylight responsive controls may be very efficient, but improper blind control can strongly reduce the effect. This paper presents the results of an investigation of a simple approach to develop a sensor that could be placed on a desk. This sensor supports blind control from the user perspective, because maintaining the user's visual comfort is necessary in work spaces. Discomfort always leads to extra energy use. This paper presents the status of ongoing research with the final objective of creating an easy to understand and easily commissionable shading control system providing maximum daylight and preventing the user(s) from glare.

Keywords: daylight, visual comfort, luminous thresholds, shading control

1 INTRODUCTION

Fully glazed office buildings have a high risk of visual and thermal discomfort, especially under sunny sky conditions. Lindsay and Littlefair (1992) found a strong correlation between the amount of sunshine, the sun position, and Venetian blind use. Shading has to be used to prevent discomfort and very often additional electric lighting will be switched on to compensate for high luminance ratios in the interior.

The use of electric lighting is not preferred due to its energy consumption, being one of the several practical challenges related to the use of shading on fully glazed facades (Altan et al., 2009). Another maybe even larger problem is the loss of an outside view which is often the result of shading being fully-closed unnecessarily. A window view provides information about time and weather, decreases the feeling of claustrophobia, and can have a positive contribution to health. The positive effects and the preference of people for natural over built or urban views is shown in many window studies (e.g., Ulrich, 1984; Tennessen and Cimprich, 1995; Hartig et al., 2003; Chang and Chen, 2005). A good view should normally include the foreground and the skyline (Littlefair, 1996), but care needs to be taken to control the glaring effects of the sky.

These days, there are several reasons why shading is often closed. The layout of offices makes it possible to have many people in one room. Multiple users means many viewing directions and therefore more chance that at least one person may experience visual discomfort. In many modern office buildings, sun shading is automatically controlled. Even though the sun usually strikes only fractions of the facade, the entire facade will be closed. Often the shading is even made out of one piece of fabric, or the blinds are facade-wide. With automated shading, there is often one sensor per sun orientation which means that all shading for that single orientation will be closed at the same time. Once the blinds are closed, they usually remain closed, as electric lighting in the office room presents no immediate need to open the shading as soon as the sun is gone. Some office employees would like to open the blinds or shading for daylight or an outside view, but as some shading systems are either hard to handle or control, or the mechanisms are hard to reach, employees may still refrain from changing the shading.

The fact is that daylight contains information about time and weather conditions, which can be interesting enough to have any resulting discomfort accepted. Osterhaus (2001) reported that discomfort glare from daylight appears to be tolerated to a much higher degree if there is a pleasant view from a window causing the glare. On the other hand, if visual and ergonomic conditions are inappropriate, visual tasks may lead to physical or psychological complaints (e.g., difficulty focussing, double images, glare, headache). Interestingly, most of the reasons for closure can be easily avoided in case visual comfort criteria are met, and shading is automatically controlled based on personal requirements.

In the literature review of Galasiu and Veitch (2006) was concluded that only very few investigations have looked specifically at the issue of occupants' acceptance, preferences or satisfaction with photo-controlled shading systems. Recently, Dounis and Caraiscos (2009) emphasize focussing on the design of agent-based intelligent control systems in building environments. Multi-agent control systems (MACS) attempt to manage the user's preferences for thermal and illuminance comfort, indoor air quality, and energy conservation (Dounis and Caraiscos, 2009). Wienold and Christoffersen (2006) developed an evaluation method to assess glare from daylight that could eventually lead to a shading control system. Integrated lighting control schemes, in combination with good fenestrations products, will be needed to allow for more comfortable and cost-effective utilisation of natural light (Osterhaus, 2005).

2 METHOD

An initial conceptual detector was used to collect data in relation to entering daylight, in both the quantity and direction of the light. Measurements were made in a laboratory test room in the Netherlands, under different weather conditions. The measurements took place between January 15th and February 16th, 2009, when the sun angle was limited in the Netherlands and likely to cause visual discomfort. The outcome for both sunny and overcast days (extreme daylight conditions) was tested against available maximum luminance criteria. Human maximum visual comfort threshold criteria were investigated in the same test facility during prior research by means of a simple light sensitivity test (Aries, 2005). This information will form the basis for further analysis with an improved and more accurately calibrated discomfort detector. The current prototype has been used to assess the feasibility of such a detector.

2.1 Sensor design

The Daylight Discomfort Detector [DDD] measures illuminances distributed over six sections, each with an aperture of 30° by 30° (horizontally and vertically). Each section is provided with a Hagner SD2 illuminance photo-sensor. The sections of the DDD are numbered as shown in Figure 1 (N11 to N32). The prototype detector is made of black, mat cardboard and mounted on an also black, mat sheet. The Hagner detectors are mounted on a metal ring and the entire formation is made light-tight by means of black tape. Dimensions of the DDD are 150 by 150 mm and originate by the dimensions of a Hagner SD2 detector. The current dimensions are no issue for the first prototype measurements, but will be mineralized in future products.

In this experiment, a second, alternative photo-sensor is located aside from the DDD. This cubic unit contains six Hagner SD2 detectors for determination of the light direction (***Figure 2***). The concept of cubic illumination was originated by Cuttle (1997). Cubic illuminance describes the directional qualities of the light reaching a chosen measurement point in terms of the illuminance on the six sides of a tiny cube centred at that point.

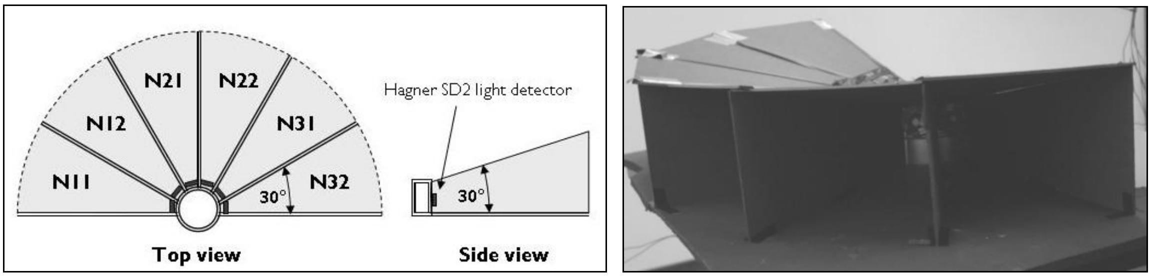

Figure 1. Daylight Discomfort Detector: schematic top and side view (left), and real-time model (right)

2.2 Test facility

The measurements took place in a daylighting laboratory located in Eindhoven, the Netherlands (51º N / 5º E). The façade of the test room faces true West. The test was conducted in the period 15 January to 16 February 2009, when there was both direct and indirect sun. The set-up (see also Figure 2) contained the following elements:

- The Daylight Discomfort Detector (first prototype), abbreviated as DDD;
- The cubic measurement device for light direction determination;
- A Hagner SD2 illuminance detector on the horizontal work plane;
- A horizontal and vertical Hagner SD2 illuminance detector near the daylight opening;
- A data acquisition equipment (16-channel Multilab TU/e-manufactured, serial number 3804 301), including software purposively written in LabView
- A luminance camera (LMK 96-2 CCD camera TechnoTeam, serial number DXP 1330), with accompanying software and data storage.

Detectors on the horizontal work plane and the detectors near the daylight opening provide information about lighting conditions in the room next to weather conditions. Figure 2 shows the entire set-up. Every five minutes, the luminance camera registered the situation, including the sky condition. During the experiments, the sensor was oriented true west, meaning that the line between sectors N21 and N22 (see Figure 1) pointed west. The experimental facility has an unobstructed view. The DDD was only slightly obstructed by a white, vertical window post (see Figure 2).

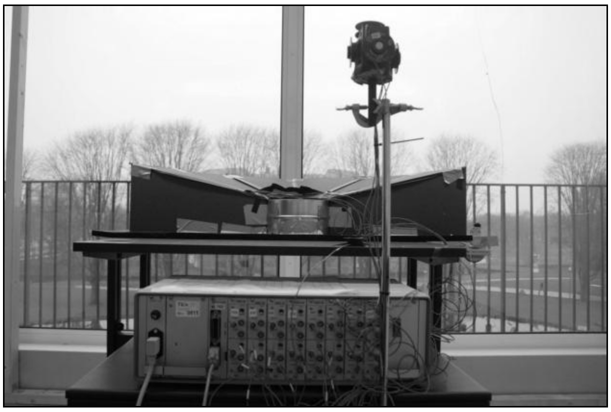

Figure 2. Measurement set-up including the Daylight Discomfort Detector, the cubic light direction detectors on the metal stand, the horizontal illuminance detector on the work plane (just right of the metal stand), the detectors near the daylight opening (partially visible on the right side of the set-up), and data acquisition equipment

3 RESULTS

3.1 Sunny day

For the purpose of this paper, January 19th was selected as representative of a typical sunny day. That this day was sunny is apparent from the results of the sensor connected to the window, but also from the cubic sensor and the sensor on the desk (see Figure 3, left graph). As the test room has a West orientation, direct sun only appears on the façade in the afternoon. In winter, this happens around 12h40 for this location in the Netherlands.

Glare will result later when the angle of the direction towards the sun with the normal on the façade becomes smaller. Measurement results made with the comfort sensor (DDD) on this sunny day are presented in Figure 3 (right). This figure shows the signals for the six viewing directions. It is clear that there are significant differences between the directions. This is especially true for the channel representing the angle between -30 and 0 degrees with the normal (green line). In this interval direct sun incidence is present, and therefore high intensities are measured. It indicates that this is the sector where glare from daylight will occur, and shows that in such situations measures should be taken to prevent glare.

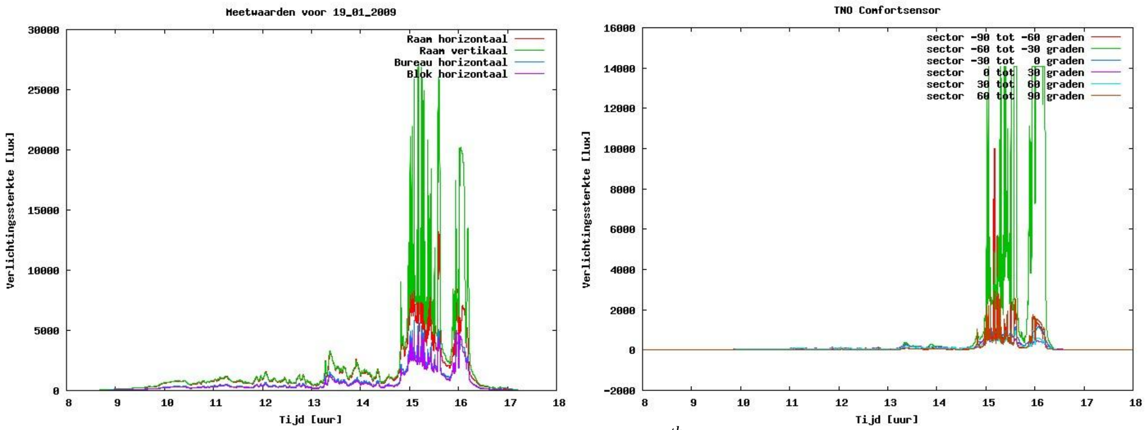

Figure 3. Daylight measurements on a sunny day (January 19^{th}, 2009), with illuminances on the glass and horizontal work plane (left), and illuminances as measured by the DDD in six viewing directions (right)

3.2 Overcast day

January 16^{th} was selected as representative of a typical overcast day for the purpose of this paper. Here daylight levels are much lower compared to the sunny day, as can be seen in Figure 4 (left). The strong variations in daylight levels are a result of layers of inhomogeneous clouds moved over each other. These variations are typical for daylight under overcast skies, but are hardly noticed by human observers. The lower luminances and the absence of a strong luminance difference both indicate that there is no risk of glare on a day like this.

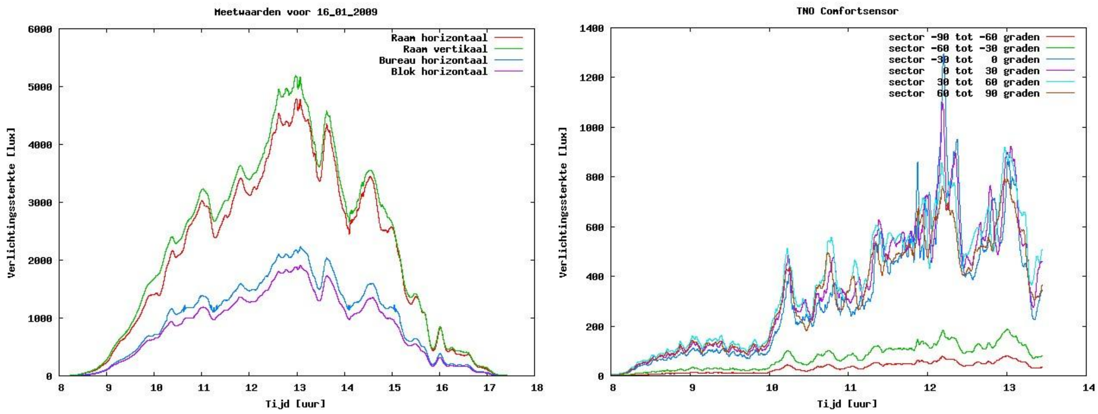

Figure 4. Daylight measurements on an overcast day (January 16th, 2009), with illuminances on the glass and horizontal work plane (left), and illuminances as measured by the DDD in six viewing directions (right). The levels are much lower with variations due to layers of clouds and variable thickness of clouds, compared to levels on a sunny day. The DDD shows no extreme peaks.

3.3 *Measurement of the direction of the incoming daylight*

Next to the Daylight Discomfort Detector measurements, measurements were made with a cubical sensor. The direction of the incoming daylight is more accurately measured with this cubical sensor. In this cubical sensor six illuminance detectors are mounted on the surface of a cube. By subtracting the signals of the opposite pairs of detectors (left from right, back from front and bottom from top) the three components of the direction vector of the daylight can be found. This vector gives both the direction and strength of the daylight at the location of the sensor. The top of the vector can be plotted (as a dot) in a three dimensional graph for each measurement. The distribution of these dots shows how the daylight is distributed.

On the clear, sunny day (January 19th) the direction of the daylight varies with the position of the sun, resulting in a spreading pattern of the direction vector (Figure 5, left). This is a second indication that a risk of glare is present in this afternoon, when there is direct sunlight available. On days like this, solar shading has to be used in the afternoon.

On the overcast day (January 16th), the direction of the daylight is perpendicular to the facade during the entire day (Figure 5, right). This shows a low glare risk. On an overcast sky the solar shading remains unused.

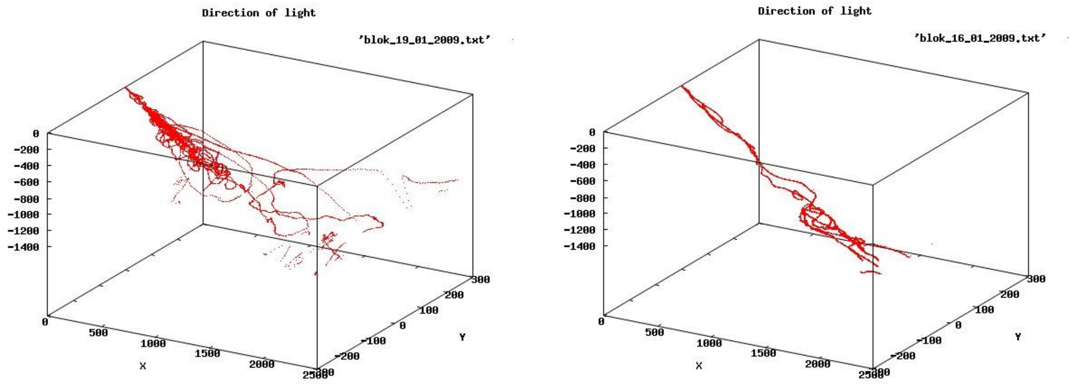

Figure 5. Direction of the daylight on January 19th (sunny sky condition) and January 16th (overcast sky condition)

4 CONCLUSION AND DISCUSSION

In this paper we investigated a simple approach to develop a sensor to assess visual comfort in the work environment. The two sensors evaluated both show a possible application in the office environment. The discomfort sensor DDD gives a direct indication of possible glare by luminance ratios, whereas the cubical sensor gives less specific information as it does not give luminance data. The advantage of the cubical sensor is the measurement of the direction of the daylight; the disadvantage is that it needs a free view in all directions. This makes its use in an office environment unpractical. The discomfort sensor, once it is miniaturised, can easily be attached to the back of an LCD display or any other suitable support on a work surface, preferably in the main viewing direction of the office employee.

This paper presents the status of ongoing research with the final objective of creating an easy to understand and easily commissionable shading control system providing maximal daylight and preventing the user(s) from glare. Continuing research focuses on sensor improvement as well as on the development of glare detection criteria. These criteria should be based on luminance ratio detection capacity in combination with human discomfort acceptance thresholds. The criteria can be implemented in software to regulate sun shading. Compared to CCD sensors, this discomfort sensor approach is relatively simple and requires less analysis and commissioning.

Human maximum visual comfort threshold criteria were investigated in the same test facility during prior research by means of a simple light sensitivity test (Aries, 2005). The aim of this test was to find an indication for the human upper (and lower) luminance limits with regard to visual comfort. Under daylight conditions in summer, test people (N=30) accepted on average a maximum luminance of 1650±680 cd/m². In winter, the accepted average luminance was significantly lower: 1390±880 cd/m² (N=16). These data can form the basis for further research with the succeeding, more accurately calibrated version of the DDD.

5 ACKNOWLEDGEMENTS

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LED/PV LIGHTING SYSTEMS FOR COMMERCIAL BUILDINGS - DESIGN OF A SUSTAINABLE LED/PV SYMBIOTIC SYSTEM

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ABSTRACT

The advantage of LED lighting is its low energy requirement: consumption of indoor lighting by LED on an annual basis can easily meet the energy produced by PV. Our aim is to develop a "sustainable symbiotic organism" which can produce its energy need for lighting and is balanced with the user's lighting wishes. We will apply an innovative approach by IDE (industrial design engineering), by considering the synergy of LED/PV for a lighting system.

The LED/PV lamp is a standalone system, thought of as a spin-off product for present or future off-grid markets in Europe: particularly referring to the idea of energetic micro-grids at the urban scale, every building being a self-sustaining organism. This scenario can be defined as an "urban ecosystem". In this likely future urban ecosystem, self-sustaining socket-products (such as a LED/PV lamp) are part and parcel of the micro-grid.

The results of our project are a quantified energy balance calculation and an autonomous lighting product that combines LED and PV technology.

INTRODUCTION

We will illustrate how an LED lighting system has been designed for commercial buildings which can be equipped with PV. In our approach we distinguish between 1) building integrated PV (systems) BIPV, and 2) building added PV (systems on the facades) BAPV [I].

IDE could play a crucial role in making PV technology fit for product applications by its focus on functionality and usability. Adding to this, LED lighting is a relatively new technology, for which reason the existing product assortment does not provide yet sufficient solutions for LED systems powered by PV.

The total energy consumption by lighting in commercial buildings is estimated to be 15-20 % of the total energy consumption due to high standards for illumination levels in offices, and the long duration of light use. Therefore it would make sense to apply highly efficient light sources (sustainable or "green" lighting) such as LEDs in commercial buildings.

Combining LED with PV has several advantages, since the technical features of PV systems match the technical features of LED (direct current, low voltage, low power). PV technology can be easily applied in the built environment, due to its modular features. The energy production on site can be seen as an advantage, but the medium energetic potential of PV in the built environment is not so high. BIPV or BAPV into fixed surfaces reduces the ability to adjust tilt angles, hence obstructing optimization and decreasing PV potential. As a consequence, small sized PV systems cannot meet the energy need for standard incandescent lamp lighting systems, but the application of LED lights could solve this issue.

This work also aims at the contemporary issue concerning the "metabolism" of urban environments, of architectures, and of products. According to the biological metaphor for sustainability, the single elements of the environment (natural or artificial) can be seen as living organisms, producing the energy they need for functioning. So, the design of a PV powered LED lamp is an attempt to experiment with self-sustainability at product scale. The PV generator (producer) and LED lamp (consumer) have to be mutually designed as if it is an unique symbiotic organism (product), that can be integrated into an urban ecosystem.

DESIGN PROCESS

The design of the LED/PV lamp is carried out in 5 process phases: analysis; formulation of a list of requirements; concept development; concept selection; detail design of a final product. Each phase will be described and illustrated in the following paragraphs

Analysis

The analysis phase takes into account costs, geographic location, technical features, and also regulations, safety directives, and other specific issues related to the project.

From the analysis phase follows a list of requirements. The requirements take into account the lamp seen as a whole product, followed by the requirements of the single technologies used for the lamp (LED and PV). Then, some choices related to other components can be made.

Based on the choice of the components, fitting the list of requirements, some design concepts can be conceived. According to some appropriate criteria only one concept for the lamp and two for the PV generator to be detailed have been chosen.

The main issues of the design process derived from the analysis phase are as follows:

The LED/PV lamp has to comply with the regulations for indoor lighting and safety guidelines for offices (e.g., Dutch case resp.: NEN 12464 and Occupational Health and Safety directive) and it must be both energy-efficient and user-friendly.

Cost of the LED/PV lamp can be considerably high, since only high quality components are selected to meet the demands for autonomy, hours of operation and, durability.

Recognisability of the product (LED/PV lamp) as a "green product" is to be taken into account, since it has to be appealing for users, interested in the green issue. This recognisability can be obtained by emphasizing the biological metaphor, in which the LED/PV lamp is a symbiotic organism, consisting of a producer (PV) and consumer (LED). The user should be able to establish a direct relationship with the "green product", to be part of the urban ecosystem, through handling the lamp by himself and to communicate its "green meaning" both inside and outside (for the public). As a consequence, we decided to focus on the design of a LED desk lamp, powered by a PV module "living" on the façades.

Formulation of a list of requirements

From the analysis a list of requirements can be developed. A summary of the main requirements of the lamp are shown in table 1.

Guidelines and directives	Color rendering index (CRI) should be ≥80 | Color temperature between 2600K and 5000K | No flickering (disturbing for people working)
Technical	10 lighting hours per day | 250lux on 1 m^2
Ergonomical	Light must be well fixed and balanced on the desk | User must be able to handle the light easily

Production	Low environmentally impact materials
Cost	Price should be kept under €500

Table 1: part of the list of requirements applying to an LED/PV lamp for office surroundings

The self-sufficiency requirement of the LED/PV desk lamp, creates an energy relationship between demand for the lighting and production of the PV generator. The find the best combination of the components, a model was created to simulate the energetic behaviour of the system considering: LEDs (type and number) suiting the right lighting features on the desk (illuminance, color temperature, CRI); PV generator (geographical location, tilt/azimuth angles, module efficiency, nominal power); battery (hours of autonomy; efficiency, technology; size); chargecontroller and DC/DC converter (both voltage, current, efficiency).

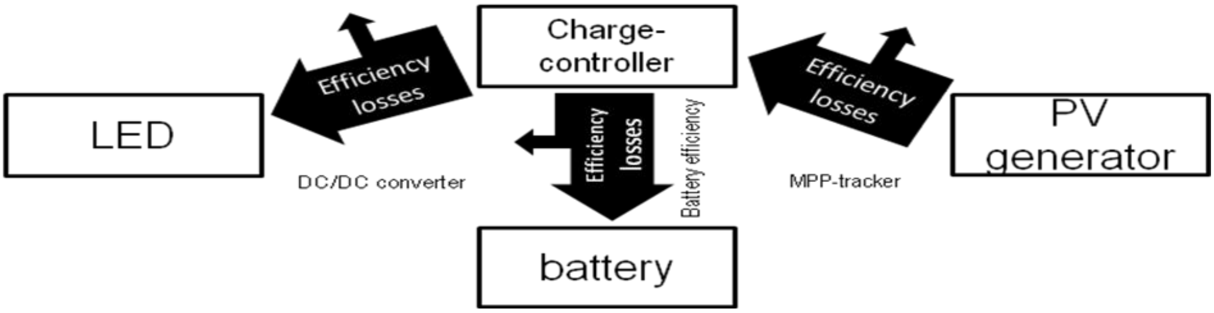

Figure 1: energy balance in an LED/PV system

Some assumptions were made with regard to the efficiency of controlling components. In particular, the efficiency of the charge controller and dc/dc converter can be respectively 90% and 85%. Taking this into account, the PV generator its nominal power has been determined, considering geographical location, tilt and azimuth angles, and module efficiency.

Small size of the PV generator is important for cost and design reasons. In particular, since the PV generator is conceived to be integrated or added into building facades, small size is not much influenced by the dimension or typology of the façade. E.g., a small façade with many windows can house a small PV generator. This condition can be considered an advantage, since in commercial buildings many desk lamps are used, and, as a consequence, many PV generator have to be integrated into the façades.

Main criteria for the battery are high charge efficiency (energy storage compared with charge losses) depending on different battery technologies, and the power density (capacity per volume). The efficiency of the battery influences the size of the PV generator, the power density influences the dimensions (physical size) of the battery. The size of the battery is influenced by days of autonomy, no-sun days and loss of load (5%), in order to allow the continuous availability of the lighting function powered by PV.

Electrical components were chosen to best fitting the highest efficiency to convert the energy generated by the PV system into light on the work plane.

Concept development

According to IDE methods, after establishing requirements and wishes, product concepts can be developed. The first choice to be made is the mutual position of the single parts of the lighting system. The product is composed of three separate elements: LED lamp (the consumer), PV generator (the producer) and battery (the storage). The concept development faces the mutual position of these elements, by using a morphological scheme (figure 2).

The position of the PV generator and LEDs with regard to the building are already established: PV need to be positioned outside (façade); LEDs are part of the lamp and need to be positioned inside (on the desk). The only element that can vary its position is the battery. So, among the solutions shown in the morphological scheme, only solution 2 (PV outside, an integrated lamp and battery inside) and 3 (an integrated PV and battery outside, and lamp inside), can be taken into account. In order to choose the best solution, essential features were evaluated of the two technologies used. In particular, solution 3 is not acceptable, since the battery would get warmer by the heat transferred from the module (higher temperatures decreases batterylife), leaving solution 2 as best choice.

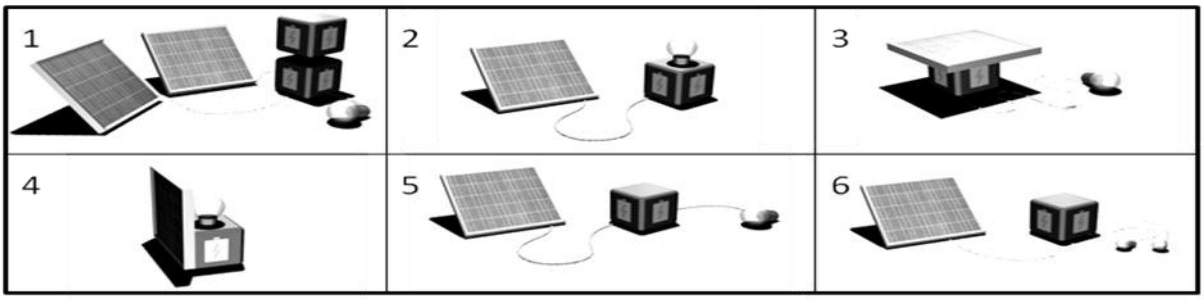

Figure 2: Six visual representations of the mutual position of lamp, PV generator and battery

After having chosen the mutual position of the three elements, (morphological solution 2), the system is reduced to two elements: LED lamp and PV generator. The design of the two elements has to be detailed considering the specific technical features of LED and PV.

For concept development of the LED lamp, essential technical features of the chosen LEDs have to be considered (e.g. production of relatively high amounts of heat, and the small size of LEDs), as well as aesthetics of the lamp. Several form studies were carried out and collages were made to get inspiration on scenarios where this particular kind of product (LED/PV stand alone lamp) can be used and three concepts were selected, as shown in figure 3.

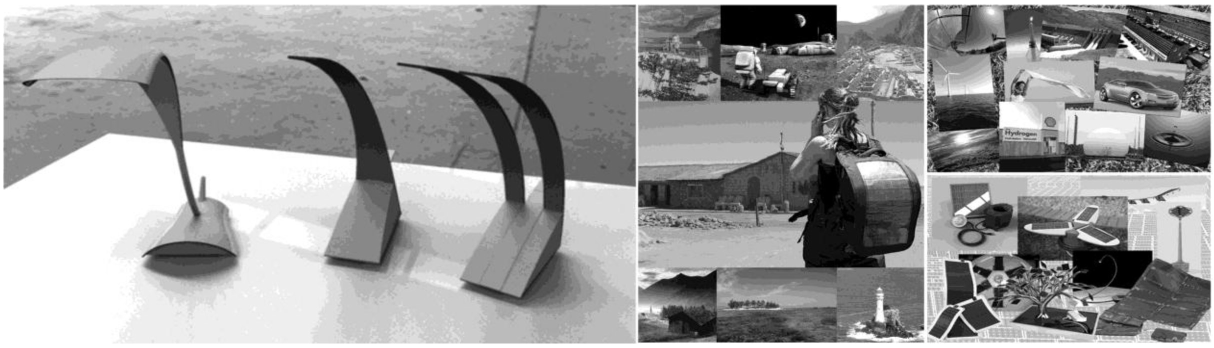

Figure 3: Three different concepts of a PV/LED desk lamp and visual collages used.

For the concept development of the PV generator, according to the design approach, the main focus is on the PV module, seen as the part of the symbiotic organism living on the building façade, converting the energy produced by the Sun into the electric energy the LED lamp can consume for lighting. So, we investigated the way the PV can "live" on the façade, and we investigated the features the PV module should have and selected three possibilities.

The first possibility is the case of commercial buildings already equipped with PV, such as façade integrated sun-shading lamellas. In this case the small PV generator can live on the façade only if it is part of the existing PV system: e.g. it might be one of the standard PV modules of the sun-shading lamellas shown in figure 4a.

The second possibility is the case of a traditional historical building, showing a "standard" façade with windows (figure 4b). In this case the small PV generator can freely live on the façade. With regard to the design of the PV generator, any shape is suitable to be added on the façade, if the preliminary requirements are met (tilt angle and size depending on technology). The PV generator can play a "media" role, if it is recognizable as an icon for sustainability, since it can communicate the public outside the building a message related to the use of "something green" inside (the "green lighting"), especially when aesthetics are considered.

Figure 4: reference buildings, 4a the ECN building in Petten, the Netherlands; 4b the Andy Warhol Museum in Pittsburgh, USA; 4c Federation Square building in Melbourne, Australia.

The third possibility is a building showing a contemporary façade. In particular, the façade shown in figure 4c is conceived by means of fractal geometry, which was first formalized by Mandelbrot (1982) and allows to represent irregular objects. In this case the small PV generator can live on the façade only if it has been conceived as a fractal module, matching the fractal geometry of the façade. Since in our discussion this building represents the likely future evolution for façade, it can be seen as an example of buildings living in a future scenario of an urban ecosystem. According to this vision, the fractal façade could be morphed into a PV façade itself, powering the building operation, but it still makes sense considering the LED/PV lighting as an autonomous symbiotic organism living on the façade, since it is coherent with the idea of the urban ecosystems with small energetic grids.

FIRST RESULTS

In the analysis phase we chose to experiment with the design of the lamp for two geographical sites (Twente in the Netherlands, Naples in Italy). After the concept development we selected a concept to be analyzed in detail for the lamp (figure 5b), and two concepts for the PV modules (figure 5a).

With regard to the lamp, this concept was chosen considering aesthetics, producibility, functionality and some other criteria. With regard to PV, we conceived two different PV modules (the first one using available technology, the second one using innovative technology) to be added on the traditional façade or on the fractal façade (figure 5a).

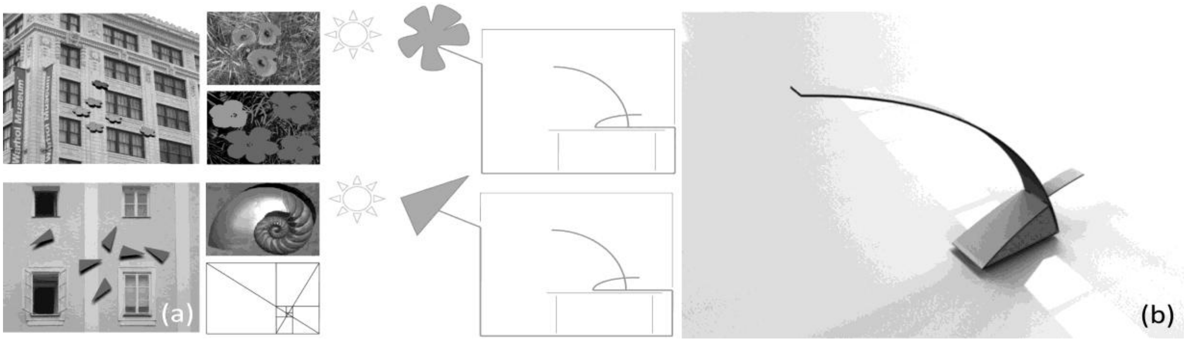

figure 5: 5a façade impressions and the relation with the chosen concept 5b of the lamp

For the first PV module design, we took inspiration from the famous poppy-flowers by Andy Warhol. The reasons for this choice are related to the possibility to use a PV module resembling the Andy Warhol poppy-flower. This flower works as an urban icon for the building and as a symbol of the green issue (an image of nature morphed into an artificial recognizable image). The petals could house standard crystalline PV cells for a nominal power of about 11Wp, suitable for the LED/PV lamp in Naples.

The second PV module is designed as a fractal module matching the fractal façade shown in figure 4c. The use of fractal geometries for PV can be considered a good option for the future, since in the field of Architecture fractal surfaces are being more and more used, because this geometry supports architects in conceiving buildings which are intrinsically sustainable, since their forms are based on the same shapes of nature. [III, IV] The fractal module (innovative in terms of shape and technology) can be used also on traditional facades, since in this case it can be a single decorative element to add on the façade or to be used in a free composition.

CONCLUSIONS

The LED needs to be a commercial available, high efficient LED, allowing 250lux on 1 m^2. This led to the choice of one with 90° emission angle, positioned 60cm above the work plane, meeting requirements for color temperature, CRI and task illumination for office surroundings. Efficacy of the chosen LED is 70lm/W (without considering the likely losses due to the controlling components). compared with incandescent lighting (8-23lm/W) and (compact) fluorescent lighting (50-100lm/W) this is very good.

To minimize the size of the PV generator, the design process was aiming at optimization of the energetic production. Since producibility depends on both placement (i.e., the azimuth and tilt angles) and technical features of the photovoltaic modules, some choices have been made.

In particular, the azimuth angle has been fixed to be 0°, and the tilt angle has been optimized to collect the maximum available solar energy in Winter to fulfil the energy demand for the lighting needs. With regard to the tilt angle, the energy demand for light is the same all over the year (10 hours/day) but the available energy for PV production varies. Lowest values of irradiation are seen in Winter (meteorology and solar energy parameters given by NASA) [II].

Simulations carried out to evaluate the energy balance of the system, show that the LED/PV lamp is suitable for the Mediterranean area (11Wp) but not for North Europe (47Wp) since the PV generator and battery size would be too large to meet days of autonomy requirements.

where a grid-connected BIPV system already exists, it does not make sense using the autonomous LED/PV lamp, since the “green” electric energy is already available (also for “green” lighting). For traditional buildings without PV, the proposed LED/PV lamp could turn the building into a BAPV, with appealing modules. For contemporary or future buildings, innovative modules could be used as BIPV. The LED/PV lamp is an experience with self sustaining appliances, since generally in the estimation of the energy balance, small appliances are not taken into account, since they depend on the user's behaviour.

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CLIMATE-BASED EVALUATION AND DESIGN OF CYLINDRICAL LIGHT TUBES

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ABSTRACT

Daylighting is traditional renewable energy technology. Visual comfort in buildings is also one of the main demands for quality and well-being of indoor environment in buildings. Tubular light guides serve opportunity to enhance daylighting of interiors. These simple daylighting devices are based on the principle of light transport from outdoor to distant indoor places due to multi- reflections on their highly reflective internal surfaces.

To predict the internal illuminances levels of any daylight system it is necessary to know the available daylight and the transmission of light through the system under different daylight conditions. Intelligent daylight harvesting presupposes detail knowledge of the basic characteristics of light: quantity, spectrum, distribution, timing, and duration. The purpose of the work was climate-based analysis, evaluation and practical design of cylindrical light tubes which reflects above mentioned basic characteristic of daylight.

Numerical and experimental analysis of light tubes was carried out to predict their light efficacy. Simulations were based on the photon maps method. The results of simulations were experimentally tested under the artificial sky. Evaluation method of internal illuminances with light tubes of various length and diameters is based on the Bratislava Daylight Reference Year (DRY). The DRY of Bratislava is valid for many regions in Central Europe.

Simplified standardised design tool was adapted for the evaluation of indoor daylighting in rooms illuminated from tubular light guides. This tool allows assessing of annual variation of average internal illuminances of rectangular spaces from light tubes and also can be used for prediction of artificial lighting. Internal illuminances can be predicted in any time of the year or on average monthly basis.

INTRODUCTION

Seeing that light tubes have been manufactured just for 30 years, research of their properties is still being developed and large amount of research targets are being made all over the world. The interest in these daylight devices has increased at the side of researches and users and there have been many questions connected to utilization possibilities, design criterion and economic task of light tubes.

Large number of mathematics models and experimental studies of light tubes evaluation have been generated mainly during last two decades. These experimental and theoretical methods were usually made for specific configurations and local daylight conditions. Therefore most of achieved data could be used just for similar systems and daylight conditions. Even though, these studies have given the proof of specialists´ interest in these systems and the necessity to deal with problem of daylight transmission through these devices. The assessment of light tubes consists of two main parts, i.e. estimation of amount of light leaving the tube (light tube efficacy) and analyses of light arrangement into internal space. Variability of daylight conditions should be taken into account.

THE METHOD OF TUBE DAYLIGHT TRANSMISSION EFFICACY PREDICTION

Light tube efficacy is defined as a ratio of luminous flux leaving the tube to internal space and luminous flux entering the tube. Light tube transmission efficacy depends on geometrical parameters (length and diameter of the tube), reflectance of internal surface and climate conditions (sun altitude). As daylight conditions change, light tube efficacy changes with them. Simulation program Radiance [1] combined with photon map algorithm [2] was used to assess the tube transmission efficacy. The efficacy was subsequently calculated by hand calculation according to simulation results.

Radiance, presently well established program in the research community, based on backward ray tracing method and enables accurate and physically valid lighting and daylighting simulations. However, developments in light redirecting materials have caused new challenges in their simulation, their specular nature makes them difficult to simulate with backward nature of Radiance, often merely resulting in a noisy results. Particularly the phenomenon of caustic (i.e. bright, iridescent highlights on surface cause by specular reflection or refraction) causes a serious problem for this simulation approach. Traditional backward ray tracing method do not account for all kinds of indirect illumination in investigated model. This is the reason why photon map algorithm [2] was used as a supplement to Radiance to achieve realistic model of light tube.

Simulation was divided into two parts. The first part was made for direct sunlight condition and the second one was made for diffuse light conditions (CIE standard overcast sky). Entire model inserted into Radiance consists of the tube with diameter (d = 0.2 m – 0.8 m) and length (l = 1 m – 5 m) lined by material with high specular reflectance (ρ = 0.94 – 0.99) with different sun altitudes (h_s = 30° – 60°) in the case of direct sunlight. The flat diffuser was placed at the bottom of the tube. Combinations of mentioned parameters (d, l, ρ, h_s) were selected randomly, whereby just one parameter was being changed every time.

The point scanner was placed above the top of the tube to record the illuminance entering the tube. Illuminance at the end of the tube (above diffuser) was computed as an average illuminance E_p with the use of the illuminance picture of tube´s bottom, i.e. parallel view of the diffuser with resolution 64 x 64 pixels. Illuminance of each pixel was recorded and resultant illuminance was calculated as an average value . Pixels creating ´black corners´ (i.e. with zero value of illuminance) were left out from the calculation. One example of rendered illuminances picture could be seen in Figure 1.

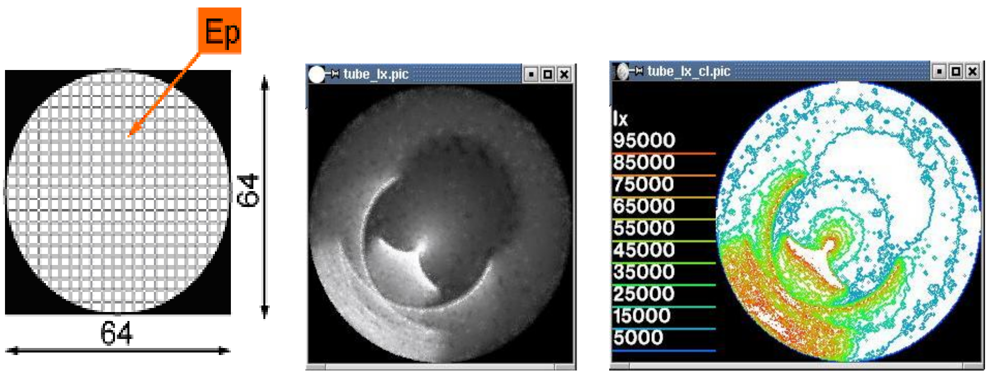

Figure 1: Parallel view of the upper part of the diffuser – scheme of generated picture (64 x 64 pixels) (left), rendered picture (middle) and illuminance isolines (right)

The light transmission efficacy η_t was then calculated as the ratio of average internal illuminance E_p on the top of the diffuser and horizontal illuminance (direct or diffuse) entering the light tube. The reliability of simulation program results was experimentally tested under the artificial sky, which represented CIE standard overcast sky with steep luminance gradation towards zenith (Figure 2).

Figure 2: Experimental measurement of light tube transmission under the artificial sky

Following calculations are made for diffuse light conditions in order to assess united calculation method for preliminary evaluation of daylight illuminance of internal space and in order to join the method with the practical method of artificial light evaluation. According to the simulation results, the equation (1) was derived (by the use of non-linear regression) in order to get data of tube transmission efficacy of light, which correspond to the range of simulated data. Average deviation between η_t computed according equation (1) and simulated data was stated as 5.37 %.

$$\eta_t = -0{,}26152 + 0{,}17333\ .\ \sin(\ln(5{,}82691.\mathrm{d})) + 0{,}377\ .\ \mathrm{e}(\rho^8) + 0{,}07899\ .\ \sin \mathrm{l} \qquad (1)$$

All achieved results are valid just for the tube transmission efficacy and not the efficacy of overall daylight device. The dome and the diffuser were not included in this part of calculation (the transmission factors of the dome and diffuser change with the type of dome and diffuser, i.e. according to used material and shape). Equation (1) was afterward used in the evaluation method of daylighting from light tubes presented below.

THE EVALUATION METHOD FOR ILLUMINANCE PREDICTION OF INTERNAL SPACES WITH LIGHT TUBES

From practical reasons we adapted European normalised method for average illuminance of working plane [3], also known as zonal cavity method. The aim of this work was to utilize the daylight climate data from Daylight Reference Year of Bratislava [4] and assess the illuminance of the working plane of the spaces illuminated by vertical straight light tubes in dynamic daylight conditions. Data of DRY were statistically processed to reach the form which is easy to use. Average illuminance data calculated by the use of this method were subsequently compared with the results made by simulation program Radiance.

The DRY was made following IDMP (International Daylight Measurement Programme) with using measured data for 8 years (from 1994 to 2001). This year represents the climatic conditions of Slovakia (Bratislava) the most and it is valid for many regions of Central Europe. DRY consists of 5-minute average data of global and diffuse horizontal illuminance and irradiance, zenith luminance and solar altitude, Linke's turbidity factor, luminous turbidity factor and relative sunshine duration. This data were calculated according to one minute instantaneous measurements at IDMP Station Institute of Construction and Architecture –

ICA SAS, Bratislava (48°10´N, 17°5´E). DRY also includes daily graphs of global and diffuse illuminance courses and CIE General Sky [5] occurrences (in percentage) typical for each day of the year, i.e. predominant sky-luminance distributions over Bratislava identified by the use of 15 theoretical sky standards.

Data from DRY were statistically processed into diagrams of diffuse and direct horizontal illuminance. So it is possible (by the use of relative sunshine duration data) to assess the illuminance within particular hour (Figure 3, 4). According to the analysis mentioned above, the tube transmission efficacy of daylight is not significantly depending on sun altitude and it is possible to work with global horizontal illuminance in the case of preliminary evaluation. Global illuminance data (Figure 5), also made according to statistically processed DRY, could be subsequently used for practical purposes as the input data into calculation method for average illuminance assessment of internal spaces with light tubes. Isolines of global illuminance could be used to assess the indoor illuminance all the year round.

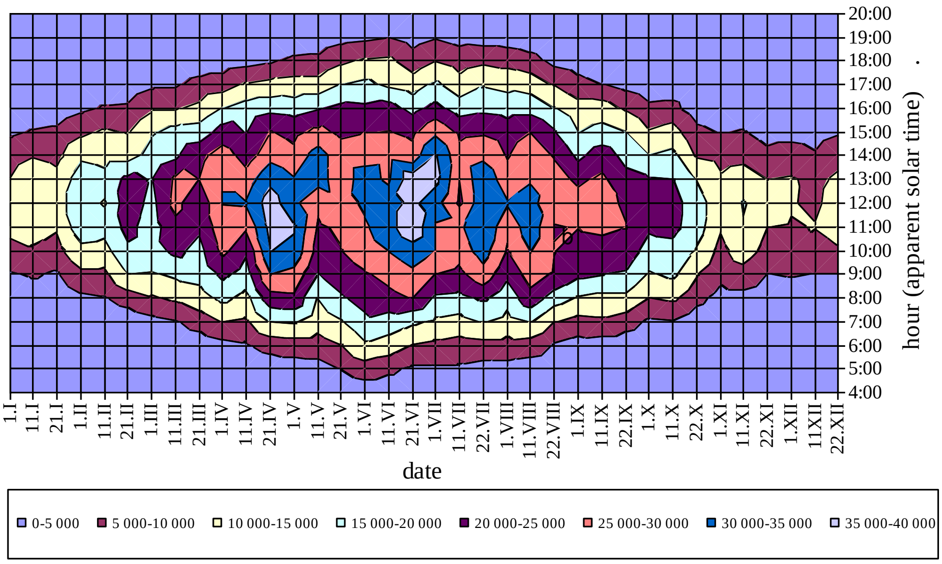

Figure 3: Diffuse illuminance isolines for all year round in Bratislava

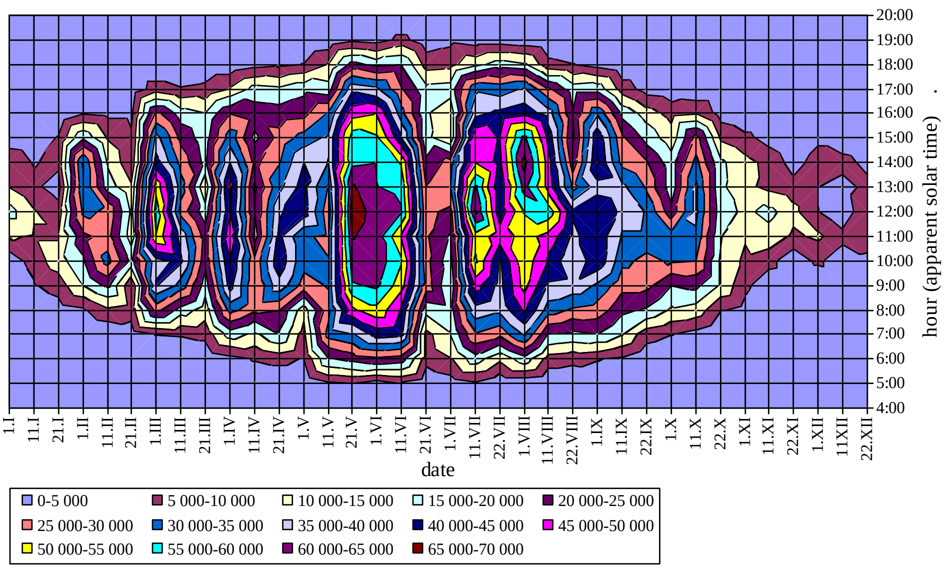

Figure 4: Direct illuminance isolines for all year round in Bratislava

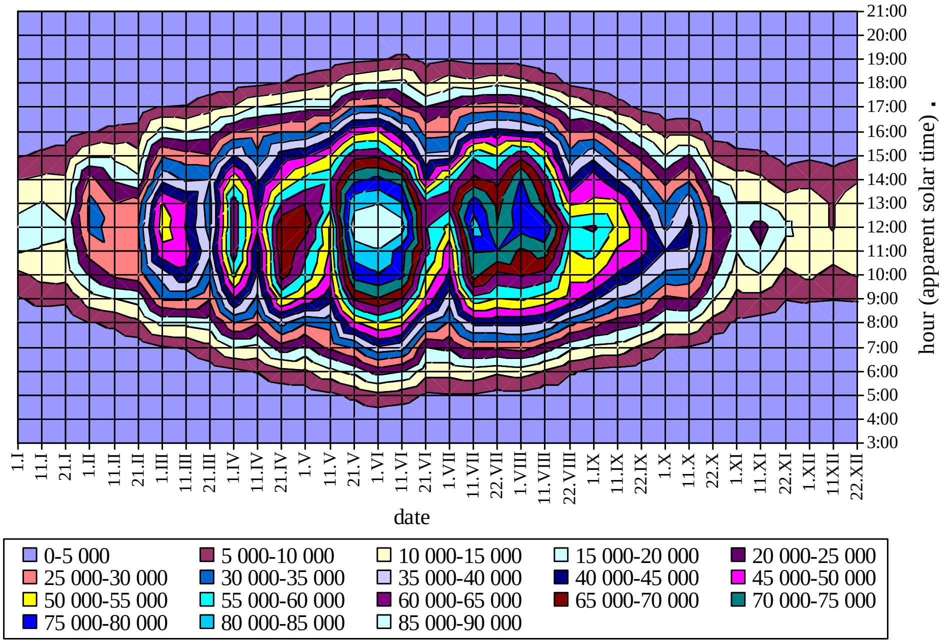

Figure 5: Global illuminance isolines for all year round in Bratislava

Data of the DRY were also statistically processed into monthly diagrams of percentage occurrence of global horizontal illuminance. Resulting diagrams represent the time (in percentage) of certain month when global illuminance is being above the chosen level (illuminance levels were divided into 5 000 lx bands). An example of diagram for April is presented in Figure 6.

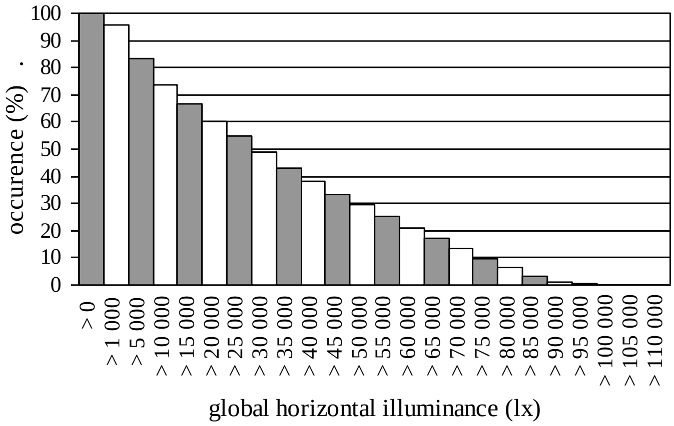

Figure 6: Percentage occurrence of global horizontal illuminance in April in Bratislava

Illuminance prediction

Zonal cavity method according [3] should be used as a tool in particularly uniform settings of luminaries if a simple, rough technique of illuminance quantification is desired. This method is based on outgoing luminous flux, luminous intensity curve, space geometry and surface reflectances. Assessed space is empty, rectangular in shape and working plane is considered to be solid and calculated as other surface in the space. Every surface in the room (ceiling, working plane, walls) reflects light uniformly into the space according to Lambert law. Light sources are regularly placed on the ceiling or suspended in light sources plane in particular distance from the working plane. Internal average daylighting on the working plane of rectangular room can be calculated following the equation (2):

$$E_p = \frac{n \,.\, E_g \,.\, A_d \,.\, \eta_t \,.\, UF \,.\, \tau}{A} \tag{2}$$

where

n is the number of light tubes;

A_d is the area of the diffuser (m^2);

η_t is the tube transmission efficacy of light, calculated according to equation (1) (-);

UF is utilization factor for working plane, calculated according to EN 13032-2 (-);

τ is the light loss factor, calculated according to CIE 173:2006 [6] (-);

A is the area of working plane (m^2);

E_g is global horizontal illuminance (lx).

Proposed simplified calculation method works with absolute photometric units and can be used for design of straight tubular daylight guides and integrated natural and artificial lighting in common internal spaces.

CONCLUSION

This evaluation method was proposed to enable the assessment of spaces illuminated by light tubes by the use of statistically processed Bratislava Daylight Reference Year. Results of the method were compared with results of simulations (Radiance) with the use of photon map algorithm, whereas the results of simulations were experimentally tested under the artificial sky. This simplified calculation tool allows assessing of annual variation of average internal illuminances of rectangular spaces with light tubes and also can be used for prediction of artificial lighting. Internal illuminances can be predicted in any time of the year or on average monthly basis.

ACKNOWLEDGEMENTS

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EFFECTS OF AUTOMATICALLY CONTROLLED BLINDS ON VISUAL ENVIRONMENT AND ENERGY CONSUMPTION IN OFFICE BUILDINGS

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ABSTRACT

The desirable control of automatically controlled blinds for energy conservation in office buildings by solar-shading and daylighting was investigated through questionnaires, preliminary experiments, measurements using a two-dimensional color analyzer, and simulations. Based on the results of these investigations, it was shown that an appropriate control of blinds could provide a more comfortable visual and thermal environment and large energy savings by shading solar radiation, making efficient use of natural light, and managing the changes of external light environment. It was also indicated that a proper introduction of daylight was not directly related to an increase in air-conditioning load, but on the contrary, energy saving could be expected by the synergistic effect due to the reduction of illumination power and cooling load.

1. INTRODUCTION

Recently it has become popular for the façade of a building to be made entirely of glass, and high-performance window systems such as air-flow, double-skin and others have been adopted for the purpose of improving energy saving and a pleasant indoor environment. In such window systems, solar irradiation is generally shielded by automatically controlled blinds, however at present the control tends to be focused exclusively on shielding sunlight.

The purpose of this study is to describe how to improve not only energy efficiency but also the internal environment by reducing the cooling load caused by solar radiation, reducing lighting energy by introducing daylight and managing the changes of external light environment using the transparency of the windows.

2. REQUIREMENTS OF OFFICE WORKERS CONCERNING AUTOMATICALLY CONTROLLED BLINDS

Figure 1: Western façade of the building.

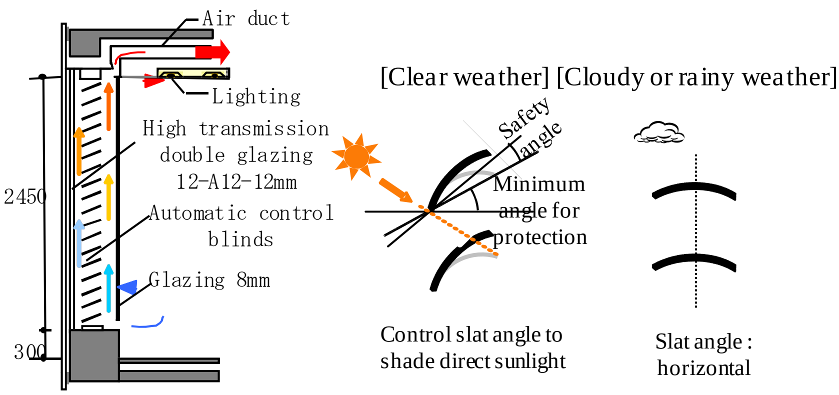

Figure 2: Cross-section of window.

2.1 Buildings to be surveyed

In order to examine office workers views concerning office windows, a survey was carried out in a super-high-rise building (Fig. 1: Tokyo, 30 stories, approx. 180,000 m2) which has many windows facing west. This building is equipped with air-flow windows with automatically-controlled blinds (Fig. 2). The protective angle of the blinds is controlled at 20 minute intervals to prevent direct sunlight, above a threshold value, from coming through into the working area. The control takes into account the calculated values of solar altitude, azimuthal angle and level of illumination of direct sunlight which is detected by an illumination detection sensor set up on the roof of the building.

2.2 Results of the survey

On most days the blind slats set in the windows facing west are totally closed for a relatively long time before sunset. However, when we proposed that a control system by which the office workers could feel the change of time of day or the weather and the change of season could be introduced, more than 70 % of the office workers supported the idea as shown in Fig. 3. In reply to the survey, most of the respondents chose such expressions as “It gives a feeling of openness;” “It will broaden our view;” and also “It makes us feel the change of weather;” “It gives us a sense of passage of time;” and “It gives us a feeling of better mental and physical health.” Obviously it seems that they have a desire to bring the outside environmental changes inside. In the past, keeping a uniform and homogeneous indoor environment was considered to be the appropriate policy. However, this survey suggests that the office workers’ sense of comfort and degree of satisfaction will be improved by introducing an awareness of changes in the outside world. In order to respond to these desires, it seems appropriate to provide a feeling of openness by keeping the blinds open by applying an appropriate blind control so long as it does not cause problems for the office workers, and also to reflect changes such as a sunset glow to the indoor office.

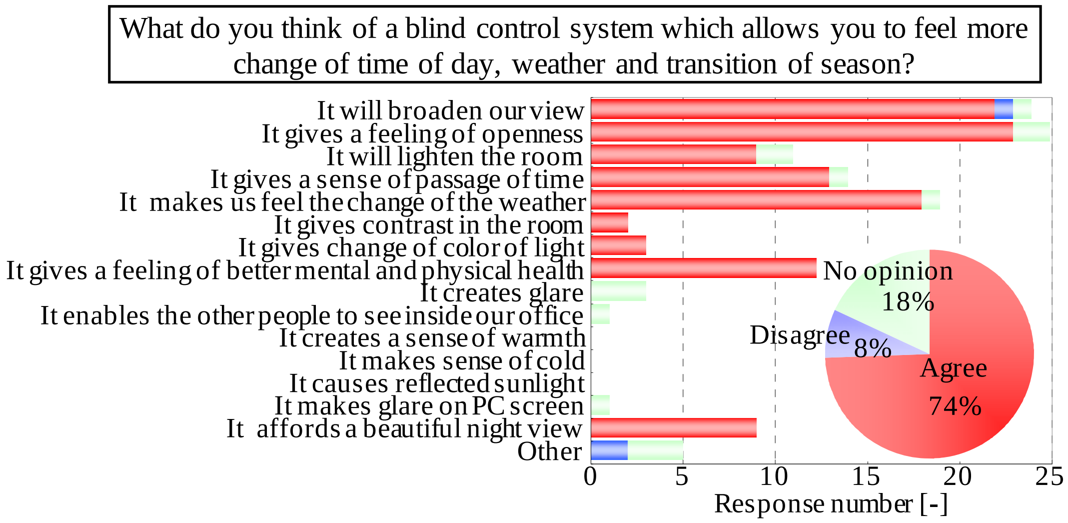

Figure 3: Results of questionnaire survey.

3. INVESTIGATION OF CRITERION FOR JUDGMENT OF SHIELDING SUNLIGHT ACCORDING TO THE RESULTS OF ANNUAL SOLAR IRRADIATION DATA

Figure 4 shows a histogram of illumination level of direct sunlight plotted against time through 2007 as actually measured on the roof of the building. Even in daytime, the illumination level is less than 500 lx during about half of the total time, and it is evident that the blinds can be opened for a long while even when the sun is located in a position where sunlight would hit the windows. According to our studies so far, it is appropriate to set a criterion for judgment of sunlight shielding (hereafter referred to as the threshold value) of about 1500 lx, but because the fraction of the time when the illumination level is 1000～2000 lx is quite small, the influence of the difference of the criteria on the result of blind control will be relatively small.

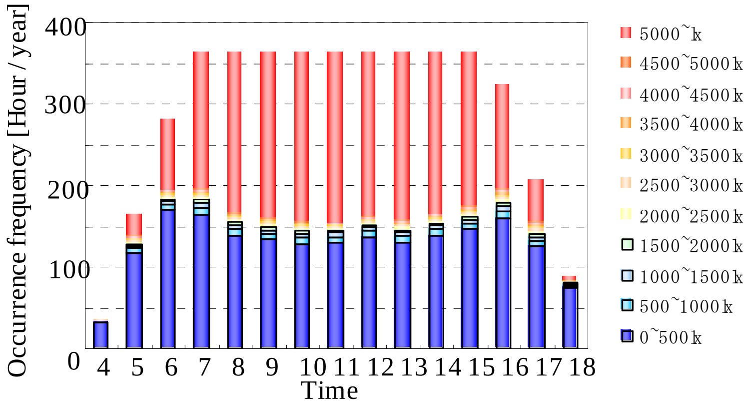

Figure 4: Histogram of illumination level of direct sunlight in daytime.

4. INVESTIGATION OF OPENING CONTROL IN THE EVENING

Opening control in the evening means keeping the blind slats in the horizontal position or curling up the blinds for a specific time so people can look at the beautiful sunset colors just before sunset. We investigated to what extent people tolerate dazzle which may be caused by the setting sun where the solar altitude is low, and what criterion must be established in order to realize proper control. Furthermore, the indoor light environment including color shade, in the case where the blinds are retracted in the evening was examined by actual measurements.

4.1 Investigation of threshold value

As shown in Fig. 5, we asked student subjects to stand facing south in a room with the opening in the west window, and asked them to estimate how dazzling the evening sun was. Figure 6 shows that after the illumination level of the direct sunlight dropped to about 2300 lx at 16:25, the frequency of the" no dazzle" response increased, and when the illumination level fell to about 1200 lx at 16:29, none of the subjects expressed concern over dazzle. Based on these facts, we concluded that the threshold value for opening the blinds in the evening should be about 1000 lx～2000 lx.

Figure 5: Subject experiment for threshold value.

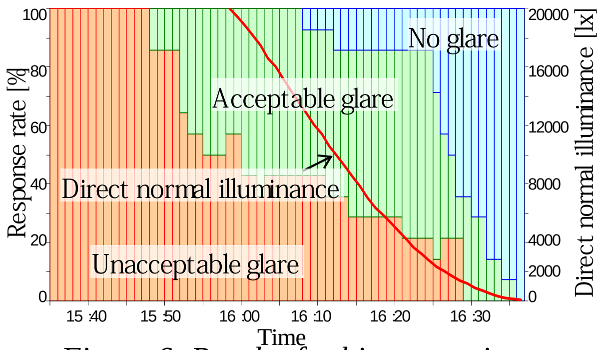

Figure 6: Result of subject experiment.

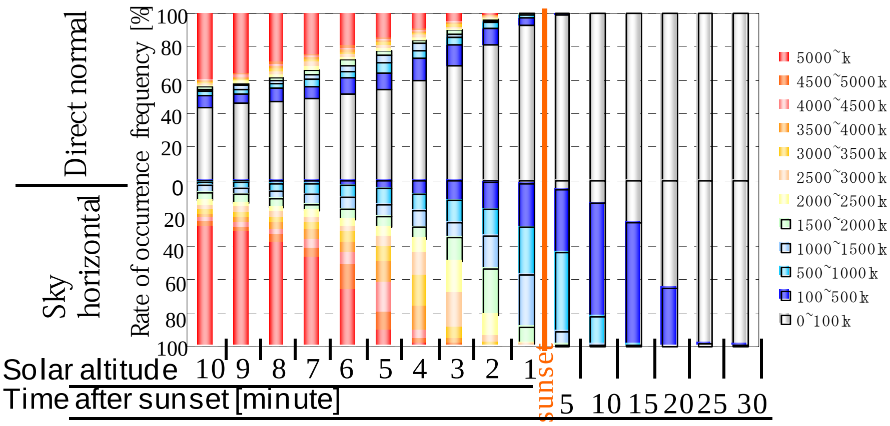

Figure 7: Change of sunlight around sunset.

4.2 Changing process of direct sunlight and diffused illumination in the evening

Referring to the above mentioned results of measurement of annual solar irradiation, the frequency when the illumination level of direct light is about 2000 lx was examined. It can be seen from Fig. 7 that when the solar altitude becomes less than 2 degrees (about 10 minutes before the sunset), the proportion of the illumination level which is lower than 2000 lx is greater than 95 %, so controlling the illumination by setting the ordinary protective angle horizontal and at the same time letting the blinds retract could be a proper way to afford outside view. It is also evident that even after sunset brightness can be maintained by diffused light for 10～15 minutes.

4.3 Distribution of color temperature by the light transmitted through window area

Many white globes made of white foam polystyrene were located within the study room as shown in Fig. 8, and spatial distribution of light was detected by measuring both brightness of the surface of the white globes and color temperature by a two-dimensional color analyzer (Fig. 9). By using the measuring apparatus, it is possible to know the distribution of measured values as a graphical image as shown in Fig. 10. If we select an arbitrary evaluating area (Fig. 11), it is possible to extract the average value of the data of that area. Pixel data in the window side were extracted to obtain the results.

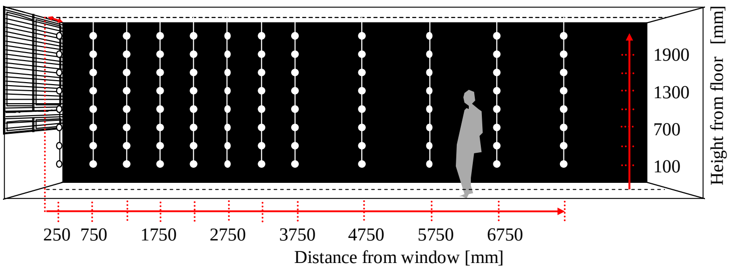

Figure 8: Sectional layout of white globes in the study room.

Figure 9: 2D color analyzer.
(KONICA MINOLTA CA-2000W)

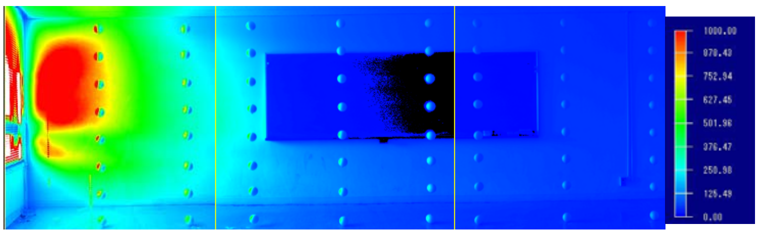

Figure 10: Spatial distribution of radiance of white globe.

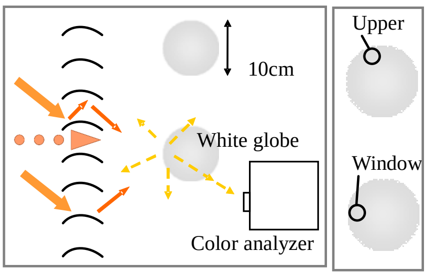

Figure 11: Measuring procedure of spatial distribution.

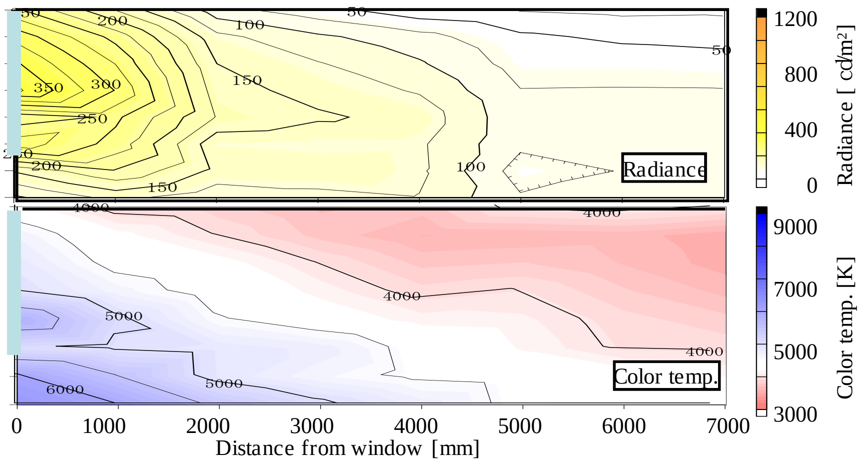

Figure 12: Spatial distribution of sphere radiance and color temp. at daytime and in the evening.

Spatial distribution of brightness and color temperature when the blinds are retracted (17:00) is shown in Fig. 12. Brightness decreases as the distance from the window area increases. Color temperature also decreases as the distance from the window area increases, and at the window it decreases as the distance from the ceiling decreases. This is due to the fact that as the evaluation area approaches the window, the fraction of diffused light, which has a higher color temperature than direct light, increases and in the vicinity of the ceiling the diffused light is interrupted by the protective effect of eaves.

4.4 Investigation in consideration of working environment

Intensity and direction characteristics of transmitted light through the window on sunny days when white blinds are simultaneously used were measured using the apparatus equipped with the integration sphere (Fig. 13), and the results are shown in Fig. 14. It is evident that as slat angle increases, the intensity of transmitted light decreases and the fraction of upward light increases. In cases where the slat angle is the same, as the solar altitude comes down and as more light is irradiate on the surface of the blinds, the above-mentioned fraction increases. These results of actual measurements can be used in the following simulation.

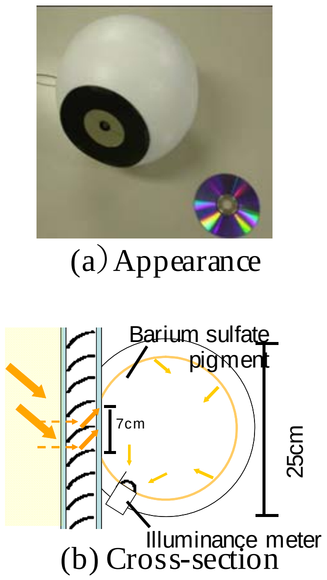

Figure 13: Proposed integral sphere.

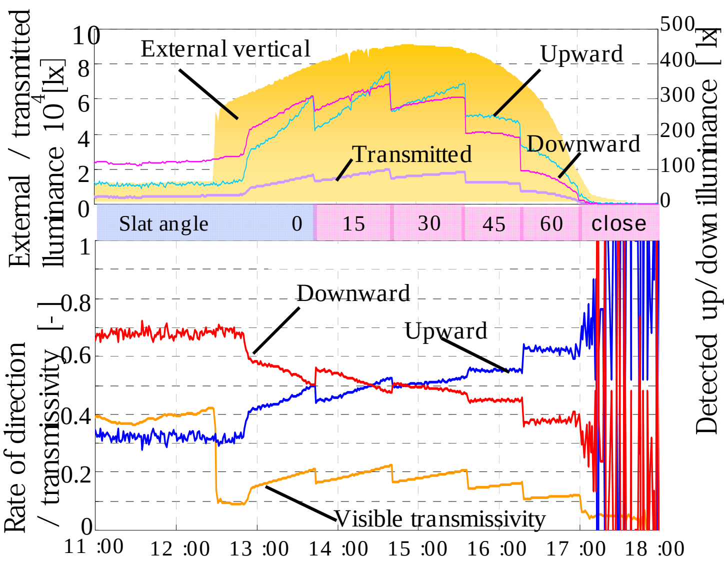

Figure 14: Intensity and ratio of upward / downward of transmitted light through windows.

Figure 15 shows the indoor color temperature as a function of time, assuming that required intensity of luminance on the desk is 750 lx and the short fall in illumination is offset with artificial light (fluorescent light, daytime white color: color temperature 6000 K). Color temperature data for both artificial light only and natural light only are also shown for comparison. When black blinds are used, the influence of artificial light is relatively large especially after 14:00, and the quality of natural light taking on a red tinge is not transferred, while the value is changing in parallel to that of natural light in the case where white blinds are used.

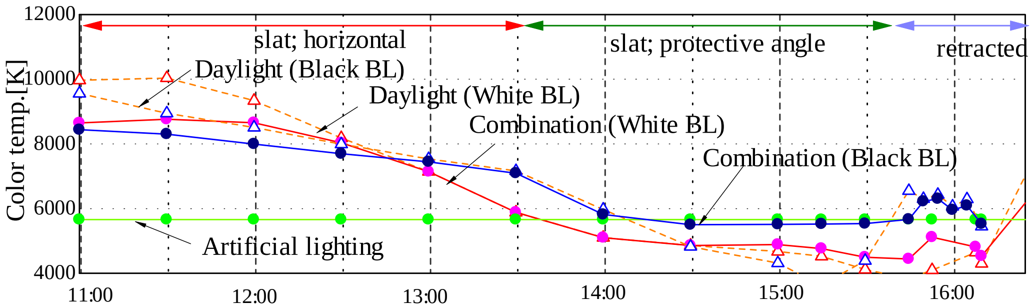

Figure 15: Change of color temp. in the office.

Figure 16 shows the spatial distribution of color temperature in the case of protective angle at 15:30. When bright colored blinds are employed, it became clear that a tinge to the natural light is introduced and more so as the point of measurement approaches the window. Based on the facts mentioned above, it seems appropriate to choose bright colored blinds not only for introducing daylight, but also for fully reflecting the change of tinge of natural light to the indoor environment. By combining the dimming control technique, tinge of natural light can be introduced to the room even when the slats are kept to the protective angle.

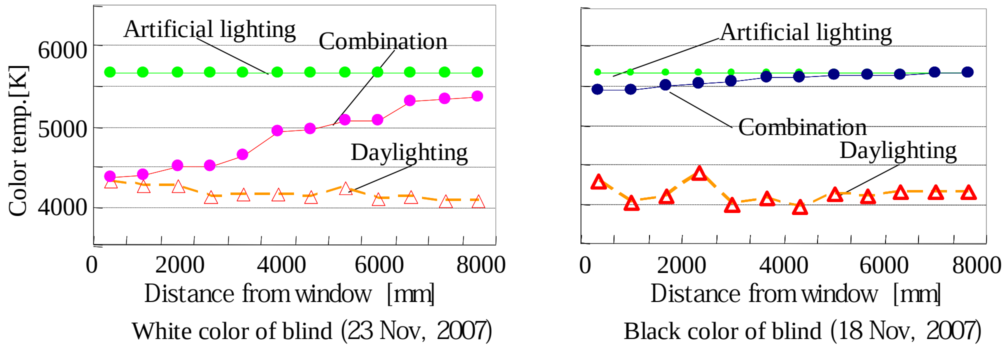

Figure 16: Influence of color of blinds on spatial distribution of color temp.

5. INFLUENCE ON AIR-CONDITIONING LOAD AND LIGHT ENERGY

So far the effectiveness of specifications and control system of blinds to introduce natural light in a positive way has been emphasized, but attention must also be paid to the increase of energy consumption due to the introduction of natural light. Figure 17 shows the calculated values of the annual air conditioning load and energy consumption for illumination assuming a general office building. Specification of windows was examined with regard to blind color and automatic controlling for each time interval. Weather data, solar irradiation and illumination level at time intervals of 1 minute were used. It became clear that a proper introduction of natural light is not directly related to an increase in air-conditioning load, but on the contrary, energy saving can also be expected by the synergistic effect due to the reduction of illumination power and cooling load.

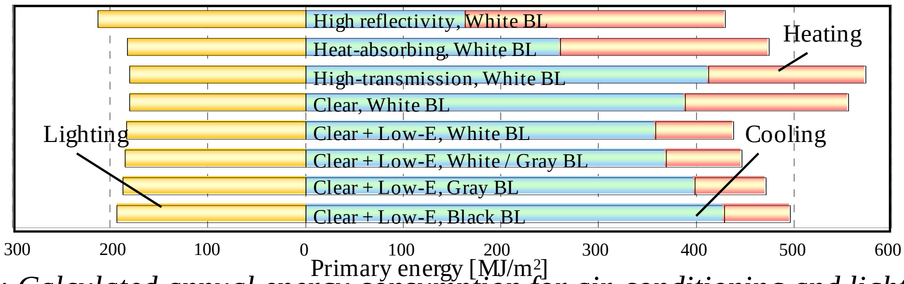

Figure 17: Calculated annual energy consumption for air-conditioning and lighting.

6. CONCLUSION

It has been quantitatively shown that changes in natural light can be fully reflected to the indoor environment even when the solar irradiation is shielded, and it has been verified by simulation that such a control system, in which the problem of energy saving is taken into consideration, can be used in practice.

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USER ASSESSMENT OF A NEW INTERACTIVE GRAPHICAL VISUALIZATION FOR ANNUAL DAYLIGHTING ANALYSIS

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ABSTRACT

Despite the abundance of daylighting design software, there are few tools which focus on annually comprehensive and climate-realistic data, and fewer which give performance as a function of time. Lightsolve, a tool under development, emphasizes the importance of full year, climate specific data in early stage daylight design. It performs a representative group of annual simulations based on TMY2 data and graphically displays the results using both temporal maps and spatial renderings.

With any new method, it is critical to determine if the intended audience finds it more useful than existing methods. Therefore, two user surveys were given. The first was given to practitioners and students attending a daylighting design workshop at MIT in January of 2009. Participants were taught to use both Lightsolve and Ecotect (with exports to Radiance and Daysim). The aim of this survey was to help validate the usefulness of Lightsolve's temporal approach and the intuitive nature of the temporal maps, and to observe architects' interaction with the software. Because of the limited number of responses, a different stand-alone survey comparing spatial and temporal daylighting data was given, mostly to student architects, in May of 2009. The aim was to judge how intuitive temporal data was to the inexperienced architect. This paper presents the findings of both surveys.

INTRODUCTION

There are many daylighting analysis tools, but few are both graphically intuitive and analytically comprehensive. Most available tools produce either renderings or numerical data for a single moment in time, a situation which is too specific to be of use to the designer and too time-costly to apply to annual analysis. Of those few which take annual data into account, none show the user how daylighting performance varies over time.

Programs like SketchUp and Ecotect have the ability to display time-lapsed shadows, and AGI32 can arrange sequences of the same image over multiple days or hours, but while interesting, these animated explorations don't give any indication of performance. The most useful time-based outputs available in tools today are Daylight Autonomy (DA) [1,2], and Useful Daylight Illuminance (UDI) [3,4]. Both metrics, which indicate the percent of occupied hours when a sensor point is above or between certain lux thresholds, are displayed in a spatial grid, as is often done with Daylight Factor or illuminance measurements. S.P.O.T. [5], Daysim [2], and Daylight1-2-3 [6], are three programs which provide calculations of DA.

Unfortunately, one cannot fit every desirable piece of information on a single clear graph. In order to show the variation of performance over space, Daysim condenses temporal information to a single number. The user may set occupancy hours (although not seasonal occupancy), which ensures the relevance of all daily data points, but the user does not know if the design fails in the morning, afternoon, summer, or winter. Unfortunately, many practical daylighting problems are caused by not anticipating the effects of sun angles and weather conditions – variables which are largely dependant on time of year and day. To fully understand these factors and to best judge the nature of a design's success or failure requires lighting data in a fourth dimension.

A very efficient way to solve this problem is by using temporal maps – color-scaled surface graphs with the year on the x- and the day on the y-axis. However, only a few explorations into their use with daylighting data have been done, and they remain largely unknown in the world of architecture. Two studies of note include those by Daniel Glaser and John Mardaljevic [7,8]. Both suggested that temporal data be displayed along side spatial data, and Glaser's work included "brushing and linking" (changing one data type as you scroll over the other) and one attempt to integrate the two into a single two dimensional graph [9]. As applied in existing tools, Glaser's Lightsketch (not widely available) [10] employs some of his data graphics research, and the tool Spot! displays direct sunlight data in a time-variant chart [11]. Most other examples do not involve lighting data.

LIGHTSOLVE

To answer the need for a new balance between spatial and temporal outputs in early design stages, a temporal-spatial pairing is being used in Lightsolve, a design tool under development at MIT that specifically focuses on exploratory, early-stage of design. Using CAD inputs from SketchUp, it performs a representative group of annual simulations based on TMY2 weather files and graphically displays the results as temporal maps and spatial renderings. The ASRC-CIE weather model [12] is used ensuring that, while all renderings are done under realistic skies, a block of transient data can be reduced to a single number [13]. Figure 1 shows the main features of the Lightsolve interface, in which the renderings update when the user scrolls over the temporal maps. In this way, the user can connect the time-based performance of the space with a realistic depiction of sun penetration and light distribution for a single weather type, or for the dominant conditions at that particular time of day and year.

The temporal maps themselves feature two goal-based metrics: one based on illuminance on workplane estimations, and one on glare risks. The authors are currently investigating the inclusion of solar gains data as a third metric. Specifically, for the first one, Lightsolve requires the user to enter a lux-level goal range for each illuminance sensor plane in the model, and the corresponding temporal map uses a color scale to show how much of that sensor plane is within the desired range. Instead of having to set a changing color scale to represent illuminance, the user is shown yellow if the sensor plane is within the given goal

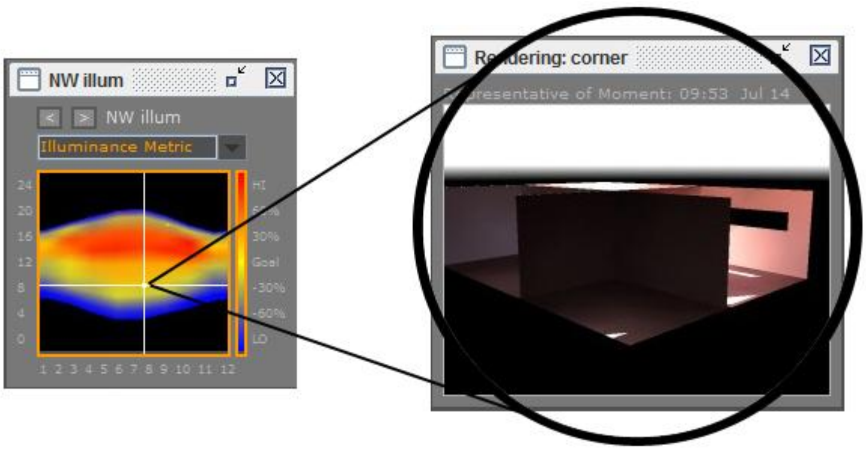

Figure 1: A piece of the main Lightsolve interface. The crosshairs in the temporal maps determine the time and date of the renderings shown below them. For color pictures, visit: http://daylighting.mit.edu/publications/Kleindienst09_UserAssessVisualLightsolve_Cisbat09.

range, red if it is too high, and blue if it is too low. The second ones, which are still being improved and are displayed as glare risk temporal maps, show the percent of vertical planes that perceive glare, as defined by Wienold's Daylight Glare Probability [14].

DESCRIPTION OF SURVEYS

Since one purpose of Lightsolve is to find more intuitive ways of presenting daylighting data to architects, it was essential to get feedback from the intended audience. Therefore, two formal surveys were given to complement informal feedback already received. The first was a comprehensive survey given in January 2009 to a small number of workshop participants. Held at MIT, the 3-day workshop taught participants to use both Lightsolve and Ecotect (with Radiance and Daysim), and assigned them a daylight design problem with which to practice using both programs. The Ecotect/Radiance/Daysim control group was selected as the most advanced set of daylighting analysis tools available. The survey given at the end of the workshop focused on software usability as well as data presentation, although only the latter is relevant to this paper. The goal of this survey was to determine whether participants created more successful solutions using Lightsolve's analysis format than with existing software. Regrettably, time was too short for the participants to go through enough design iterations of their project to enable such conclusions to be drawn, but the results regarding use of temporal data were still valuable. As a further exploration, another survey about data presentation was given which did not depend on learning or using Lightsolve.

In May 2009, a survey comparing data formats was given mainly to student architects at MIT. Given a basic model, daylighting goals, and resulting data in spatial format (as a control) and temporal maps, participants were asked to assess how well the model had achieved the desired goals. The model consisted of two 34 ft by 22 ft by 8 ft classrooms on a double-loaded corridor with punch windows facing either Southeast or Northwest. A second iteration of this model included an indirect skylight which gave some bilateral lighting to both classrooms. The given goal was to keep the workplanes of both classrooms between 400 and 2000 lux from 8am to 4pm between September 1st and June 30th in Boston. Spatial data was given as an array of falsecolor illuminance graphs for CIE clear skies at 9am, 12pm, and 3pm on December 21st, March 21st, and June 21st, for one 10,000 lux CIE overcast sky, and for daylight autonomy (with occupancy hours set as 8am-4pm and the illuminance threshold at 400 lux). Temporal data was given in the form of one temporal map for each classroom's workplane, showing the percent of the workplane which achieved the given goals (see figure

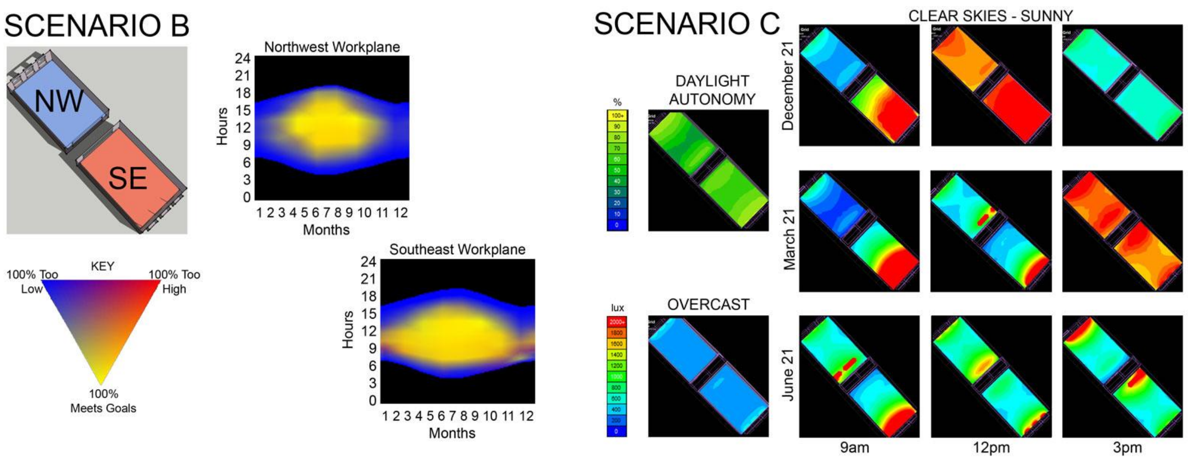

Figure 2: This figure is an example of the data used to compare available temporal and spatial data. Both scenarios represent the better of the two models (the original model very obviously did not let in enough daylight).

2). Before the survey, a very brief introduction to workplane illuminance, daylight autonomy, and temporal maps was given by the survey administrator. Photorealistic renderings were not given for either data format. Participants were not told which model they were assessing, and neither were they informed that there were only two iterations of the basic model. Finally, the survey was strictly timed – participants were given 3 minutes to answer questions about the first scenario and 2 minutes 15 seconds to answer the same questions for each following scenario. The restrictive time limits forced participants to rely on intuition and put a special emphasis on the speed of the analysis.

RESULTS

Lightsolve User Survey

Of the 13 people who took the LightSolve user survey, 9 were student or practicing architects, 3 were lighting specialists and one was an engineer. When asked how intuitive each program set was, they gave Ecotect an average of 2.86 out of 5, and Lightsolve an average of 3.55 out of 5. Although 3 people thought these graphs were sufficient to judge daylighting performance, 6 thought they were not, but nearly all agreed that adding daylight autonomy data really improved the analysis. Five of those who used the Lightsolve interface (which included both temporal maps and renderings) thought it gave sufficient information to judge performance, and all others skipped the question. When asked which program was more useful in early stage design, 10 of 13 chose Lightsolve, but when asked which was quicker to use, 8 of 13 chose Ecotect. This may have been influenced by Lightsolve's usability issues.

Data Formats Survey

Through queries about software experience, and familiarity with a number of daylighting terms, the 58 participants (mostly student or practicing architects) were shown to have little daylighting experience in general. However, one third was familiar with the term "temporal maps" and 22% said they could explain it. This is unusual, but unsurprising given that some students were familiar with the authors, and that a few lighting specialists were also surveyed.

The main body of the survey asked 6 questions about each of four scenarios (see figure 2). Paraphrasing, these questions were 1) did the scenario meet the goals during occupied hours, 2) if not, what was the biggest problem, 3) when do problems occur, 4) where in the room do problems occur, 5) how confident are you in your analysis, and 6) what other information do you want? The tallied responses to all scenario and follow-up questions are given in figure 3.

DISCUSSION

The consistency in responses to the temporal data (scenarios B and D) – especially questions 2 and 3 regarding what the problem was and when it happened – and the first follow-up question show that temporal maps are both readable to the untrained eye and quick, intuitive methods for displaying comprehensive daylighting data. Also, several participants commented on the "at-a-glance" nature of temporal data and the intuitive nature of the "goal-range" color scheme, although another comment unfavorably mistook the temporal maps as a collection of average illuminances. Both surveys, interestingly, revealed the architects' attachment to spatial graphics. Renderings and illuminance maps were the most requested pieces of "extra information" in question 6, and a surprising number of people revealed – through comments and confidence levels – an abiding faith in traditional single-moment illuminance graphs. The spatial data was also considered more complete, as the discrete illuminance graphs gave an illusion of temporal information. This can also be seen in the fact that nearly no one considered the spatial data "not enough information" to answer the time-dependent question 3

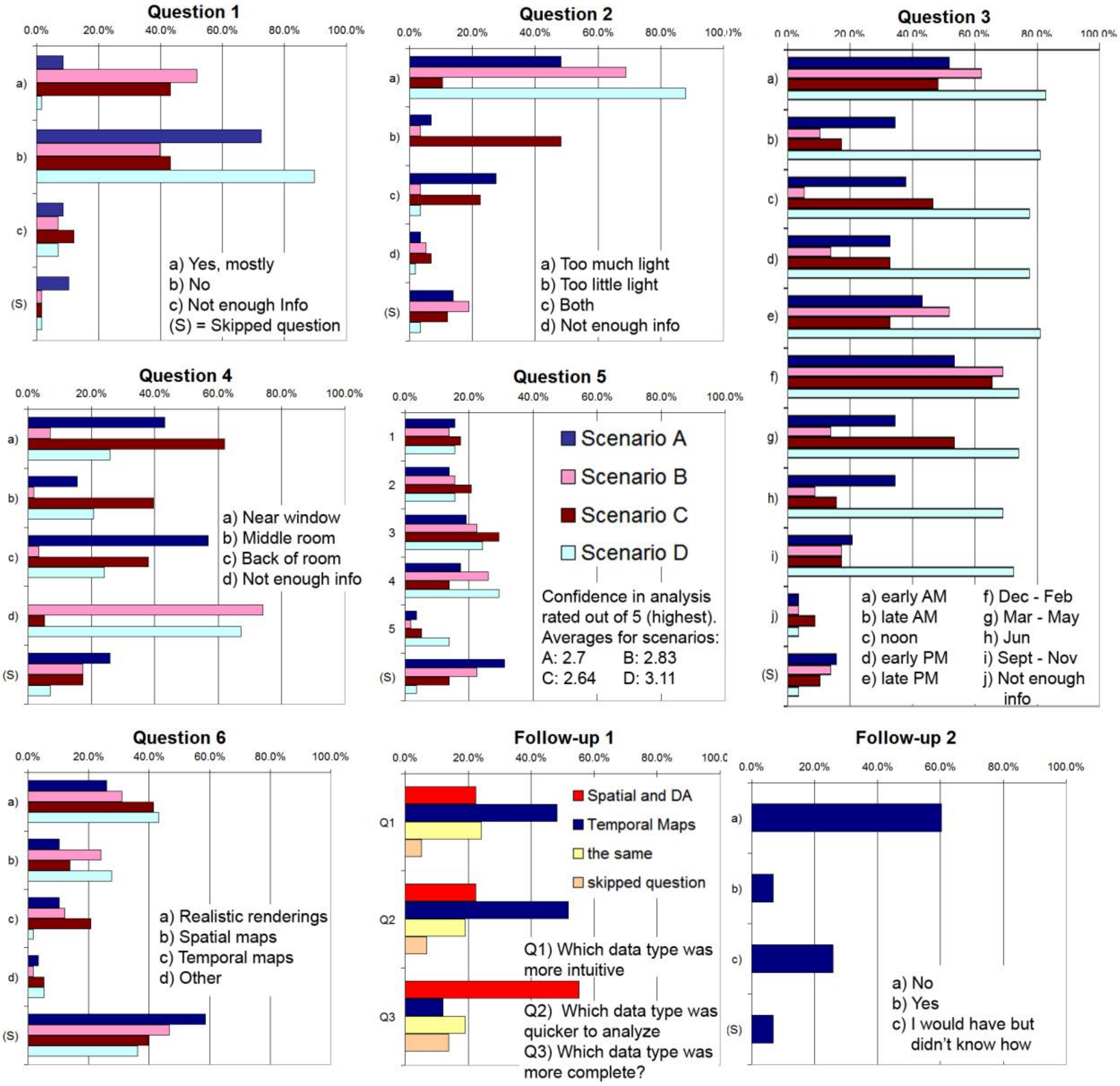

Figure 3: The results from the bulk of the data formats survey. Scenario A is the original model spatial data, B is the improved model temporal data, C is the improved model spatial data, and D is the original model temporal data.

(and the answers were highly inconsistent with each other), but the vast majority recognized there was not enough information in temporal maps to answer the spatial-dependant question 4. Finally, for the improved model, participants decided that the biggest problem was "too much light" when given spatial data, and either no problem or "not enough light" when given temporal data. This is most likely because too much attention was paid to the clear-skies illuminance data over the climate-specific daylight autonomy, while the temporal maps took Boston weather (which is often overcast) into account. The majority of participants admitted that they did not take weather into account when using spatial data.

Since there's a slight redundancy between renderings and spatial graphs, temporal maps could give daylighting data new depth. However, the choice should not be spatial versus temporal data – both should be used to create the greatest understanding of daylight performance.

There were a couple complaints that the time designations in question three were somewhat ambiguous (see figure 3) and that the spatial data page was found to be a little 'crowded' and 'confusing'. It is also the authors' suspicion that most participants ignored the daylight autonomy data in favor of the 3x3 clear sky illuminance graphs, despite the fact that the daylight autonomy graphs should have been the focus. However, it was not the authors' intention to show that either data format was superior, rather to show the weaknesses of either without the other and to prove that temporal maps are intuitive enough for non-experts to use.

CONCLUSION

The goal of the surveys described above was to prove the usability and usefulness of temporal daylighting data and to show that, in combination with spatial data, they improve an architect's understanding of daylighting performance. While the former claim is well supported by the results above, there is still some work to be done in demonstrating the latter. The authors plan to readdress the issue by administering a new survey in the coming month.

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HIGH PERFORMANCE INTEGRATED LIGHTING SYSTEMS: RECENT ACHIEVEMENTS WITHIN THE FRAMEWORK OF THE "GREEN LIGHTING"-PROJECT

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ABSTRACT

The „Green Lighting" project (LESO-PB/EPFL and Swiss Federal Office of Energy) explores different ways to combine advanced day- and artificial lighting technologies for achieving highly energy-efficient office lighting scenarios. This communication gives an overview of recent achievements within the framework of the project, in particular in terms of visual comfort in office rooms equipped with Anidolic Daylighting Systems (ADS), minimization of lighting power density, possible use of novel light sources such as light emitting diodes (LEDs) and possibilities to generalize these results.

It could be shown that occupant satisfaction in the considered ADS-equipped office rooms is very good and can even be optimized by a more sophisticated glare management. Lighting power densities well below 5 W/m² are already achievable today, in different types of office rooms and at various locations, provided that daylight is used intensively (for example through facade-integrated ADS). White LEDs will offer interesting options for office lighting scenarios once they reach luminous efficacies of 80 lm/W and once appropriate luminaires become widely available.

INTRODUCTION

The „Green Lighting" project, launched in 2006 at the Solar Energy and Building Physics Laboratory (LESO-PB) of the Swiss Federal Institute of Technology in Lausanne (EPFL) with the support of the Swiss Federal Office of Energy (SFOE), explores different ways to combine advanced day- and artificial lighting technologies. The main objective of the project is the development of energy-efficient integrated solutions which minimize the electric lighting load while maximizing the building occupants' visual comfort and wellbeing. These developments are based on Anidolic Daylighting Systems (ADS) [1], which are highly efficient daylighting systems based on the theory of non-imaging optics [2]. Different integrated systems were set up in an office room within the LESO solar experimental building and monitored for different periods of the year.

This communication gives an overview of recent achievements within the framework of the project. In particular, we discuss occupant satisfaction in office rooms equipped with ADS [3], ways to minimize the artificial lighting power density in such office rooms [4] and the possible ways to extend the results of the Swiss „Green Lighting" project to different office rooms (such as open space offices) and other countries [5]. Furthermore, we discuss the possibility to use light emitting diodes (LEDs) for office lighting applications [6].

OCCUPANT SATISFACTION IN ADS-EQUIPPED OFFICE ROOMS

The use of daylight (issued from the sun and the sky vault) for illumination purposes inside office buildings is a key element to energy-efficient office lighting. However, electricity savings do not come automatically with the *installation* of a sophisticated daylighting system. Lighting load reduction can only be ensured if the building's occupants *accept* and agree to *properly use* this system. If, for example, building occupants override a sophisticated daylighting system by simply closing the window blinds and switching on electric light in order to avoid glare related problems, then all effort is wasted. One main concern of architects and engineers should therefore be to develop daylighting systems that are easy to use and that allow the occupants to create a comfortable luminous environment within their office at all times.

The southern façade of the LESO solar experimental building (LESO building), located on the EPFL campus in Lausanne, is equipped with a given type of ADS [3, 7]. In order to get an insight into the occupants' satisfaction and well-being when working within office rooms equipped with this type of façade-integrated system, a detailed post-occupancy satisfaction assessment (based on questionnaires and personal interviews) has recently been carried out amongst 23 building occupants [3]. The objective of this study was not only to find out "whether occupants are satisfied with their office lighting or not", but also to identify weak spots in the lighting installation (e.g. within the ADS itself or the associated control system) and to find solutions for eliminating them.

This satisfaction assessment clearly showed that the ADS installed within most offices of the LESO building are in general very well accepted by the occupants. There are, however, some issues that should be taken into consideration when installing ADS in other buildings. Our study has revealed that most of these problems are caused by temporary daylight overprovision within the offices. Figure 1 gives an overview of the main problems and quantifies how annoying they are to the occupants (mean annoyance values calculated according to [3], where 100% signifies "totally annoying" and 0% signifies "not annoying at all").

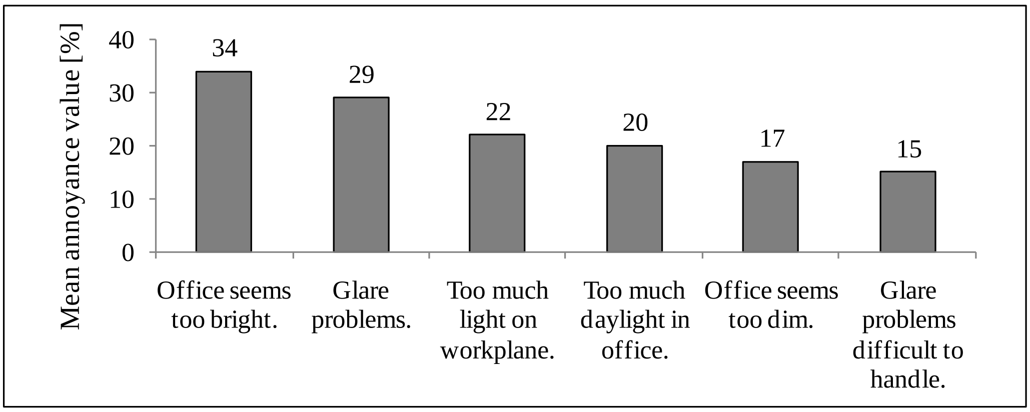


Figure 1: Overview of the main lighting related problems within the examined ADS-equipped office rooms. Annoyance values are in general quite low, and most problems are due to temporary daylight-overprovision, resulting from inappropriate blind configuration and control, as well as problems with ADS handling.

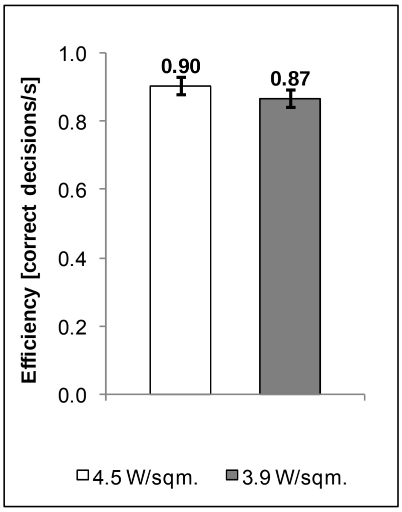
We were able to conclude that the annoyance of most problems revealed during our study could be drastically reduced by optimizing the blind configuration and related control as well as by giving introductions on how to properly handle the ADS to the building's occupants. If such systems could be optimized in this regard, they have indeed a large potential for becoming the basis of future energy-efficient office lighting designs.

MINIMIZATION OF LIGHTING POWER DENSITY

As explained in the previous section, optimized ADS can have a large potential for becoming the basis of future energy-efficient office lighting designs. They would enable office workers to comfortably work under natural lighting conditions during large parts of their working days, without even having to switch on any electric lighting. Nevertheless, even in such office rooms with abundant access to daylight and very effective glare control, the installation of complementary artificial lighting systems will always be necessary: office occupants have to be able to also work effectively during periods of darkness, for example in the early morning, late evening or when the outside sky is extremely dark (e.g. during thunderstorms).

The simplest design strategy for artificial lighting systems would therefore be a dimensioning for the worst case scenario (i.e. night-time with no daylight at all), but we believe that it is not the optimal strategy for the design of low-energy office buildings which are mainly occupied during daytime: dimensioning an electric lighting system for the nocturnal worst-case scenario can lead to unnecessarily high lighting loads during daytime because occupants might simply close the window blinds all the time (to avoid any kind of glare) and keep the powerful electric lighting system switched on during the entire day. Taking this risk might make sense in some cases (e.g. in buildings where people regularly work at night), but definitely not in office buildings where people typically work normal office hours (from 8:00 to 18:00, with some exceptions).

One very simple but yet extremely effective way to reduce the electric lighting load of an office building is to minimize the lighting power densities (i.e. the connected lighting power in an office room divided by the corresponding floor area), also referred to as LPDs. During a study carried out in the LESO building from April to June 2008 (comparable to a study previously described by Page et al. [8]), two different low-LPD lighting designs (4.5 W/m^2, current best practice in LESO building and very much appreciated by the occupants, vs. 3.9 W/m^2, new lighting design) were compared [4]. Twenty persons were asked to perform various tasks at a workplace situated in an office room with a ceiling mounted quick positioning system for luminaires. The test persons' performance (during a screen-based [9] and a paper-based task), their subjective visual comfort (questionnaire-based office lighting survey [10]) as well as their subjective alertness (Karolinska Sleepiness Scale) were assessed. Two important outcomes of the study (a detailed discussion of all results being far beyond the scope of this article) are presented in Figure 2.



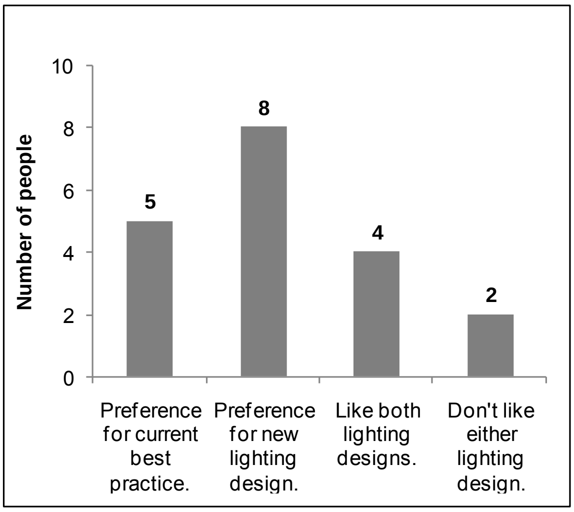


Figure 2: Visual performance (Landolt-ring test) of study subjects under the two different lighting designs (left) and subjective user preferences for the two different solutions (right).

Figure 2 (left) shows the results of a computer-based visual performance test, where the study participants had to determine the correct orientation of Landolt-rings shown to them on a VDT screen [9]. The efficiency is measured in correct decisions per second. Figure 2 (right) visualizes the fact that around 90% of the subjects could be satisfied with one of the two low-LPD lighting designs; only 2 subjects (i.e. around 10%) didn't like either of the two solutions.

This study shows that it is possible to reduce the LPDs in this office building down to less than 5 W/m^2 without jeopardizing the occupants' visual comfort and performance. Even reductions to less than 4 W/m^2 are feasible.

USING THE "GREEN LIGHTING"–APPROACH IN DIFFERENT CONTEXTS

During the "Green Lighting"-project, highly efficient daylighting systems and complementary low-LPD artificial lighting systems were designed for an office building. So far, we have only discussed this approach for one particular ADS (i.e. the anidolic façade element [3, 7]), one particular office type (i.e. a small office room occupied by one or two office worker(s)) and one particular daylighting climate (i.e. the Geneva lake region). However, if the "Green Lighting"-approach is to make a larger impact, possibilities to apply it to different offices with different daylighting systems situated in different climatic regions have to be discussed. This has been done within the framework of a joint project by LESO-PB/EPFL and a group of researchers at the National University of Singapore in 2007.

Wittkopf et al. had previously simulated the performance of an Anidolic Integrated Ceiling (AIC) installed in a 36 m^2 office room under Singapore daylight conditions [11]. Based on their calculated daylight autonomies for this office room, we have designed an appropriate low-LPD artificial lighting system [5]; it leads to an LPD of 4.9 W/m^2. Figure 3 gives an overview of this lighting design.

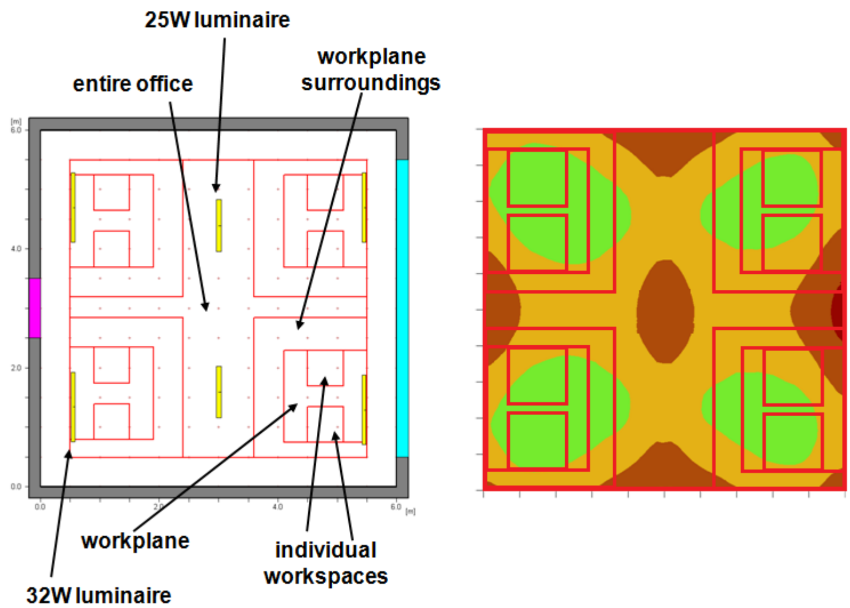


Figure 3: Luminaire positions and reference planes considered during computer simulations for the 36m^2 office room in Singapore (left) and resulting illuminance distribution at a reference height of 80 cm above floor level (right).

The resulting average illuminance varies between 230 lux and 260 lux for the different reference planes (just underneath the required value of 300 lux) and can thus be expected to be sufficient in this type of office room equipped with an AIC and abundant access to daylight. The uniformities

g_1 (i.e. the lowest illuminance value measured on a particular reference plane divided by the corresponding mean illuminance) range between 0.6 and 0.85 for the different reference planes and are thus also acceptable.

The suggested electric lighting system can be used as a starting point in a 1:1 scale test setup in Singapore. Occupant satisfaction assessments, further simulations and in-situ monitoring can contribute to design an even more energy-efficient lighting solution for this type of office room in Singapore.

WHITE LIGHT EMITTING DIODES (LEDS) FOR OFFICE LIGHTING

Over the last few years, light emitting diodes (LEDs) have witnessed a breathtaking development and have become widely available at competitive prices for various consumer products. Colored LEDs have been put to use as a source of emergency and decorative lighting, as indicator lamps, traffic lights and automotive applications for example. White LEDs have become more and more common for portable lighting solutions such as torches or bicycle lights but are not yet widely used as a light source for general lighting applications such as office lighting.

During a project carried out at EPFL in 2007, we have studied the impact of using white LEDs instead of conventional light sources in an office environment [6]. After identifying suitable LED products, we have used the RELUX Vision software tool for simulating energy-efficient lighting solutions based on LED technology in an office room. In particular, the use of white LED light sources in ceiling mounted spot luminaires (Altea LED Bianco 180 mm manufactured by ARES S.R.L) has been considered. Those luminaires were initially equipped with five white LEDs (1.2 W power consumption) and designed rather for decorative than for general lighting. During the simulations, we have gradually increased those luminaires' output flux to values between 60 lm/w and 100 lm/W. We were able to show that, if used in such a way, white LEDs would become a real alternative to replace fluorescent lighting solutions once they reach luminous efficacies of 80 lm/W. Figure 4 shows the simulation of a corresponding 3.25 W/m^2-lighting design for a LESO building office room. A combination of eight Altea LED Bianco luminaires and two additional high power LEDs (OSRAM) installed right above the individual workspaces was used. The resulting illuminance distribution at a reference height of 80 cm above floor level is shown in Figure 4 (left) whereas Figure 4 (right) shows the positioning of the LED luminaires on the office room's ceiling (if luminaires are not pointing vertically downwards, this has been indicated by means of directional arrows). The different reference planes (i.e. entire office, workplane surroundings, workplane and two individual workplaces) are indicated by red rectangles.

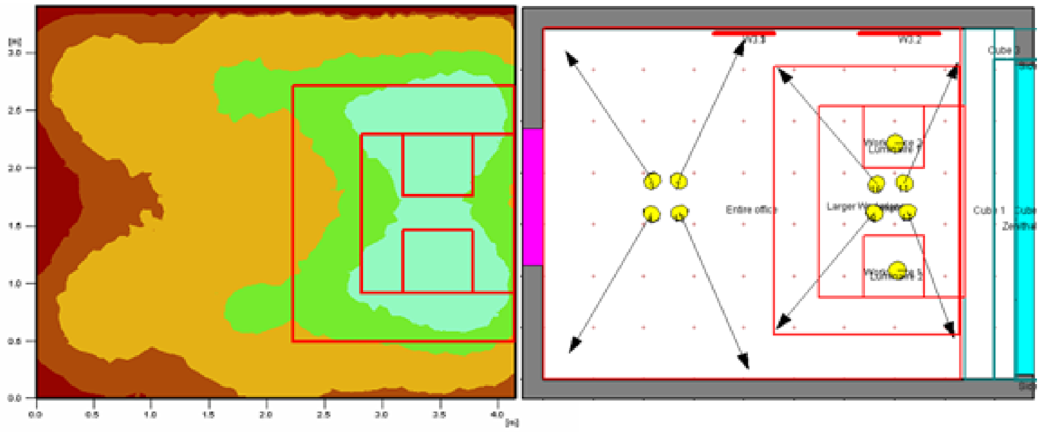


Figure 4: Resulting illuminance distribution for the LED-based lighting design at a reference height of 80 cm above floor level (left) and positioning of the LED luminaires on the office room's ceiling (right).

Figure 5 shows the resulting average illuminances and uniformities g_1 for the lighting design shown in Figure 4. The obtained illuminance values are comparable to those tested by Linhart and Scartezzini in 2008 [4], the uniformities being reasonably good. The lower value for the reference plane “entire office” are due to very low illuminances near the door, but this might not be too annoying to office workers. In any case, this simulated lighting design is an interesting situation to test in a future study within our test office room in the LESO solar experimental building.

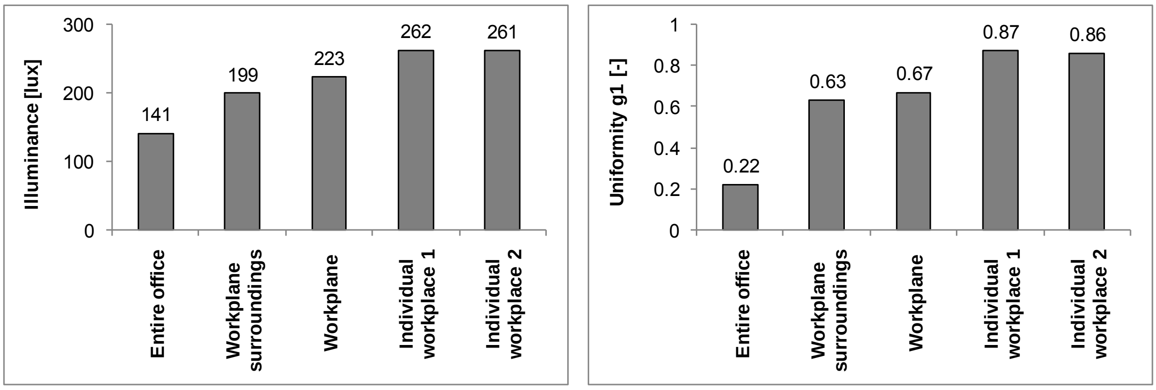


Figure 5: Resulting average illuminances and uniformities g_1 (i.e. the lowest illuminance value measured on a particular reference plane divided by the corresponding mean illuminance) for the LED lighting design (cf. Figure 4).

CONCLUSION

It was shown during this project that occupant satisfaction in the considered ADS-equipped office rooms is very good and can even be optimized by a more sophisticated glare management. Lighting power densities well below 5 W/m² are already achievable today, in different types of office rooms and at various locations, provided that daylight is used intensively (for example through facade-integrated ADS). It can also be pointed out that white LEDs will offer interesting options for office lighting scenarios once they reach luminous efficacies of 80 lm/W and more. They have large potential for becoming a real alternative to fluorescent lighting when more appropriate LED luminaires become available.

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ANALYSIS OF THE DAYLIGHTING EFFECT OF SHADING DEVICES IN A RESIDENTIAL BUILDING USING BRIGHTNESS IMAGE

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ABSTRACT

In previous research, the authors obtained the results that a good balance of the contrast between window brightness and interior brightness was able to increase the resident's perception of the brightness in interior spaces. As a consequence, the purpose of this research is, firstly, to analyze the interior of a housing scale model with various shading devices by means of a "brightness image" which can quantify the contrast of the brightness based on the luminance images, and secondly, to clarify the possibility of achieving a good balance between reduction of thermal load by sun-shading and obtaining interior brightness in the daytime. On the rooftop of the Institute for Land and Infrastructure and Management, digital images of luminance distribution in the interior of a one to ten scale model with shading devices were measured. The opening is placed to face the south, and 19 shading devices (blind, curtain, awning, Japanese style device etc.,) were attached to the opening. Measurements were carried out at 12 noon and 3 pm. under clear sky. Then the luminance images obtained were transformed into the brightness images, and the relation between the luminance images and the brightness images was analyzed. As a result of the analysis by means of the brightness image, we found that using certain types of shading devices can in certain conditions increase the interior brightness, while there are low luminance values on the interior surface. This means that an appropriate selection and appropriate usage of shading devices can assure both good daylighting design and solar radiation shielding.

INTRODUCTION

This research was conducted as part of a study on daylight utilisation technology in order to improve both the quality of light environments and the efficiency of lighting by means of sunlight control at the opening of houses. Many cases have quantitatively proven that due to a contrasting effect, despite interior low luminance, the perception of brightness of lateral daylighting in the house is high [1].

This means that the appropriate control of the window (opening) prevents extreme high luminance parts, where glare occurs, from entering and helps improve the brightness perception of space. In other words, there is a possibility that a well-balanced and highly effective daylighting environment can be created.

Thus, this research discusses the effect of various types of sunlight-controlling devices attached to a living room model on the light environment, along with the usage of brightness images, which quantify brightness perception.

Furthermore, based on the analysis, the research also discusses the simulation of sunlight-controlling effect, as this can serve as an application of light environment design with long eaves and flower blocks often used in hot and humid areas.

METHOD

A scale model experiment was conducted under clear sky on February 21, 2007 on the rooftop of the National Institute for Land and Infrastructure Management. The model was a 1:10 reduced scale house with a living room measuring 360-mm width x 360-mm depth x 250-mm ceiling height and a 200 mm x 200 mm sweep-easy window. As shown in Figure 1, the opening of the house was set to face south directly, and 19 patterns with sunlight-controlling devices (including with no device) set up at the opening were prepared. The measurement was conducted twice at 12 noon and 3 o'clock in the afternoon where the locations of the sun differed, respectively. Moreover, the photos and luminance distribution images of those 19 types of devices were taken with the help of a digital camera. Figure 2 show the photographs taken at 3 pm.

Figure 1: Appearance of scale model

Figure 2: Photographs of 19 types of devices; 1) None 2) Horizontal louver 3) Vertical louver 4) Lattice louver 5) Glass block 6) Bamboo screen (interior) 7) Bamboo screen (exterior) 8) Shoji or paper-sliding door 9) Horizontal blind (interior) 10) Horizontal blind (exterior) 11) Vertical blind (interior) 12) Vertical blind (exterior) 13) Lace curtain 14) Roll screen (interior) 15) Roll screen (exterior) 16) Horizontal eave 17) Vertical eave 18) Eaves 19) Awning

RESULTS AND DISCUSSION

Analysis on Experimental Results with the Brightness Images

The luminance images obtained from the experiment were transformed into the brightness images which considered the brightness perception quantified as "brightness scale" by Nakamura's method [2,3]. In brightness image, all pixels have predicted brightness values on the scale given in Table 1.

Degree of brightness	Score
Very bright	13
Bright	11
Slightly bright	9
Neutral	7
Slightly dark	5
Dark	3
Very dark	1

Table 1: Brightness scale

In order to understand the effect of each type of sunlight-controlling device on the luminance and brightness scale, varied images between the luminance/brightness images of each device and luminance/brightness images without any device were prepared. Examples of those varied images are shown in Figure 3.

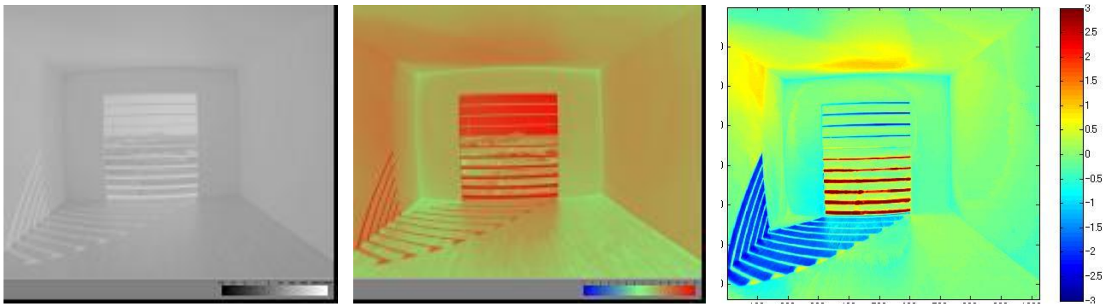

Figure 3: Examples of luminance image (left), Brightness image (centre) and Image by differences of brightness images with/without devices (right)

In addition, to fully investigate changes in the brightness scale value for each interior part, the following were extracted: the brightness scale value of 14 points (Figure 5) from any luminance/brightness image and different values among the cases with/without sunlight-controlling devices.

Figure 4: Extracted points on luminance/brightness image for analysis

Table 2 and Table 3 show differences of brightness scale values among the cases with/without sunlight-controlling devices while demonstrating changes of the luminance value. These can be considered as important findings for the luminance value and brightness scale value.

Point No. / Device type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	The number of rising value points
1) None	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
2) Horizontal louver	−0.16	0.03	−1.73	0.39	0.38	−0.21	−2.06	−0.04	0.26	0.20	0.27	−0.30	0.47	0.13	3
3) Vertical louver	−03.3	−0.41	−0.97	0.59	−0.15	−0.62	−1.04	−0.24	−0.44	−0.36	0.04	−0.20	−0.04	−0.14	2
4) Lattice louver	−0.39	−0.46	−1.83	−1.04	0.01	0.74	−2.12	−0.12	0.11	0.03	0.16	−0.30	0.09	−0.17	2
5) Glass block	−0.33	−0.57	0.12	−0.23	−0.15	0.30	−1.12	−0.16	−0.37	−0.23	0.09	−0.26	0.05	−0.13	3
6) Bamboo screen (interior)	−0.88	−0.99	−0.83	−0.44	−0.35	0.65	−0.18	−0.70	−0.57	−0.69	−0.57	−0.82	−0.58	−0.86	1
7) Bamboo screen (exterior)	−0.71	−0.98	−3.28	−0.29	−0.56	−0.39	−0.82	−0.71	−0.61	−0.71	−0.57	−0.81	−0.55	−0.88	0
8) Shoji or paper-sliding door	−0.75	−0.78	−2.90	−0.19	−0.31	−0.50	−2.42	−0.35	−0.44	−0.32	−0.01	−0.32	−0.09	−0.27	0
9) Horizontal blind (interior)	−0.59	−0.59	0.85	0.23	0.01	3.40	−2.40	−0.15	−0.20	−0.23	0.15	−0.33	0.25	−0.07	3
10) Horizontal blind (exterior)	−0.54	−0.66	−1.94	0.11	−0.05	−0.12	−2.27	−0.19	−0.13	−0.30	0.14	−0.23	0.12	−0.12	3
11) Vertical blind (interior)	−0.09	−0.20	0.29	−0.03	−0.02	1.52	0.11	−0.07	−0.10	−0.11	0.10	−0.22	0.11	−0.08	1
12) Vertical blind (exterior)	0.00	−0.17	0.14	−0.09	0.10	−0.20	0.08	−0.05	−0.14	−0.14	0.09	−0.20	0.13	−0.10	2
13) Lace curtain	−0.06	−0.06	0.16	−0.06	0.08	0.45	−0.02	−0.03	−0.05	−0.06	0.13	−0.07	0.21	0.16	0
14) Roll screen (interior)	−0.47	−0.39	−0.11	−0.10	0.07	1.28	−1.93	−0.05	−0.21	−0.15	0.20	−0.15	0.28	0.13	1
15) Roll screen (exterior)	−0.37	−0.46	−0.95	−0.05	−0.01	−0.20	−1.69	−0.10	−0.24	−0.22	0.17	−0.21	0.24	0.01	2
16) Horizontal eave	−0.12	−0.26	0.28	0.13	−0.12	0.13	−1.44	−0.03	−0.08	−0.17	−0.04	−0.17	−0.05	0.03	4
17) Vertical eave	0.01	−0.16	0.13	0.04	−0.04	−0.04	0.19	−0.08	−0.07	−0.14	−0.04	−0.14	0.06	−0.03	3
18) Eaves	−0.11	−0.29	0.39	0.14	−0.15	0.11	−1.43	−0.04	−0.08	−0.17	−0.06	−0.17	−0.09	−0.06	2
19) Awning	−0.46	−0.47	0.69	0.54	−0.37	0.33	−1.42	−0.30	−0.14	−0.19	−0.28	−0.25	−0.33	−0.10	2

Table 2: Differences of brightness scale values among the cases with/without sunlight-controlling at 12 noon

Point No. / Device type	1	2	3	4	5	6	7	8	9	10	11	12	13	14	The number of rising value points
1) None	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
2) Horizontal louver	0.04	−0.38	−0.39	−0.20	−0.42	0.06	−0.21	0.07	0.52	0.23	0.81	−1.85	0.19	−0.09	0
3) Vertical louver	−0.27	−0.83	−0.68	−0.44	−2.09	0.37	−0.13	−0.77	0.01	0.24	0.14	−2.25	0.30	0.58	2
4) Lattice louver	−0.44	−0.90	−0.96	−0.66	−2.34	−0.21	−0.30	−0.70	0.18	0.21	−0.15	−3−37	0.17	0.13	1
5) Glass block	−0.39	−0.54	−0.63	−0.65	−1.14	−0.20	−0.05	−0.31	−0.04	−0.23	0.05	−1.38	−0.13	−0.10	0
6) Bamboo screen (interior)	−0.55	−0.86	−1.21	−0.85	−1.23	−0.66	−0.78	−0.78	−0.57	−0.63	−0.43	−0.98	−0.54	−0.68	0
7) Bamboo screen (exterior)	−0.61	−0.79	−0.74	−0.74	−0.86	−0.63	−0.75	−0.71	−0.56	−0.53	−0.42	−1.10	−0.54	−0.67	0
8) Shoji or paper-sliding door	−0.71	−1.03	−0.92	−0.88	−3−31	−0.48	−0.30	−0.86	0.01	−0.37	−0.31	−33−3	−0.41	−0.61	1
9) Horizontal blind (interior)	−0.53	−0.84	−0.92	−0.61	−2.08	−0.14	−0.19	−0.43	0.08	−0.10	0.21	−2.15	−0.07	−0.23	2
10) Horizontal blind (exterior)	−0.51	−0.91	−0.86	−0.69	−2.25	0.07	−0.17	−0.50	0.12	−0.10	0.20	−2.20	−0.07	−0.26	3
11) Vertical blind (interior)	−0.14	−0.63	−0.49	1.58	−1.87	0.44	0.06	−0.30	−0.03	0.19	0.20	−2.18	0.25	0.16	1
12) Vertical blind (exterior)	−0.12	−0.71	−0.33	0.98	−1.96	0.61	−0.01	−0.40	−0.05	0.16	0.20	−2.21	0.32	0.29	1
13) Lace curtain	−0.16	−0.31	−03−3	1.43	−0.75	0.08	−0.02	−0.16	0.08	0.07	0.17	−0.37	0.08	−0.04	1
14) Roll screen (interior)	−0.43	−0.82	−0.77	0.64	−1.92	0.11	−0.11	−0.42	0.14	0.11	0.08	−1.84	0.09	−0.14	1
15) Roll screen (exterior)	−0.35	−0.81	−0.76	1.39	−1.92	0.13	−0.08	−0.43	0.16	0.15	0.11	−1.99	0.12	−0.14	2
16) Horizontal eave	−0.02	−0.25	0.18	1.97	−0.06	0.04	−0.11	−0.18	−0.09	−0.13	0.15	−1.56	−0.09	−0.07	1
17) Vertical eave	0.05	−0.24	0.18	2.34	−0.14	0.10	−0.15	−0.14	−0.10	−0.10	0.22	−1.63	−0.07	−0.01	0
18) Eaves	−0.03	−0.27	0.17	1.55	−0.10	0.01	−0.25	−0.17	−0.11	−0.17	0.17	−1.60	−0.09	−0.01	1
19) Awning	−0.37	−0.42	0.33	1.73	0.00	−0.32	−0.41	−0.27	−0.09	−0.29	0.00	−1.50	−0.33	−0.31	0

Table 3: Differences of brightness scale values among the cases with/without sunlight-controlling at 3 pm

The deep-coloured cells in Table 2 and Table 3 show that as the luminance value decreased, the brightness scale value increased (low luminance and high brightness acquired) due to the sunlight-controlling devices, while the light-coloured cells indicate that both the luminance and brightness scale value increased due to the sunlight-controlling devices.

The following findings can be drawn from these tables, given the relationship between the control and increment of the luminance value and those of the brightness scale value with/without the sunlight-controlling devices.

1) The horizontal louver eaves (at 12 noon) have the most points that can allow both the control of the luminance value and the improvement of the brightness scale value.

2) The bamboo screen (interior and exterior) (at 12 noon) has the highest effect of luminance value control. The points that have been controlled in the interior and exterior are slightly different. There was no improvement concerning the brightness scale value, but the overall contrast balance becomes better. Shoji at 3 pm also shows a similar inclination.

3) The luminance and brightness scale values both become high at the horizontal louver, especially at 3 pm. This can be caused by the reflection of the louver's top surface. Additionally, at 12 noon, the control of the luminance value and the improvement of the brightness scale value can be made possible at the left and right areas of the window.

4) The lace curtain, both at 12 noon and 3 pm, does not allow the brightness scale value to increase across the whole space, but increases the luminance value, thus causing the contrast between the window surface and its surrounding area to be high. This can be explained by the curtain's high diffusion and the fact that window surface becomes brighter compared to the case without the device.

5) Results of the roll screen are similar to those of the lace curtain, where the brightness scale value is not high, but the luminance value of the window surface becomes higher. In addition, due to lighting leakage through interior and exterior attachments, the brightness of the area of the window differs.

6) Vertical blinds see the control of the intensity value and improvement of the brightness scale value on the left and right areas of the window at 12 noon and on the ceiling and upper wall at 3 pm.

From the above-mentioned facts, it can be said that some of the sunlight-controlling devices attached to an opening part of a room on a sunny day can keep in check a high luminance value and improve the brightness perception of the space.

Discussion on Light Environmental Design Based on Simulations of Eaves and Flower Block in Hot Humid Areas

From the previous section, it was discovered that the specifications of the sunlight-controlling devices can help improve the brightness perception of a room interior with low luminance. To apply this notion to a practical case, eaves and trellis block were put together in an image simulation. In general, long eaves are used as sunshade, while flower block (lattice type), primarily against typhoons and isolation, are used for exterior architecture design in hot and humid areas. The study will try to use them as a pilot design for sunlight-control effect.

Under the conditions shown in Figure 5, comparisons were made between luminance images and brightness images with/without flower block. Figure 5 shows that the brightness scale value for the wall surface in the inner part of the room drew an almost parallel between the type with flower block and the type without the block even though the conceived idea was that the type with flower block would allow the quantity of luminous flux to become drastically smaller due to the fact that the sunlight can be controlled for the vertical direction of the setting sun, whereas the type without flower block would only give sufficient amounts of luminous flux. In addition, in case where there is no flower block, brightness contrasts between the window surface and its surrounding area are high, assuming that consequently the level of comfort becomes lower.

From the viewpoint of light environment design, the specifications of the sunlight-controlling devices can raise the possibility of efficiently creating a well-balanced contrast and brightness perception in the inner part of a room.

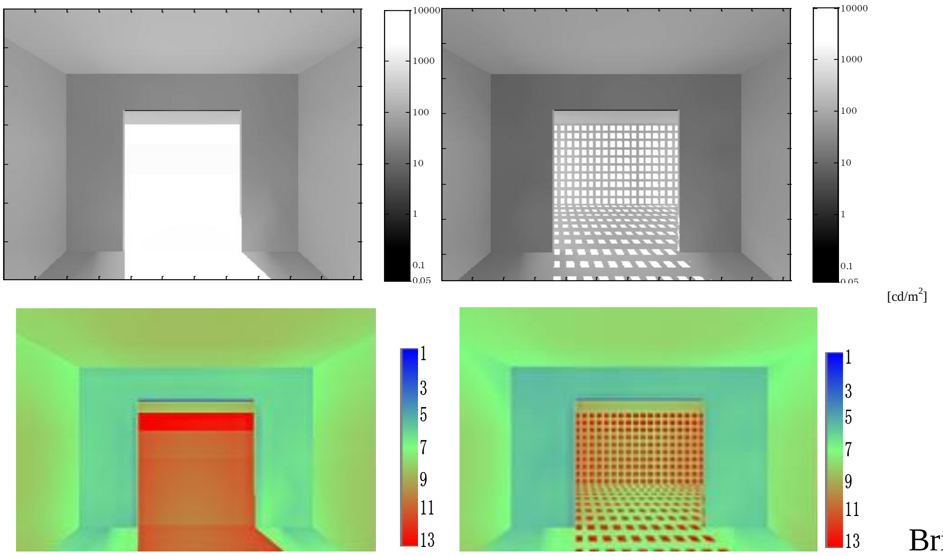

Figure 5: Comparisons between luminance images and brightness images with/without flower block (West opening, 3pm, March 21, Naha, Okinawa)

CONCLUSION

A model experiment was conducted as a basic study on the effect of sunlight control on light environments in houses, and as an application to the light environment design of analysis results from its brightness images, the image simulation of a match-up of eaves and flower blocks in hot and humid areas was observed with the following findings:

The sunlight-controlling devices attached to the opening of houses help improve the contrast balance linked to the level of comfort and interior brightness perception. In other words, it is possible to pursue the quality of daylighting and to secure the lighting efficiency linked directly to the reductions of environmental burdens by appropriate sunlight control.

This observation comes not only from the sunlight-controlling devices as opening designs that can link the interior to the exterior, but also from design that includes the interior light environments that have been formed by the attached devices.

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GEOMETRICAL INTERPRETATION OF SKY LIGHT IN ARCHITECTURE PROJECTS

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ABSTRACT

Natural light comes from a main source, which is sunshine, and from a secondary one, the sky vault illuminated by the sun. But the latter produces a very different light: lighter, cooler (its spectrum moves towards blue colors) and diffuse (it does not project shadows).This diffuse light offers important advantages with regard to the artificial one: it is free, its variation is generally appreciated, and, moreover, it has an excellent luminous efficiency. That is, for the same quantity of light it heats much less than incandescent lamps, and twice less than fluorescent ones.

Here, we will only talk about blue or overcast skies, once the sun is masked, and about how we can help the designer to open the project to them, by means of descriptive geometry, through synthetic representations. We will concentrate on the problem offered by the sky factors, i.e. the solid angle corresponding to the visible part of sky. We can color entirely the surfaces of a scene with these sky factors. The quality of the resulting gradations is amazing: they appear as a very refined render, where the feeling of depth is emphasized. Nevertheless, this kind of picture only exhibits geometrical information. We want also to compare sky factor and view factor. The latter is the usual parameter used in the solution of the radiosity equations, and is always related to a surface that is receiving or sending light or energy. We will perform original simulations to compare them, revealing strong similitude and coherence of behavior. However, while the view factor is a direct product of projective geometry, the sky factor is proposing a very different interpretation of the same illuminated space.

It is here where sky factors are of interest: by definition, they qualify not the surfaces but the volume, where they vary smoothly, indicating the direct relation between sky and geometry, and that, without taking into consideration any physical data. Their use in geometrically complex architecture projects fits perfectly with some contemporaneous intuitions about "volumetric" or "solid" light and with the more recent concerns about visual and energetic impact of new constructions in dense cities.

INTRODUCTION

The diffuse light of the sky offers important advantages with regard to artificial illumination: it is free, its variation is generally appreciated, and, moreover, it has an excellent luminous efficiency (until 150 lumens for any Watt of solar energy). That is, for the same quantity of light it heats much less than the incandescent lamps, and twice less than fluorescents (efficiency is about 75 lm/W) [1]. In the first picture (on the left), that represents a house of the architect Alberto Campo Baeza, we can see the four components of natural illumination all together: sun light, sky light, specular reflection and diffuse reflection. It is a photograph but it could be a hyperrealist painting or a render, as well. Nowadays, it is no longer difficult to obtain this level of "photographic realism" with software.

Figure 1: Turégano house (left and center) and Gaspar house (right), by the Spanish architect Alberto Campo Baeza.

Unlike painters, that do not need to distinguish with so much rigour the different aspects of natural illumination, the digital mock up designer "is painting with parameters", adjusting the different values that regulate the simulation. Direct light and specular reflection can be calculated with a simple ray tracing [2], but diffuse light needs more sophisticated algorithms, based on *radiosity* [3]. Owing to the complexity of the resultant hybrid methods, and also to the commercial character of most rendering software, the user knows less and less about the calculus behind, and is only guided by the visual results, and thereafter by previous experience about light appearance. Although this is a positive and didactic aspect, it cannot help directly in architectural projects. Rendering software tools are too slow to be considered as design tools (interactivity is not yet conceivable) and their computations lack of the necessary limpidity for a secure interpretation.

In the centre of Figure 1, we can see how the entry of the sunbeam completes the scene equilibrium desired by the architect. The illumination is not only a problem of thermal or visual comfort, but a fundamental part of the composition. The sun moves throughout the day and year; a double sequence of renderized pictures, or a sequence of animations, can show such a variety of paths, but with so diluted information that these representations are impracticable in the design process, when forms and orientations are still modified: it would be necessary to use a much more synthetic representation of the paths and of their effects. The render programs do not offer it because their main goal is photographic realism [4].

On the left of Figure 1, light is very different: the sun, closer to twilight, does not project more shadows in the patio. However, the illumination presents subtle gradations, the same that would be observed with an overcast sky. It is darker where sky is less visible: at the bottom of the walls, in the corners, in the recesses. Hence, the level of illumination due to the sky at any point of the space is clearly connected with the quantity of sky visible from this point, that is, with the solid angle that embraces the sky from this point (this angle, normalized as a percentage of the complete vault of heaven is called: *sky factor*). It is a very different type of shadow than the one projected by the sun, but no less geometrical. Furthermore: the sky factor does neither depend on the hour nor on the day, on the latitude or altitude: it is a pure geometrical factor. Would it be possible to design with it?

A thermal software tool, that computes the diffuse light, cannot help with this, because it generally evaluates sky light as a fraction of direct light, not accounting the geometry [5]. Moreover, as rendering software, it is not focused on design, but on analysis.

A DESIGN SOFTWARE FOR ARCHITECTURE

A software dedicated to design must propose computations and representations that should be fast (allowing interactive handling), synthetic (allowing the visualization of all the useful information) and limpid (with unambiguous interpretation). Since the year 2003, we are developing the software “Heliodon” with the intention to realize a true tool for aided design with natural light [6]. We started with the direct sun light, using the classical stereographic representation, thên we added other projections, which can be evaluated on arbitrary plane sections, yielding to sky factors or sunlight maps. Here, we will concentrate on the problem posed by the sky factors, and by the diffuse light of the sky. To evaluate the *sky obstruction*, an equivalent projection is needed, where the relation between the free space (not coloured) and the complete disc (the vault) gives directly the sky factor. We can colour entirely the surfaces of a scene with the sky factors, as in the next picture of an imaginary square (Figure 2 on the left). The quality of the resulting gradations is amazing: they appear as a very refined render, where the feeling of depth is reinforced in the axonometric projection. Nevertheless, this picture only exhibits geometrical information: the highest roofs are white (sky is totally open), and greys become darker when the sky is masked, with subtle point-wise effects on the ground, near the salient corners.

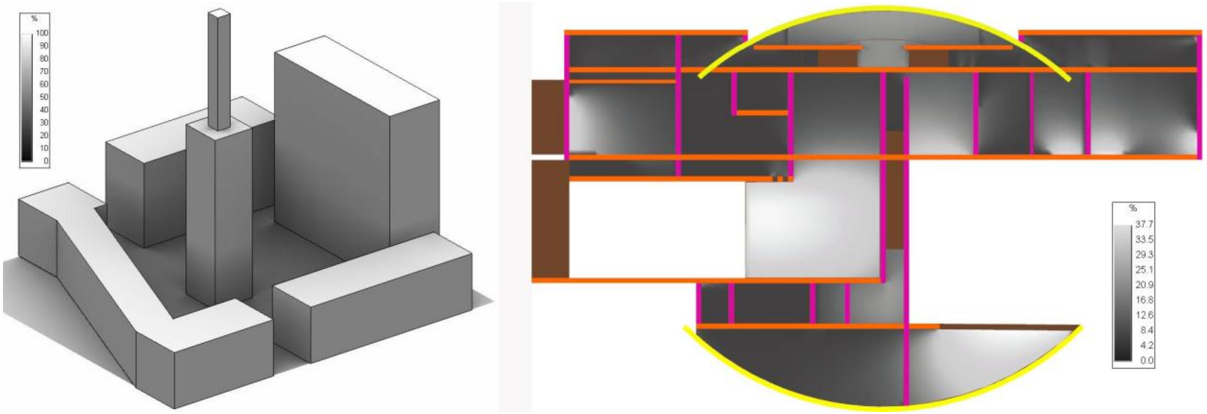

Figure 2: Two scenes painted with sky factors values

The top views darkened in this manner are of particular interest, as in this house by Tadao Ando where the shadows representation derived from the entrance of natural light is highly suggestive (Figure 2 on the right). Many architecture sketchers usually draw their top views with shadows projected by sunshine. They appear on the ground proportionally to the different heights, by oblique projection. However, these shadows only correspond to a brief instant of the day and year. That is why they are arbitrary somehow. Besides, although they enrich the information of the top view, they deform it, superposing lines to lines, as well. The sky shadows do not present such defects and reveal different, very interesting, information: they reveal the apertures and their importance, the patios and their deepness, the spots more or less open, the bottom of the high walls… they do not talk about magnitudes, but about relations. At this point, the question is: shall these sky factors, so easy to calculate and to interpret, allow to quantify the diffuse light and to participate to an energetic evaluation?

THE LIGHT ON THE SURFACES

Various normalized models offering luminance maps of the vault of heaven [7] are available to compute the sky contribution in diffuse light. The problem is that sky luminances and their spatial distribution vary a lot in function of the atmospheric conditions. Here we do not want to consider such complex problems; we rather prefer to think first about the possible uses of sky factors. Another, more practical, way to study this problem consists in measuring, under determined conditions, the response of a luxmeter maintained horizontally in a fully open place. The question of interest is: how much shall we measure with a luxmeter in a street or inside of the projected building? At first sight, the sky factor could give the answer, because it indicates the visible proportion of sky for the selected point. However, after analysing the diffuse light properties, we deduce that it is not correct, even for a uniform sky.

We need to consider the radiosity equations to solve the problem completely. They allow us to compute the illuminances on each surface of the scene taking into account the interactions between all the objects. In this method, we express the radiative equilibrium, considering that the radiosity of a small area is the sum of its proper emission and that of all the radiosities emanating from the other visible elements and those reflected on this element [3]. Such perfectly realizable computation needs to introduce a great number of physical parameters, however, and, since all the possible interactions between the plane elements constituting the scene must be considered, the process is very long and requires the use of complex algorithmic techniques. A computation of this nature can be very useful for the analysis but totally inoperative in the stage of design, not only because it is very slow, but because it requires defining with precision the optical characteristics of all the materials. This often results difficult in the first steps of the design. However, here we are only interested in the diffuse sky light, and we avoid diffuse reflection. We assume then that all the obstructions of the scene are very dark, and absorb completely the incident light. In these conditions, we will study the simple case of the interaction between a plane element of the scene (the luxmeter) and the sky, partially obstructed by the objects of the scene.

In the *method of radiosity*, the interactions between the different elements are described using a pure geometrical expression called *view factor* (or *form factor*). This term, resulting of a double integration on two elements in relation, is proportional to the cosines of the angles formed by the beam with the perpendiculars to the two surfaces, and inversely proportional to the square of the distance between them. Its physical meaning deduced from the properties of the radiative exchange, is that it represents the proportion of the total power leaving the first element and received by the second one. It can be shown, using the Nusselt analogy [3] [4], that this factor can be evaluated very simply by projecting orthogonally the spherical projection of the masks on the studied plane: the relation between the representation of the sky surface and the disc surface gives precisely the *punctual view factor*. This observation is very important for us, because the Heliodon software already evaluates the sky factor using an azimuthal equivalent projection; it is enough to substitute it with an orthogonal projection to obtain the view factor. In the case of a uniform sky, the *view factor* applied at a point on a surface and at the visible part of the sky will directly give the relation between the illuminances that correspond to the complete vault of heaven and to its not obstructed part.

Now, we will compare the view factor with the sky factor in two examples.

- *Comparison between the sky factor and the view factor calculated on a horizontal plane, for a zenithal portion of the vault of heaven, which opening varies between 0 and 90°*. We can imagine ourselves moving from the bottom of a well with circular section upwards until reaching the surface. The well orifice can be considered as the base of a cone with an angular opening increasing from 0 (at the bottom) to 90° (at the surface). According to their definitions, the two factors vary from 0 to 1, but following rather different laws. For little openings, *the view factor is twice superior to the sky factor*. This property is general for zenithal portions of the sky (up to an opening of about 20°). In the zenithal zone, in effect, the relation between the equivalent projection of the hemisphere and the orthogonal one equals two.

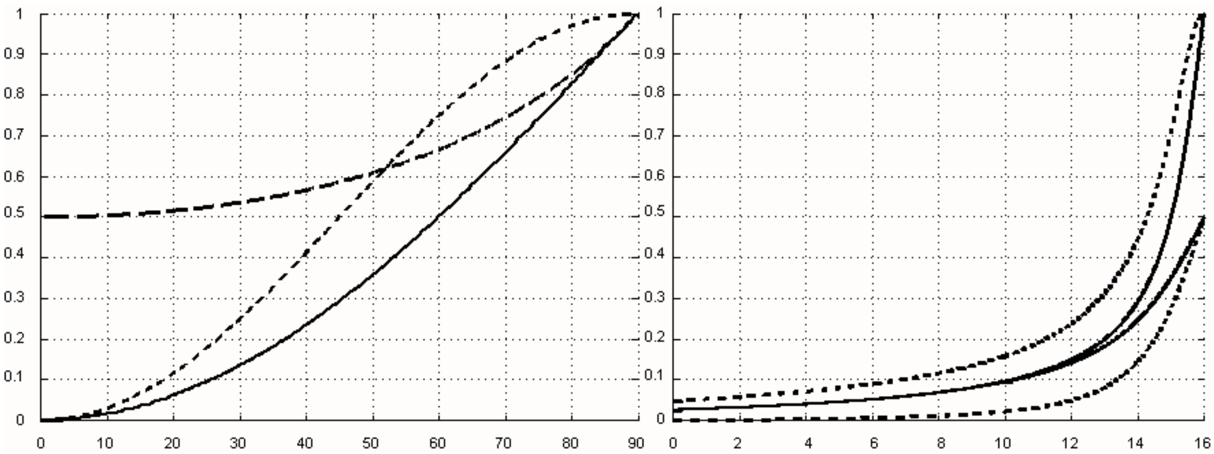

Figure 3: On the left: *View factor (dashed) and sky factor (continuous), relation between both of them (long dashed), for a portion of sphere.* On the right: *View factors in dashed and sky factors in continuous (centre and façade).*

- *Comparison between the two factors in a parallelepiped cavity.* We can imagine ourselves now at the bottom of a straight lane with both ends closed, 2 metres wide and 32 metres long, bordered by a five-storey building (16 metres high). We first produce a computation at ground level, at the centre of the lane. The sky factor and the view factor respectively measure 0.028 and 0.051. As in the previous case, standing at the bottom of a deep cavity, we verify that the view factor on a horizontal surface doubles approximately the sky factor. In Figure 3 on the right, the view factors (in continuous) are compared with the sky factors (in dash). The upper curve shows the view factor evolution on a horizontal surface moving upward in the centre of the street. It varies from 5% at the ground level to 100% at the roofs level. The second curve shows the sky factor evolution calculated in the same points. It varies from 3% to 100%. In all the lower part of the lane, it is half the horizontal view factor.

The two inferior curves represent the same factors calculated on a vertical plane located on one of the façades. Here, the view factor is calculated on a vertical plane. As expected, both factors tend towards 50% at roof level (the same wall where these are calculated masks half of the sky). In the lower part of the lane, the sky factor is more than ten times superior to the vertical view factor. It is interesting to observe that the sky factors curves are located between the two view factors curves. For the energetic computation, only the view factors are correct. So, assuming that the totality of a uniform sky produces an illumination of 20000 lux in a horizontal luxmeter, and then locating this luxmeter in the centre of the obscure lane at ground level, we will measure about 1000 lux, while maintaining it at the same level, but vertically, against a façade, we will only measure 0.0032 * 20000 = 64 lux. The façade illumination will only reach the lane ground one at a height of about 12 metres.

This corresponds to experience: when we want to read a book in a narrow lane where sunshine is not entering, we have to maintain it horizontal, towards the sky. If we place it vertically, the pages seem too dark (obviously, the situation will change considerably if the façades are clear, providing multiple reflection). The *view factor* reflects this situation; the *sky factor* does not, because it is not concerned with the surfaces orientation. It is inadequate for an energetic computation, even an approximated one. However, in a global consideration, the sky factor is not inconsistent: its values are situated between the illuminations of the two extreme cases (the horizontal plane and the vertical one), and it makes the contrasts smooth. The previous graphic explains why the visualizations of objects painted with sky factors as shown before satisfy the eye.

LIGHT AND VOLUME

The Californian artist James Turrell has observed that "we have been a culture of surfaces in such a way that we have never really looked to light; we have only looked to the painting, to the things, although this is changing now" [8]. In some works, as the "Deuce coop" in Barcelona, he managed to erase the surfaces, submerging the visitant eye in a light volume without frontiers. The architecture, always depending on natural light, does not enjoy the same freedom allowed by the intensive use of artificial light, but architects like Peter Zumthor or Alberto Campo Baeza seem to pursue similar intuitions in their works. Hence, a tool able to help in such designs would be in need. And it is here where sky factors are of interest: by definition, they qualify the volume (and not the surfaces), where they vary smoothly, indicating the direct relation between sky and geometry. It is achieved without considering the reflection, that is, the result does not depend even on colour of surfaces; only on form. Therefore, we intend to integrate in a near future the development of Heliodon software, a computation of these factors on a 3D mesh. Thus, we could determine the proportion of the interior volume of a building where the sky factor is superior to certain value. This new parameter would allow us to compare very different buildings (for example: a series of gothic cathedrals or a set of modern houses), without needing to know their finishing, orientation or geographical location. As such, we will compute an aspect that cannot be represented, given that we can only draw surfaces, but that corresponds to the three-dimensional nature of architecture, as we perceive it with our eyes, that are not surfaces, but complex organs, active and restless, that are continuously moving, in middle of the fluxes of light.

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I would like to thank here all the architects who are working with Heliodon in the postgraduate program of the UPC (Barcelona), and specially Tannya Pico and Rafael López, authors of the 3D models of the houses of Alberto Campo Baeza and Tadao Ando. As well, I would like to thank the kindness of architect Alberto Campo Baeza, by having passed to us extensive graphic information about his projects and works, including the three pictures here reproduced.

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CIE STANDARD SKIES IN SWITZERLAND: RELATIVE OCCURRENCE AND IMPACT ON DAYLIGHTING SYSTEM PERFORMANCE

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ABSTRACT

The purpose of this work is the definition of a representative sky for the Geneva Lake Region (south-west Switzerland). A representative sky is a theoretical blended sky based on the relative occurrence of a subset of the 15 standard general skies suggested in 2003 by the Commission Internationale de l'Eclairage (CIE) [1]. By employing Tregenza's method [4] and the Swiss Norm 150 911 [5], a reduced set of CIE standard skies (and their relative frequency of occurrence), named the Geneva Lake Region Representative Sky (GLRRS), is proposed. In addition, by means of a GLRRS-based Virtual Sky Dome (VSD) and the lighting software Photopia 3.0, the behaviour of three different kinds of mirror lightducts is simulated for the Geneva Lake Region.

INTRODUCTION

Climate change is one of the major challenges that humanity will have to deal with. In order to correctly face this hazardous problem, it is necessary to intervene on one of our society's key parameter, which is energy. A way of decreasing greenhouse gases emissions, which trigger global warming, is to use energy in a more efficient way. An important field to focus on is the building segment, in particular the lighting sector; electrical lighting in office interiors can in fact contribute to more than 30% of the total building energy consumption [2].

A representative sky is a theoretical blended sky based on the relative occurrence of a subset of the 15 CIE standard skies [1]. The first five (1-5) describe daylight conditions under various overcast conditions, the second group (6-10) reflects the influence of sunlight with some clouds in the sky and the last group (11-15) models sunny situations with various levels of turbidity (haziness in the atmosphere due to aerosols). Focusing on the above mentioned issue, a representative sky could play an important role towards a more sustainable building lighting segment. It could give, for given location and a given time, an accurate knowledge of sky luminance distributions. By taking already into account a determined range of standard sky types which have the highest relative frequency of occurrence, representative skies simplify daylight simulations, allowing a much faster implementation of simulations. The knowledge of a representative sky for a given location is highly important, for instance, for energy saving programmes employing simulations which model the daylight distribution in complex interior spaces with and without the integration of particular daylighting systems. Worldwide, representative skies have been defined in the UK, Japan [10], Singapore [9, 10], Hong Kong [11], Greece and Slovakia [3] and overall it was seen that errors in predictions of interior and exterior daylighting resources based on the 15 standard skies were significantly less than when calculations were based on an overcast sky alone. Moreover, local best fit sky types have been used for assessing the performances of Anidolic Integrated Ceilings in Singapore and in the UK [2].

In Switzerland, daylight and irradiation data have been recorded for many years in Geneva and Lausanne, but so far no representative sky has been defined for the region. The present paper is structured in two main parts: the first one regards the definition of the Geneva Lake Region Representative Sky (GLRRS), while the second one deals with computer simulations of different mirror lightducts using the GLRRS. Both parts begin with a brief introduction, followed by the adopted method and the obtained results.

DEFINITION OF THE GENEVA LAKE REGION REPRESENTATIVE SKY (GLRRS)

The Geneva Lake Region lays in the south-western part of Switzerland, at the north-western tip of the Alps. A coarse, but very useful definition about Geneva's climatic and environmental main features states: "Temperate maritime climate, with central Europe continental influence. Persistent nebulosity enhanced by "blocking position" at foot-hill of the Alps" [6, 7].

The GLRRS has been determined by means of a detailed analysis, based on Tregenza's method [4], of the available data from the International Daylight Measurement Programme (IDMP) station located in Geneva.

Methodology

To determine the typical sky luminance distributions, Tregenza's method uses the ratio L_p/E_{dh} (sky scanned luminances of the sky vault/diffuse horizontal illuminance). The database employed comes from Geneva's IDMP station and consists of hourly sky luminance data (measured by means of a PRC Krochmann scanner), hourly values of global horizontal illuminance (E_{gh}) and direct normal illuminance (E_{bn}). The available measurements from the IDMP station go from the second half of 1994 until the first half of 1995.

In order to determine a local representative sky, mainly for daylighting-linked energy studies, it has been considered opportune to focus on a daily hour range included between 9.00 and 17.00, which corresponds to the main office working period. The initial volume of 4363 observations, after a data pre-processing consisting in quality tests [3, 8] and other specific selections among measured data [3, 9, 10], has been globally reduced to 1027 data, which represents the final database of this work. Each scanned sky has been analysed individually and the standard distribution giving the closest fit to the scan has been determined in the following way: the sky scan luminances have been normalized with respect to horizontal illuminance calculated from these monitored luminances and then the same has been applied to the 15 Standard General Sky types for the solar angles at the time of scan.

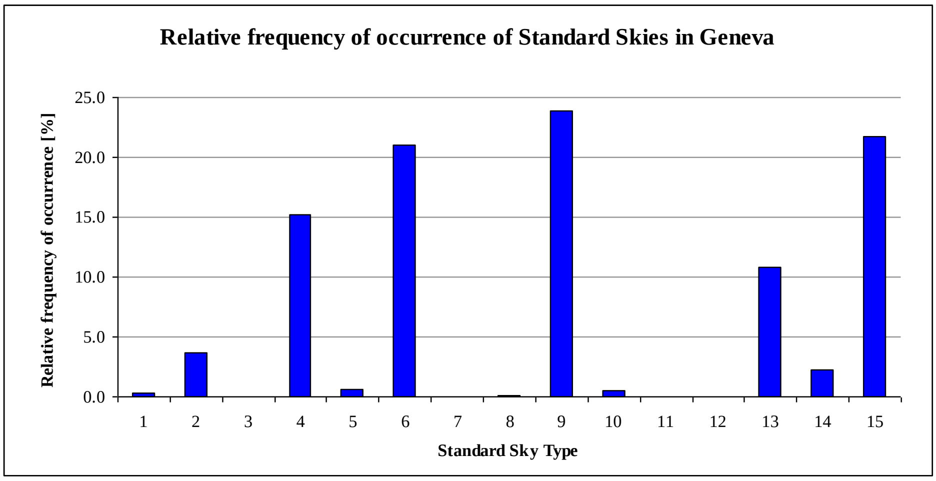

Figure 1: Relative frequencies of occurrence of the 15 standard sky types in Geneva according to Tregenza's method.

The RMS error between the measured normalized luminances and each of the standard distributions has been computed: the standard luminance distribution that had the minimum least-squares error over the whole hemisphere was the best fit standard sky type. The obtained relative occurrence frequencies for the 15 sky types are shown in Figure 1.

After applying the overall procedure, it can be seen on Figure 1 that, during the given monitored period, partly cloudy skies are globally the predominant ones (45%), followed by clear skies (35%) and then by overcast skies (20%).

Results

Tregenza's method has given valuable and useful outcomes, but, due to the limited sample size, the results obtained might not necessarily be representative for a long term sky luminance distribution in Geneva. Nevertheless, it is important to underline that the typical local standard skies are likely to have been correctly determined, the relative frequencies of occurrence being however not fully representative. That is why these results, together with the Swiss Norm SN 150 911 on "interior lighting with daylight" [5], were taken as a basis for the development of the representative sky for the Geneva Lake Region.

By adapting the percentages of this norm (see Figure 2) to the three CIE standard sky groups for Geneva, the annual sky can be described as: 43% overcast over the year (7.5 to 10 tenths of cloudiness), 36% intermediate (7.5 to 2.5 of cloudiness) and 21% clear (0 to 2.5 tenths of cloudiness). Knowing these percentages, together with the standard sky types determined by means of Tregenza's method, it has finally been possible to assess the Geneva Lake Region Representative Sky (GLRRS).

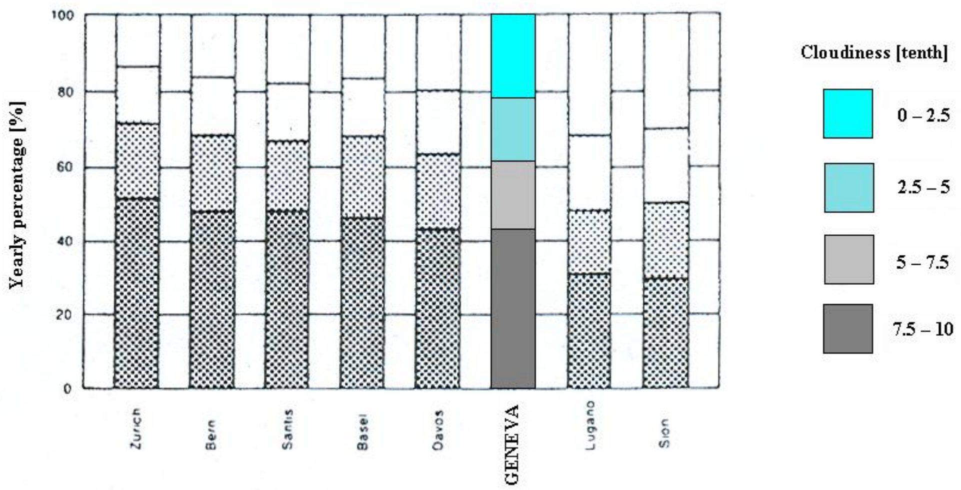

Figure 2: Yearly percentage, in tenths, of the different levels of cloudiness in some Swiss locations, adapted from [5].

Assigning sky 4 as representative for overcast skies, sky 6 for highly intermediate skies, sky 9 for slightly intermediate skies and sky 15 for clear conditions, the GLRRS can be defined as follows (analogically to the Hong Kong Representative Sky (HKRS), introduced by Ng et al. in 2007 [11]):

$$\text{GLRRS} = 0.43(\text{sky4}) + 0.20(\text{sky6}) + 0.16(\text{sky9}) + 0.21(\text{sky15}) \qquad (1)$$

This means that the contribution to the GLRRS sky luminance distribution is given by sky 4 (43%), sky 6 (20%), sky 9 (16%) and sky 15 (21%). In daylight simulations where sky models based on different sky patches are used, the luminance of each patch can be calculated according to equation (1).

SIMULATION OF MIRROR LIGHTDUCT DEVICES' PERFORMANCES USING GLRRS

After having defined the representative sky for the Geneva Lake Region, the acquired result has been applied in a specific daylighting case study. Together with a reference case, the performances of three different types of mirror lightducts have been assessed using the GLRRS for four façade orientations (north, east, south and west).

Mirror lightducts are devices which collect diffuse and direct daylight through an external collector and channel it into a reflective ceiling plenum. The exit apertures located on the ceiling distribute the daylight flux to the deep and gloomy zones of the room and thus reduce the demand for electric lighting, which is one of the major building loads. Furthermore, by efficiently redirecting daylight into the interior, it also enables to achieve a uniform daylight distribution in the room [2, 12].

Methodology

The assessment of the daylighting performances was made by means of computer simulations. The Virtual Sky Dome (VSD) approach was used to generate a CIE general sky consistent with the daylighting conditions to be used in 3D-CAD simulation software. A VSD imitates the spatial luminance distribution of the sky vault by 145 distinct light sources, whose distribution over the hemisphere follows the IDMP conventions for sky patch luminance measurements and whose individual luminous flux is calculated using the equations of the 15 sky types [12]. In the current work the VSD approach was used to generate the sky patch luminances [cd/m^2] for a given Sun position and a local sky distribution reproduced by the GLRRS. A solar elevation γ_s = 34°, an average between the lowest and the highest solar angles that occur in Geneva, and a solar azimuth α_s = 180° have been selected for the simulations.

Using the on-line VSD software [13], the luminance of each patch was obtained for every standard sky, giving a total matrix of 145 x 15 data. Subsequently, through equation (1), the values were weighted in order to determine a luminance distribution corresponding to the GLRRS. The obtained VSD has then been imported into the software Photopia 3.0, together with the 3D-CAD models of the open space office (with and without the mirror lightducts) for four different façade orientations (north, east, south and west).

The room chosen for the simulations is a large and deep open space office (18m width x 9m depth x 3.6m height) located at the ground floor of a three floor building. The room is illuminated only from one side and is shaded by the upper floors. The "reference building" case refers to the default façade configuration, without any integrated device. It is used for comparing the mirror lightducts' performances, which are modelled for three different cases. Each model includes six ducts, but the differences are basically given by the ends of the ducts and the number of openings (see Figure 3). The first type has got straight vertical endings and four openings (basic ducts case); for the two other types the ducts' ends are tilted (inclined of 45°), one is characterised by three openings (tilted ending ducts with three openings), the other one by four (tilted ending ducts with four openings).

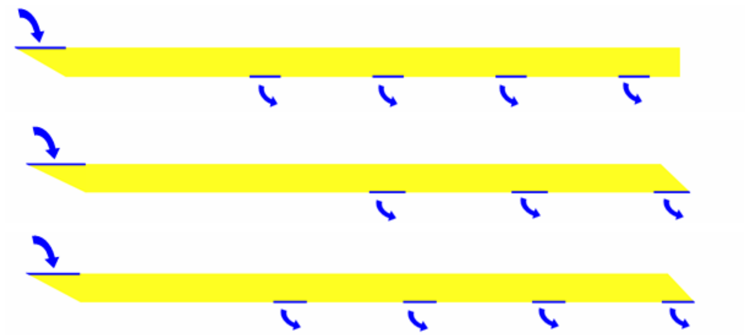

Figure 3: Details of the openings of the three different kinds of mirror lightducts: basic ducts, tilted endings with three openings and tilted endings with four openings, respectively.

Results

In order to assess the global performance of the three mirror lightduct devices used in the simulations, the criteria IR (Illuminance Ratio: ratio of indoor horizontal illuminance [lx] over the external horizontal illuminance [lx], expressed in percent), IR IF (Illuminance Ratio Improvement Factor: quantifies the performance improvement over a reference façade without a mirror lightduct device) and UF (Uniformity Factor: ratio between the minimum and the average of the indoor horizontal illuminances [lx]) are employed for the four given orientations of the building's façade.

Figure 4 shows that out of the three proposed daylighting systems, the better overall results are achieved for the one which has three exit apertures per duct and a tilted end. The inclined back of the ducts is a key solution for an optimal redirection of daylight into the rear of the office room. Moreover, for the given cases, it is seen that four openings in the ducts do not lead to an improvement, but actually decrease the performances. With this configuration, in fact, the aperture close to the window (where the IR is anyhow high), contributes to a considerable loss of the daylighting flux which is more useful in the back of the office room. Focusing on the four building orientations, the simulations' results suggest that the most suitable directions of the façade with the integrated mirror lightducts are (considering both the UF and the IR IF) the west and east orientations.

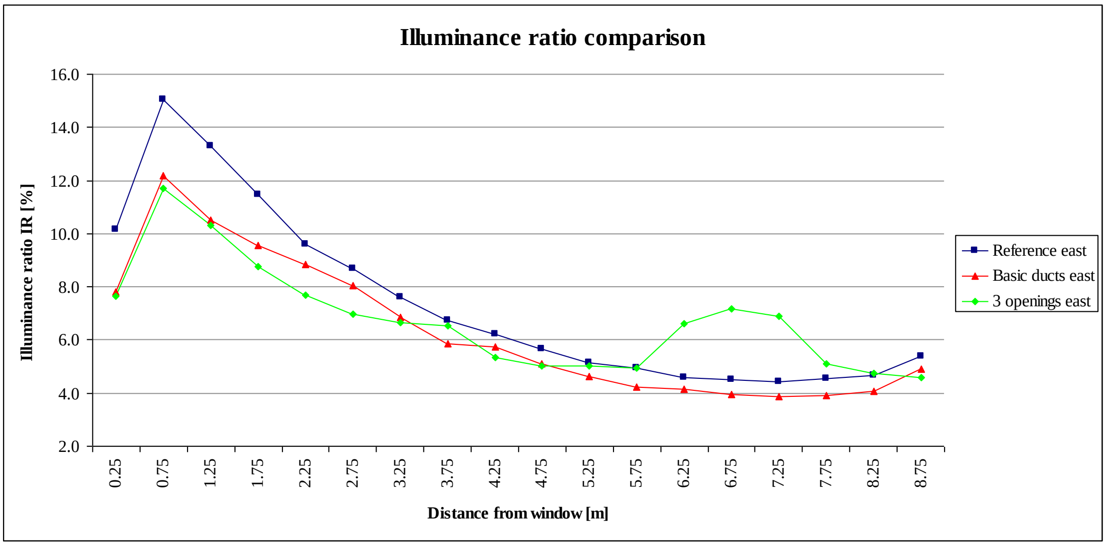

Figure 4: Illuminance ratio comparison between the reference, the basic duct and the 3 openings case, for an east facing façade.

CONCLUSION

The aim of this work was the assessment of a representative sky for the Geneva Lake Region (south-western Switzerland), which can be used to reproduce a typical local sky luminance distributions for daylighting and energy saving studies. In order to determine the Geneva Lake Region Representative Sky (GLRRS), Tregenza's method [4], together with the Swiss Norm 150 911 [5], have been employed.

The obtained GLRRS has then been used to evaluate the performance of three kinds of mirror lightducts. Their behaviours, compared to a reference case (without any device), have been simulated by means of a Virtual Sky Dome (VSD) based on the GLRRS and the Photopia 3.0 software. In order to determine to what extend the chosen daylighting systems improve the illuminance ratios (IR) and the uniformity in a given open space office, both the illuminance ratio improvement factor IR IF and the uniformity factor UF have been employed. The results show that the most performing daylighting device is the mirror lightduct with three openings and a tilted end; the best outcomes are achieved for the west and east orientations of the building facade. Further research should be carried out to implement and optimize the new solutions for the considered mirror lightduct: this would mean for instance the use of anidolic collectors, the integration on two or three different facades or the optimization of the lightduct's dimensions.

Further studies, possibly with more complete data sets, have to be conducted in order to improve the GLRRS obtained in this work, to get more detailed simulations of the mirror lightducts as well as to assess the performances of other daylighting systems.

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EFFICIENT DAYLIGHTING, HEATING AND SHADING WITH ROOFLIGHT HELIOSTATS

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ABSTRACT

Classical rooflights are normally not optimized for annual energetic and daylighting performance as the winter sunlight is transmitted to a small extent while in the summer a high fraction of sunlight may enter the building. This leads to relatively low solar gains and low daylighting performance during the heating season and high solar thermal loads in the summer even if glazings with low g-values are implemented.

The integration of a heliostat mirror into a rooflight may change the situation considerably:

1. The effective aperture area for direct sunlight is increased considerably during winter months.
2. A large fraction of the transmitted light may be reflected in the same direction at any time. This allows the installation of light sculptures which may redirect, scatter or transmit light in a well-defined way.
3. The option of closing the heliostat “lid” during winter nights may reduce heat losses significantly.
4. In the summer the heliostat mirror may operate in a shading mode during hot days in order to reduce cooling power and cooling energy requirements, whereby the rear side of the heliostat may be equipped with PV modules, which are tracked at an optimum angle.
5. Under overcast sky conditions the heliostat can be turned open to allow a maximum of daylight entering the building.

In this paper the annual energetic performance of the Soldec® heliostat rooflight system is analysed considering all of the abovementioned aspects. A prototype installation in the framework of the new school building “Science College Overbach” is described.

INTRODUCTION

Classical rooflights are normally not optimized for annual energetic and daylighting performance as the winter sunlight is transmitted to a small extent while in the summer a high fraction of sunlight may enter the building. This leads to relatively low solar gains and low daylighting performance during the heating season and high solar thermal loads in the summer even if glazings with low g-values are implemented.

In recent years several attempts have been made to improve the optical and thermal performance of rooflights. One example is the heliobus® system, which has been installed at a school building in St. Gallen, Switzerland (Figure 1) /3/. However, the mirror is static and does not track the sun.

Figure 1: The heliobus® mirror installed at the school building Boppartshof in St. Gallen, Switzerland (Source: www.heliobus.com).

Another option of daylight system is to feed sunlight into a lightpipe or other light-guiding system by use of a sun-tracking heliostat. Several systems have been erected in the past years (see Figure 2). Another approach is the Japanese Himawari system, which uses lenses and optical fibre cables to direct sunlight into buildings. A brilliant overview on this topic is provided in /1/.

Figure 2: Heliostat-lightpipe systems (left: heliobus® system at Potsdamer Platz, Berlin, right: Daylighting system with EGIS heliostat at Solar-Institut Jülich /2/).

However, the market for such applications remains small as costs are still high compared with the benefit that is achieved with the available systems.

A new approach is the integration of heliostats into rooflights. One way of realisation is presented in Figure 3.

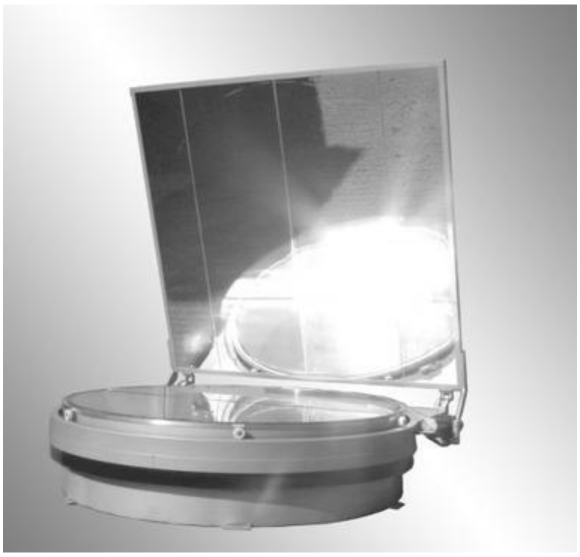

Figure 3: One option of rooflight-integrated heliostats (source: www.soldec.de)

In this way, costs for separate heliostat components are reduced and additional benefits can be obtained, as there are:

- Additional thermal insulation when the system is closed
- Full transparency under cloudy-sky conditions
- User-adjustable shading-daylighting optimum under hot conditions
- Option of PV integration on tracked surface (mirror backside)

METHOD

Assumptions

In order to quantify these benefits, numerical calculations have been performed. As a reference site the German city of Würzburg was chosen. The solar radiation at Würzburg is characterized by the data provided in Table 1. The rooflight-heliostat system is compared with 6 standard horizontal rooflights of similar area using the following assumptions. Characteristic data is given

- Solar radiation on tilted surfaces is calculated according to the model of Hay/Davies assuming a ground reflection of 20%. A uniform diffuse sky is assumed.
- Solar radiation is transferred to illuminance using 90 lm/W for direct and 110 lm/W for diffuse radiation (1 kWh direct solar radiation is equivalent to 90 klmh)
- Mirror reflection (type Alanod Miro 4270KKS) is assumed to be 89 % (solar radiation) and 91 % (visible light).
- The rooflight is assumed to have a round transparent surface area of 2.8 m diameter. The mirror is a square of 3.20 m x 3.20 m.
- The mirror may be tilted max. 75°.

- The glazing is characterized by a visible transmission of 80 % and a g value of 60 %, no angular dependence
- Thermal properties of the complete unit are characterized by a U value of 1.4 W/m²K (open), and 0.75 W/m²K (closed). Room and indoor air temperature: 20 °C
- The following control strategy is applied:
  - PV mode (mirror backside tracked towards the sun from May 1st to September 30th
  - From October 1st to April 30th there are two modes:
    - sunny sky: Mirror reflects light vertically into the building
    - cloudy sky: Mirror at max. angle
    - at night: Mirror closed.
    - the closing of the system due to high wind speed is not considered.
- The reference system:
  - 6 standard rooflights 1.20 m x 1.20 m (clear opening: 1.0 m x 1.0 m)
  - g-value: 0.35, τ_{vis}: 0.55
  - U_w value: 2.5 W/m²K

The following quantities are determined:

- Energy saving for cooling due to reduced solar gain in summer
- Energy yield of PV system covering the mirror backside
- Energy saving due to increased thermal insulation
- Additional thermal energy gain due to increased solar gain in the winter
- Potential electricity saving due to increased daylight transmission in winter

Table 1: Solar radiation characteristics of Würzburg/Germany

Radiation sums in kWh/m²	**1.5.-30.9.**			**1.10.-30.4.**		
Type of tracking	**Direct**	**Diffus**	**Global**	**Direct**	**Diffus**	**Global**
Horizontal Surface	316	394	710	145	237	382
Tracked surface facing the sun	507	415	922	320	255	575
Radiation at rooflight-mirror aperture during sunny-sky tracking	494	408	902	314	261	575
Radiation on mirror backside during sunny-sky tracking	0	189	189	0	105	105

RESULTS

Energy saving for cooling due to reduced solar gain in summer

In the period from May 1st to September 30th the system operates in the shading (= PV tracking) mode. In this period the transmission of solar energy into the building is 579 kWh compared with 1493 kWh in the reference case. Therefore the maximum saving potential for cooling energy is about 914 kWh.

Energy yield of PV system covering the mirror backside

The amount of electric energy produced by a PV system mounted at the mirror backside is calculated under the assumption that there are 10.24 m² of PV modules with a nominal efficiency of 12.5 % and a performance ratio of 85 %.

The expected yield in summer is 919 kWh, and in winter 75 kWh are expected: 994 kWh per annum.

Energy saving due to increased thermal insulation

Due to the lower U value of the heliostat rooflight in both open and closed conditions, a total space heating energy saving of 948 kWh is calculated as transmission losses are reduced from 1423 kWh in the reference case to 475 kWh.

As in reality air temperatures near the rooflight may often exceed 20 °C and thermal losses are underestimated as radiative losses to the cold sky are not explicitly considered, real energy savings are expected to be even larger. Details will have to be examined in a forthcoming project.

Additional thermal energy gain due to increased solar gain in the winter

During the winter the solar gain through the heliostat rooflight is calculated as 2373 kWh while in the reference case only 802 kWh of solar energy are transmitted into the building. This corresponds to a heating energy saving potential of about 1571 kWh.

Potential electricity saving due to increased daylight transmission in winter

In the winter months the transmission of light through the heliostat rooflight can be integrated to 156000 klmh direct sunlight and 159000 klmh, a total amount of 315.000 klmh. Assuming an efficacy of 80 lm/W, as it is observed at good fluorescent lamps, the generation of the same amount of light with electric lighting would require about 3900 kWh of electricity.

In the reference case, 129.000klmh are radiated into the building, corresponding to 1612 kWh.

Therefore a maximum saving potential of about 2300 kWh lighting electricity is obtained. It should be noted that this potential can only be used to a large extent if highly efficient daylight directing elements are placed inside the building into the path of reflected light.

Summary

As the results refer to different forms of energy, the total benefit of the system is expressed in terms of primary energy savings, where primary energy factors are 1.0 (cooling energy), 1.1 (heating energy) and 3.0 (electricity).

Table 2: Summary of energy saving results

	Annual saving/Generation potential	**Annual primary energy saving potential**
Reduced cooling load	914 kWh	914 kWh
PV generation	994 kWh	2982 kWh
Increased thermal insulation	948 kWh	1043 kWh
Increased solar gain	1571 kWh	1728 kWh
Increased illumination	2300 kWh	6975 kWh
Total	-	**13642 kWh**

The rooflight heliostat will contribute to the energy supply and daylighting of the Science College Overbach at Jülich-Barmen, Germany (see Figure 4).

Figure 4: Rooflight heliostats at the construction site of the Science College Overbach

DISCUSSION

The total primary energy saving potential of the examined heliostat rooflight is quite impressive: 13.6 MWh/a. If a general cost figure of 50 €/MWh is assumed, about 700 € per annum may be saved by using this system instead of standard rooflights. The fact that half the saving potential is related to the daylighting properties of the system stresses the importance and often underestimated primary energy relevance of daylight. However, if the system is used without further light-directing elements, the high amount of daylight will lead to overexposure at the areas underneath the rooflights. The expected savings may be reduced to 50 % or less. Nevertheless, the value of the high fraction of natural light and the interesting lighting effects may exceed the value of saved energy by far.

ACKNOWLEDGEMENTS

The analysis was carried out by Solar-Institut Jülich under contract of the company Augsburger Holzhaus, Germany.

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DAYLIGHTING AND LIGHTING ENERGY DEMAND ANALYSIS OF THE NEW TOWN LIBRARY OF PIOMBINO (ITALY)

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ABSTRACT

The recovery of old buildings out of use to be designed for services for which they were not designed for originally has become, in Italy, a widespread practice. The choice to reuse old buildings with strong architectural and monumental connotations, generally poses problems relating to structural adequacy, energy consumption control, functional distribution of new spaces as well as to the satisfaction of indoor comfort parameters (i.e. the minimum lighting requirements).

In this paper the preliminary plan of the new town library of *Piombino* (*Livorno*, Tuscany - Italy) intends to realize in the ex-Church of *S. Antimo* (medieval age, c.1250) is illustrated. The results of an extensive analysis concerning day- and artificial lighting of the consultation and reading areas of the new library to be realized in the nave of the ex-Church are shown. Finally, the evaluation of energy demand for artificial lighting, by calculation of Lighting Energy Numeric Indicator (LENI), is presented.

THE PROJECT OF THE LIBRARY

The monumental complex of buildings, which is composed of the *S. Antimo sopra i canali* church (medieval age, c.1250), the *Tarsinata* tower (c.1200) and the *S. Anastasia* monastery (c.1600), had housed the town hospital since 1806 (date of the Church deconsecration) till to 1994. It is located in the historic centre of *Piombino* (*Livorno*, Tuscany - Italy) and thank to its privileged position can dominate the small harbour of *Marina* (Fig. 1). The realization of the new town library of *Piombino* in the ex-Church of *S. Antimo* is a part of the renovation project that involves the old town hospital.

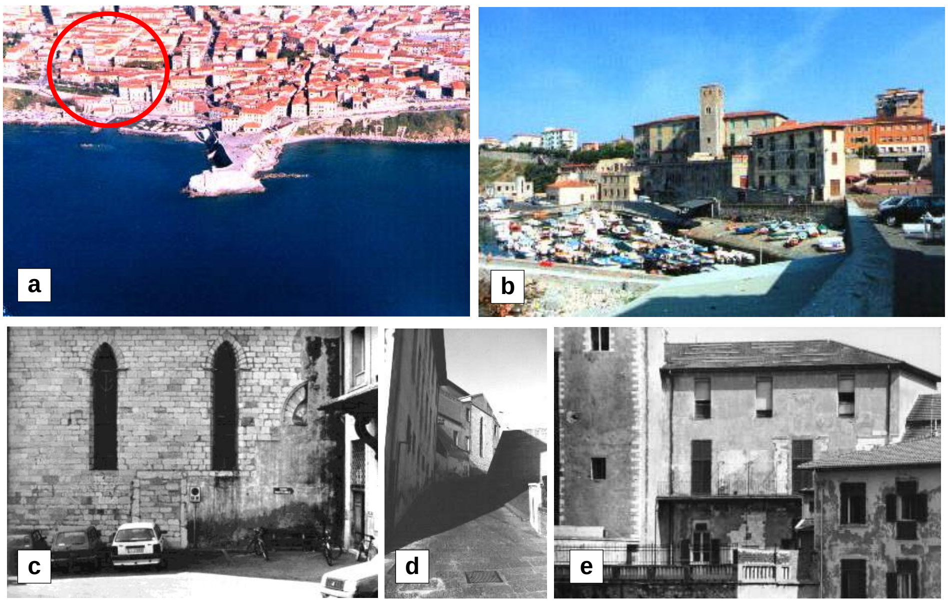


Figure 1 – a) Aerial view of Piombino; b-e) the ex-Church of S. Antimo.

The renovation project provides for a rearrangement of the internal spaces of the church and a subdivision of the nave in three different levels with a structure made of steel and concrete (independent from the bearing structure of the building) [1]. The Ground floor and the 1st floor, that have been hence obtained, have a net height of 2.95 m, whereas the 2nd floor have an average net height of 2.75 m. The 1st floor and the 2nd one don't take up the whole surface

of the Ground floor (Fig. 2): the 1st floor is detached from the original vertical walls but it follows their shape, whereas the 2nd floor is smaller and it allows the view of the 1st floor and the old gothic arch windows which are present on the North façade of the building (Fig. 1c). The Ground floor, leading to the heart of the library, houses the “Web” area, the “Newspaper” area and a part of the consultation and reading area, the consultation and reading areas are present also at the 1st and at the 2nd floor and they are served by stairs and lifts. The service rooms (i.e. books storage, staff’s offices, manager’s office) and the children rooms are placed in the spaces contiguous to the reading rooms and they have independent entrances, to promote direct and controlled accessibility (Fig. 2).
The lighting design, which is described in the next sections, mainly concerns of the consultation and reading areas. The daylighting and artificial lighting simulations have been done by using *RELUX Lighting Simulation* software [2-4], the analysis of the Lighting Energy Numeric Indicator (LENI) has been done by using *LUX R0.1* software, which has been developed by the Authors in accordance with the European technical standard EN 15193 [5].

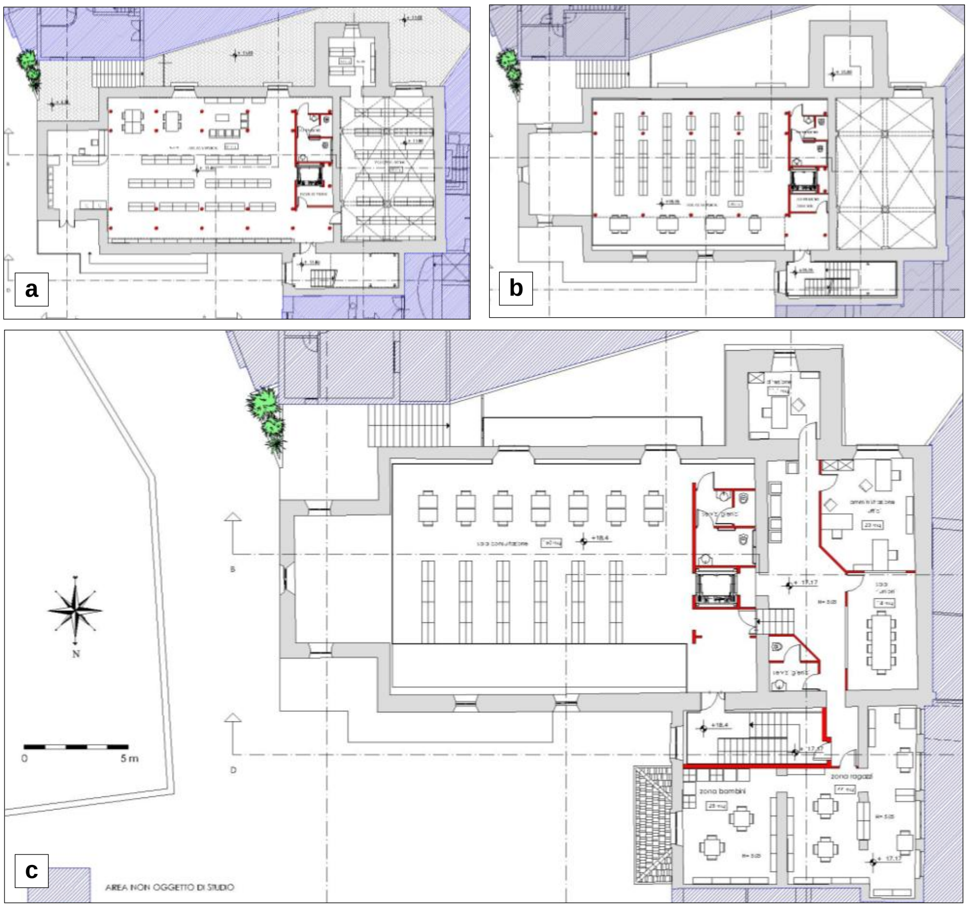


Figure 2 – Project drawings [1]: a) Ground floor; b) 1st floor; c) 2nd floor (the furnishings positions are shown).

DAYLIGHTING DESIGN

Since the preliminary project, in order to have the maximum availability of daylight, an accurate analysis of the furnishings arrangement has been conduced with reference to the windows locations, which are on the North façade (old gothic arch windows) and on the South façade (Figs. 1c, 1e). In Fig. 3 it is well pointed out how the presence of the new floors (inside the nave of the Church) changes the daylight distribution. The daylight simulations, which are shown in Fig. 3, are referred to 21st of June (CIE overcast sky) and they are evaluated for 10.00 am, time in which the maximum users’ presence is expected. In the case of the 2nd floor, chosen as example, the daylight simulations results are shown. In particular in

Tab. 1 the values (average, minimum and maximum) of the daylight factor (D) and of the illuminance (E) are reported for working planes (reading tables) which are located 0.8 m above the floor. The simulations have repeated for the 21st of June and for the 22nd of December both in the case of CIE overcast sky and in the case of CIE clear sky at 10.00 a.m., noon, 4.00 and 6.00 p.m., which represent the central time range of the diurnal opening of the library. From the simulations results it can be observed that the calculated values of D (for every floors) are inferior to the average reference value of 0.03 [6]; hence an accurate artificial lighting design has been developed.

Figure 3 – Daylight simulations, 21st of June (CIE overcast sky) at 10.00 am.

time	**Illuminance, E** (lx)			**Daylight factor, D**			**Illuminance, E** (lx)		
	ave	min	max	ave	min	max	ave	min	max
	June, 21th – Overcast sky						June, 21th – Clear sky		
10.00 am	77	1	330	0.5	0.01	2.2	113	4	213
noon	100	2	422				117	5	326
4.00 pm	87	2	367				78	2	287
6.00 pm	56	1	233				58	1	172
	December 22sd – Overcast sky						December 22sd – Clear sky		
10.00 am	33	1	141	0.5	0.01	2.2	893	11	572
noon	45	1	196				1970	23	14800
4.00 pm	13	0.5	57				136	3	225

Table 1: Daylight simulations (2nd floor, reading tables), values of E (lx) and D.

ARTIFICIAL LIGHTING DESIGN

In this case the average horizontal illuminance on the working planes (E_{Have}), the average vertical illuminance on the bookcases (E_{Vave}), the uniformity of illuminance ($U=E_{min}/E_{ave}$), and the Unified Glare Rating (UGR) have been calculated. The artificial lighting design has been developed by taking into account the following requirements [7]: $E_{Have}\geq500$ lx and $U\geq0.8$ on the working planes in the reading areas (0.8 m above the floor), $E_{Have}\geq100$ lx on the working planes in the hallways (0.2 m above the floor), UGR<19 for observers in the reading areas, $E_{Vave}\geq200$ lx on the bookcases, $U\geq0.20$ on the bookcases (notice that this last value has been fixed by the Authors in absence of a standard reference value). In order to avoid direct glare phenomena, luminaries with very controlled light emission have been selected. In Tab. 2 and Fig. 4 the selected luminaries with their main characteristics and the luminaires positioning are respectively shown. In Tab. 2 the areas to which each luminaire is functionally dedicated are also indicated. In the case of the 2nd floor, the simulations results about artificial lighting are summarized. In Tab. 3 (left side) the values of E (lx) and of U on the working planes (i.e. reading tables, hallways and bookcases) are reported. For the observer in the 2nd floor (Fig. 4c) the UGR values are inferior to 19 for all the directions that have been considered (North, West and North-West, see Fig. 4c). Once defined the artificial lighting system, the simulations have been repeated also in the case of mixed (day- and artificial) lighting (see Tab. 3, right side). From the analysis of the values reported in Tab. 3, it can be noticed that the standard lighting requirements [6-7] are completely satisfied. Finally, both in the case of artificial lighting (Figs. 5a-b) and in the case of mixed lighting (Fig. 5c) three 3D photorealistic images of the library are shown.

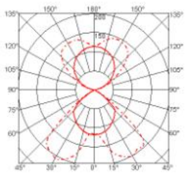
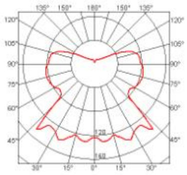
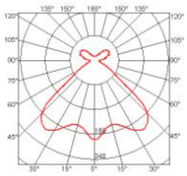
Photos	Polar diagrams	Main characteristics	Quantity
		Name: iGuzzini LIGHT AIR up/down cod.3376 Overall dimensions: 1400x240x56 mm (LxWxH) Luminaire efficiency: 0.89 N° of lamps per luminaire=2 Lamp: linear fluorescent (T16) ▪ Electric power: 35 W ▪ Luminous flux: 3.7 klm ▪ Luminous efficacy: 104 lm/W ▪ Colour temperature: 4000 K (Location: “Web” area, “Newspaper” area, Consultation and reading areas)	**60** 20 at Ground floor 24 at 1st floor 16 at 2nd floor
		Name: iGuzzini MINIBERLINO cod.6326 Overall dimensions: 108x128 mm (DxH) Luminaire efficiency: 0.83 N° of lamps=1 Lamp: low-voltage halogen (QT12) ▪ Electric power: 50 ▪ Luminous flux: 0.93 klm ▪ Luminous efficacy: 18 lm/W ▪ Colour temperature: 3000 K (Location: Entrance)	**3** 3 at Ground floor
		Name: iGuzzini BERLINO cod.4337 Overall dimensions: 395x446 mm (DxH) Luminaire efficiency: 0.69 N° of lamps=1 Lamp: metal halide (HIT) ▪ Electric power: 70 W ▪ Luminous flux: 5.2 klm ▪ Luminous efficacy: 74 lm/W ▪ Colour temperature: 3000 K (Location: Entrance, Hallways)	**14** 6 at Ground floor 4 at 1st floor 4 at 2nd floor

Table 2: Luminaires technical data.

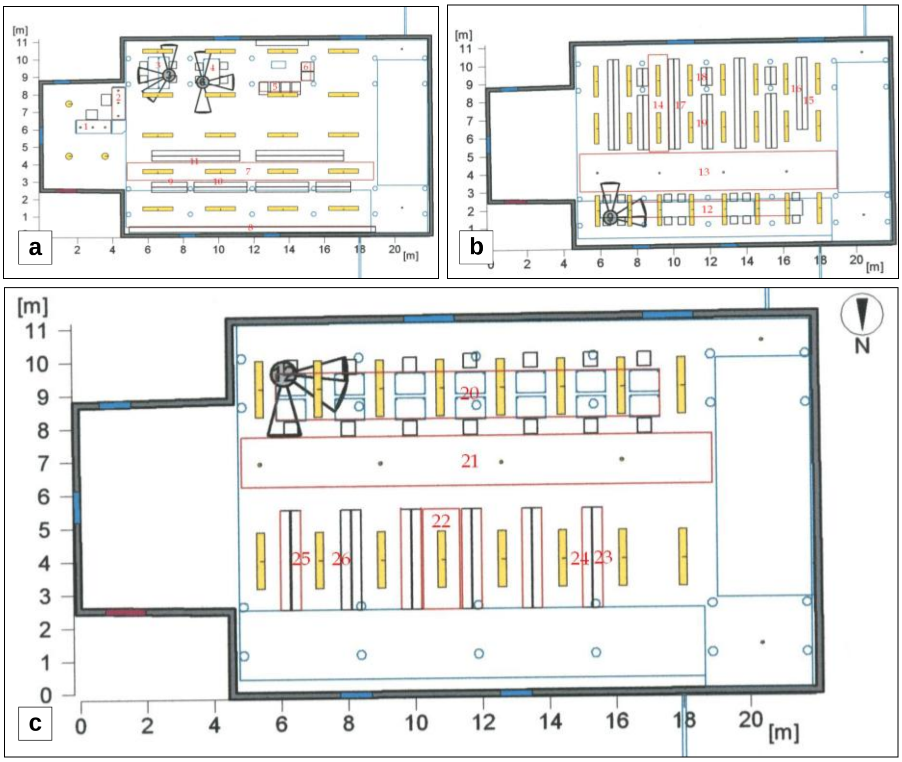


Figure 4 – Luminaires positioning: a) Ground floor; b) 1st Floor; c) 2nd Floor.

Working planes			ARTIFICIAL LIGHTING				MIXED LIGHTING			
			Illuminance (lx)			U	Illuminance (lx)			U
N° (Fig. 4)	Type		ave	min	max		ave	min	max	
20	**Reading tables**	E_H	640	556	749	0.84	738	632	1040	0.79
21	**Hallway**		305	175	438	0.58	357	228	525	0.64
22			198	126	228	0.65	256	180	293	0.72
23	**Bookcase**	E_V	261	80	673	0.34	326	106	792	0.35
24			216	46	658	0.24	239	70	688	0.32
25			219	50	789	0.26	267	97	894	0.40
26			210	49	653	0.26	246	66	725	0.30

Table 3: Lighting simulations (2nd floor, working planes), values of illuminance (E, lx) and uniformity (U).

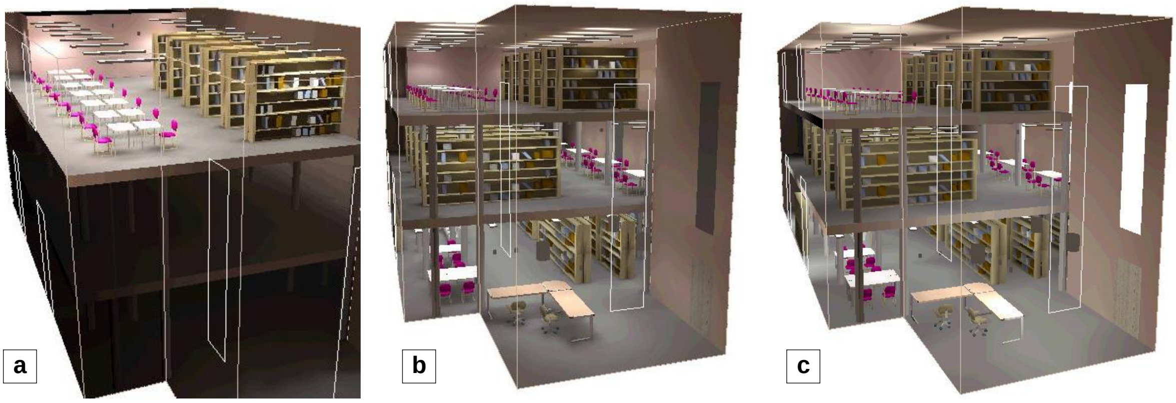


Figure 5 – 3D photorealistic images: a) 2nd floor artificial lighting; b) artificial lighting; c) mixed lighting.

EVALUATION OF THE LIGHTING ENERGY NUMERIC INDICATOR

The total energy used for artificial lighting, W (kWh/year), in a room (or in a building) can be estimated by the following equation [5]:

$$W=W_L+W_P \tag{1}$$

- W_L is the lighting energy required to fulfill the lighting requirements (e.g. in accordance with Ref. [7]);
- W_P is the parasitic energy required to provide charging energy for emergency lighting and for standby energy for lighting control.

The evaluation of W_L and W_P can be made using the following equations [5]:

$$W_L=P_N F_C F_O(t_D F_D+t_N) \qquad W_P=P_{pc}(t_Y-t_O)+P_{em}t_{em} \tag{2}$$

- P_N (kW) is the total installed lighting power;
- P_{pc} (kW) is the total installed parasitic power of the lighting control devices;
- P_{em} (kW) is the total installed charging power of the emergency lighting luminaries;
- t_O (h), is the annual number of operating hours of the lamps and luminaries: $t_O=t_D+t_N$, with t_D (h) operating hours during the daylight time and t_N (h) operating hours during the non-daylight time;
- t_Y (h) is the standard year time (t_y=8760 h);
- t_{em} (h) are the operating hours during which the emergency lighting batteries are being charged;
- F_C is the factor relating to the usage of the P_N when constant illuminance control system (CTE systems) is in operation;
- F_O is the factor relating to the usage of the P_N to occupancy period;
- F_D is the factor relating to the usage of the P_N to daylight availability.

Known W, it is possible to evaluate the Lighting Energy Numeric Indicator (LENI, kWh/m^2 year), of a room (or a building) with S (m^2) total useful area, using the following equation [5]:

$$LENI=W/S \tag{3}$$

In the case of the lighting design of the new town library discussed in the previous sections, the LENI has been calculated for each floor. In Tab. 4 the calculations results are summarized. The values of P_N are estimated considering the type and the quantity of the installed luminaries (see Tab. 2 and Fig. 4); the values of P_{pc} and P_{em} are estimated by considering the parasitic and emergency specific powers of 0.8 and 5 W/m^2 respectively. The factor F_O is calculated by the equations [5]: $F_O=1-[(1-F_{OC})F_A/0.2]$ (for $0 \leq F_A < 0.2$) and $F_O=F_{OC}+0.2-F_A$ (for $0.2 \leq F_A < 0.9$), with F_A a factor related to the period of absence of occupants and with F_{OC} a factor related to the system used to switch on-off the luminaires. F_D is calculated by the equation [5]: $F_D=1-(F_{D,S}F_{D,C})$, with $F_{D,S}=K_1+K_2\lambda$, where λ is the latitude (*Piombino*, λ=42.9° N) and K_1, K_2 are coefficients depending on the design illuminance values on the working planes (calculated using the results of the artificial lighting design) and whit $F_{D,C}$ a factor depending on the penetration level of the daylight (calculated using the results of the daylighting design). The total LENI for the library has been calculated with the arithmetic mean of the LENI values obtained for each floor, weighted with the floor surfaces, and it results 29.7 kWh/m^{2}year.

	Ground Floor	**1st Floor**	**2nd Floor**	**TOTAL**
S (m^2)	160	155	125	440
P_n (W)	1910	1880	1320	5110
P_{pc} (W)	130	125	100	355
P_{em} (W)	800	775	625	2200
F_C (*) absence of CTE systems	1.0*			
F_O (F_A, F_{OC}) (**) manual ON/OFF type devices	1.0 (0.0, 1.0**)	0.9 (0.3, 1.0**)	0.7 (0.5, 1.0**)	
F_D ($F_{D,S}$, K_1, K_2, $F_{D,C}$)	0.89 (0.54, 0.94, 0.94·10^{-2}, 0.2)	0.89 (0.54, 0.94, 0.94·10^{-2}, 0.2)	1.0	
t_y (h/year)	8760			
t_d (h/year)	2250			
t_n (h/year)	250			
t_{em} (h/year)	200			
LENI (kWh/m^{2}year)	**32.9**	**30.6**	**24.5**	**29.7**

Table 4: LENI calculations.

CONCLUSIONS

The results of an extensive analysis concerning daylighting and artificial lighting of the consultation and reading areas of the new town library to be realized in the nave of the ex-Church of *S. Antimo* are discussed. The use of the *RELUX* software has allowed investigating both the nave daylighting in the current state and the mixed lighting (day- and artificial) of the new-design areas obtained dividing the nave height by a steel structure lying on three levels. The reading of the lighting calculations results in the different simulated conditions has led the design choices towards a more as possible intensive use of daylight as well as to a reduction in the artificial light demand. The energy demand for artificial lighting has been evaluated by calculation of LENI recently introduced in the Italian technical standards.

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DAYLIGHT EXPOSURE AND CIRCADIAN EFFICIENCY IN OFFICE ROOMS EQUIPPED WITH ANIDOLIC DAYLIGHTING SYSTEMS

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ABSTRACT

Anidolic Daylighting Systems (ADS) typically reduce the daylight flux reaching an office room's window section and increase it in the rear of the room. They offer interesting possibilities for the combination of comfortable daylighting and highly energy-efficient office lighting designs. The objective of this study was to get an insight into typical ocular daylight exposures in office rooms equipped with ADS and to compare them to an artificial blue-enriched light source. Results from a recent study by Viola et al. [9] demonstrated that the use of the same light source positively influenced subjective wellbeing and sleep quality in office workers. We recorded daytime irradiance values for several weeks from April-May 2009 in an experimental office setup in our laboratory using a portable digital spectroradiometer. The artificial light sources were measured during the night. With respect to more circadian aspects of day- and artificial lighting designs we finally corrected the measured irradiances with a c(λ)-curve.

Our results showed to which extent external sky conditions influenced light exposure of office workers in an ADS-equipped office room for different sky types. The considered ADS was able to supply natural blue light irradiance levels during large parts of days with intermediate and clear skies, which were much higher than those created by our artificial lighting installation based on two blue-enriched fluorescent lamps. The same was true for weighted circadian irradiance values E_{ec}. We conclude that for the tested ADS-equipped office room, complementary artificial lighting with blue-enriched polychromatic fluorescent tubes might be useful on days with predominantly overcast skies and before 09:00 and after 16:30 on all days.

INTRODUCTION

The southern front of the Solar Energy and Building Physics Laboratory (LESO-PB), located on the campus of the Swiss Federal Institute of Technology in Lausanne (EPFL), is equipped with Anidolic Daylighting Systems (ADS) [1]. These highly efficient daylighting systems typically reduce the daylight flux reaching an office room's window section and increase it in the rear of the room. Thus, glare related problems can be largely avoided and gloomy rear areas can be brightened [2]. Preliminary results in ADS-equipped office rooms within the LESO solar experimental building showed both satisfied office occupants [3, 4] and possibilities for highly energy-efficient integrated lighting solutions [4, 5]. Besides the visual comfort in ADS-equipped office rooms, it is not well understood to which extend the change in room lighting conditions

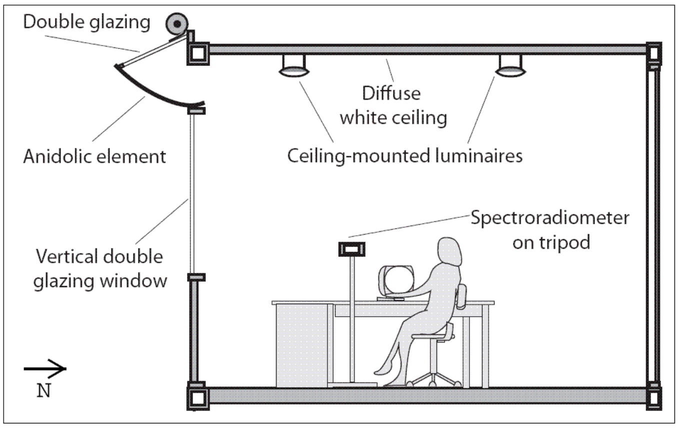


Figure 1: Overview of the experimental setup used during our measurements in spring 2009.

during daytime has an impact on the circadian rhythms and neurobehavioral performance of office occupants. Considering that many people spend a fair amount of their time inside of office rooms, this is a topic that should be taken more into consideration when designing lighting scenarios for office buildings [6, 7].

Recent research has revealed that the impact of lighting conditions on human circadian rhythms is strongly dependent not only on light intensity and timing of light exposure but also on spectral properties of the visible light. In particular, it has been shown that in humans, the circadian peak sensitivity to light as assessed by nocturnal melatonin suppression is in the blue range of visible light between 457-464 nm [8, 10].

We aimed to get an insight into typical ocular daylight exposures in ADS-equipped office rooms and to compare them to an artificial blue-enriched light source. Results from a recent study by Viola et al. demonstrated that the use of the same light source positively influenced subjective wellbeing and sleep quality in office workers [9]. As light in the blue range of the electromagnetic spectrum is most effective to influence circadian rhythms in humans, we wanted to take a closer look at the blue part of the measured ocular irradiance values, especially on its time course across a day. As a last step, we aimed to weight the measured irradiance levels with the only currently available circadian function c(λ), which represents a circadian efficiency-curve based on data from human melatonin suppression by light [11].

METHODS

A portable digital spectroradiometer (Specbos 1201, JETI Technische Instrumente GmbH, Jena, Germany) was fixed on a tripod at the approximate eye level of an office occupant (height 115 cm from the floor; Figure 1). The spectroradiometer was installed in one of the ADS-equipped office rooms in the LESO solar experimental building. We recorded daytime irradiance values for several weeks from April-May 2009. The device was programmed to perform a complete spectral irradiance scan between 380 and 780 nm (with resolution of 1 nm) every 5 minutes. It was connected to a PC and the measured values were continuously stored after each scan. In order to classify the weather on the recorded days, we obtained meteorological data of the same period from the local weather station (Meteosuisse, Pully, VD, Switzerland), which is located at the approximate distance of 7.7 km from the LESO building.

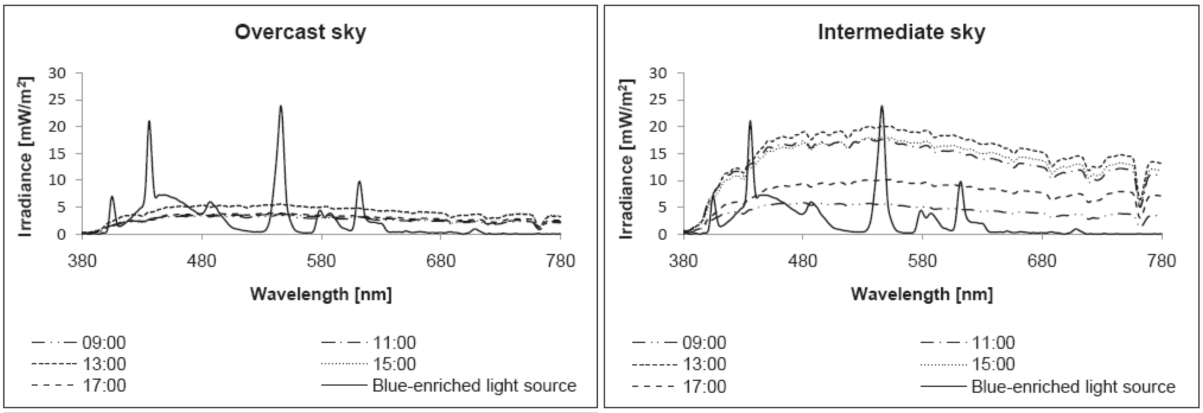
This information was used to assign one of three different sky categories to all of our recorded days: Either “overcast” (0 to 25% of sunshine / working day), or “intermediate” (25 to 75% of sunshine / working day) or “clear” (75 to 100% of sunshine / working day) sky were assigned. For the recordings of the artificial lighting, two ceiling-mounted luminaires (Tulux “Zen 3”) were installed in our test office room (Figure 1). These luminaires were used to measure the ocular light exposure created by two 58 W blue-enriched polychromatic fluorescent tubes (17’000 K, Activiva active, Philips) during nighttime. The resulting horizontal illuminance on the work plane (80 cm above floor level) was 383 lx, the average vertical illuminance at eye level (i.e. the value measured through the cosine-corrected spectroradiometer lens) was 260 lx.

For the analysis of the spectral irradiance values in the blue range of the visible light, we collapsed the data obtained at 465 nm into 2h bins from 09:00 to 17:00, resulting in 4 bins averaged over the days for the same sky condition.

To obtain the c(λ)-corrected irradiance values, a weighted circadian irradiance E_{ec} was calculated from the measured spectral irradiances $E_{e\lambda}$ by using the 'circadian action function curve' (c(λ), [11]). This inverted-U shaped curve c(λ) is based on experimental findings in humans from the action spectra for light induced nocturnal melatonin suppression done by Brainard [8] and Thapan [10]. By means of this circadian action function, a weighted circadian irradiance E_{ec} can be calculated: $E_{ec} = \int E_{e\lambda}\, c(\lambda)\, d\lambda$ [11]. We used the circadian action function curve which was already implemented as selectable function in our spectroradiometer. We took into account the entire visible light spectrum between 380-780nm.

RESULTS

We recorded 18 complete working days (i.e. from 09:00 to 17:00) between March and April 2009. By means of the previously explained classification method, we obtained two days with a mainly overcast sky, nine days with intermediate skies and seven days with mainly clear skies. For visual illustration of the time course across the visible light spectrum between 380 and 780 nm, we plotted the irradiance levels at five different times of day for each sky condition (Figure 2). Plots correspond to averaged values of the corresponding days at 09:00, 11:00, 13:00, 15:00 and 17:00. The spectral irradiances obtained under artificial lighting are equally plotted on each graph for comparative reasons.



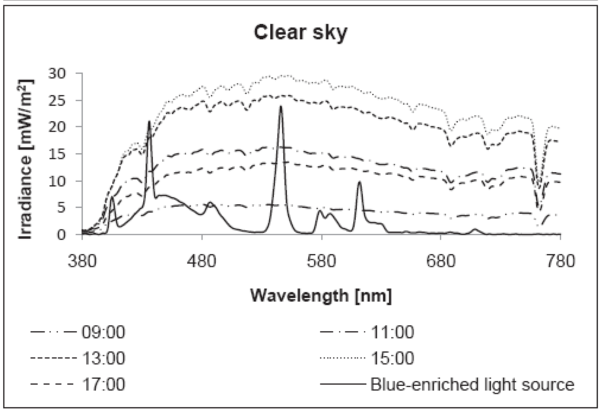


Figure 2: Irradiances at eye level in the visible range of the electromagnetic spectrum for overcast, intermediate and clear skies are shown every 2 hours from 09:00-17:00 h. In addition, the spectrum of the blue-enriched light source is plotted.

In order to investigate the blue range of visible light, the averaged irradiances values at 465 nm are plotted in four time bins across the working day for the three sky types separate (Figure 3). For comparative reasons, the resulting blue light at 465 nm obtained under artificial lighting at nighttime is also shown. A Mann Whitney U-test revealed significant differences between the clear and the overcast sky during all times ($p<0.05$) except for the morning hours (09:00-11:00). There was no significant difference between days with intermediate and clear skies. On overcast days, blue light irradiance at 465 nm was lower in the later afternoon when compared to the intermediate sky condition. The time course on days with clear and intermediate skies exhibited higher values between 11:00 and 15:00 than in the morning or later afternoon ($p<0.05$;

Friedmann-Anova). For the overcast sky there was no significant change in the irradiance level across the day.

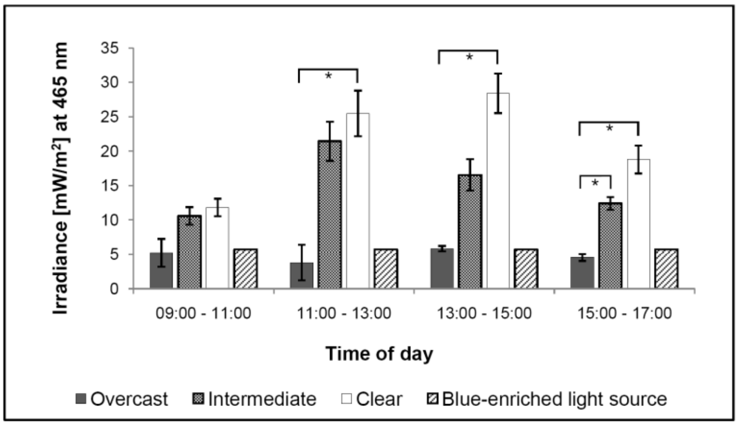


*Figure 3: Daylight irradiances (mW/m2) at 465nm for three sky types between 09:00 and 17:00. *=p<0.05; ± SE, expressed in 2h bins. The irradiance of the artificial blue-enriched light source at 465nm (during night time) is also shown.*

The c(λ)-corrected irradiances (E_{ec}) for overcast, intermediate and clear sky conditions are shown in Figure 4. The c(λ)-corrected irradiance we obtained from the artificial blue-enriched light source was 0.5032 W/m^2 in our specific setting and is indicated in Figure 4 as a vertical line.

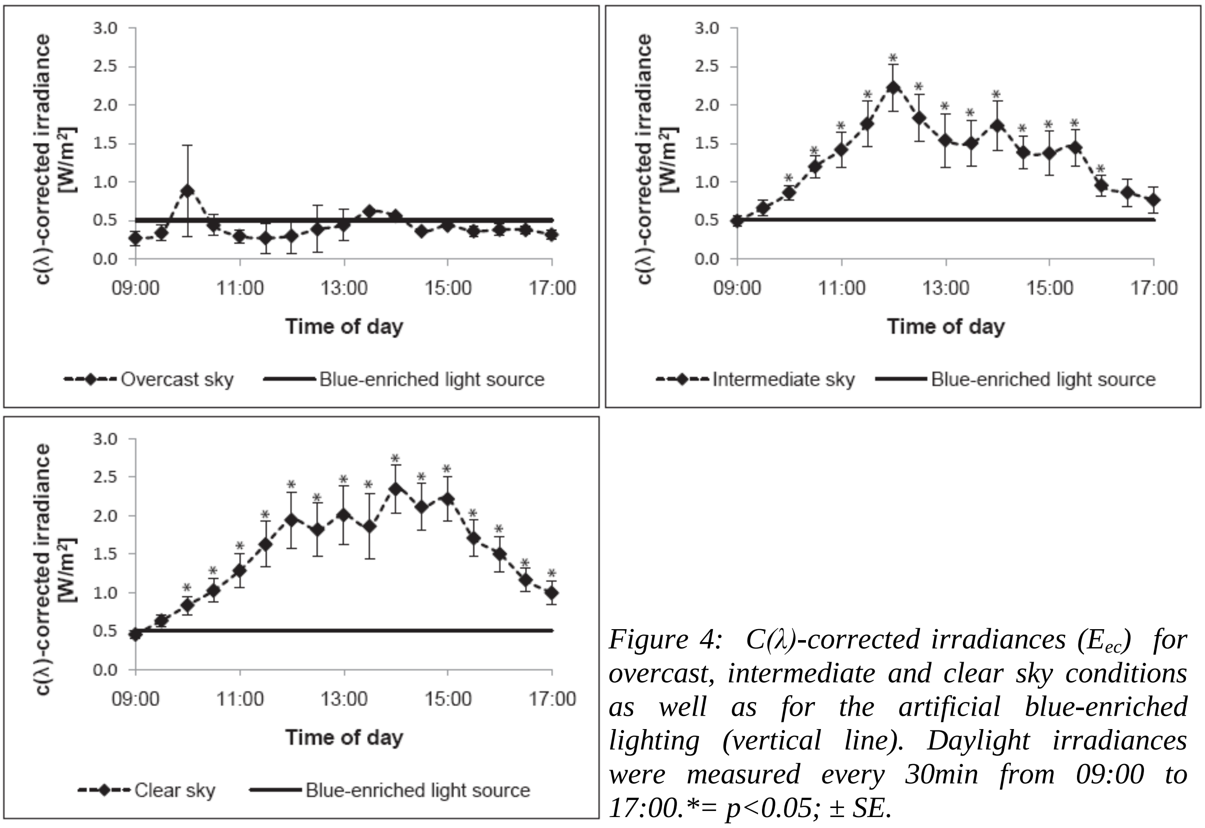


Figure 4: C(λ)-corrected irradiances (E_{ec}) for overcast, intermediate and clear sky conditions as well as for the artificial blue-enriched lighting (vertical line). Daylight irradiances were measured every 30min from 09:00 to 17:00.= p<0.05; ± SE.*

For intermediate and clear days, the c(λ)-corrected irradiance levels were significantly higher during large parts of the working day than the artificial lighting ($p<0.05$; t-test), except in the morning hours before 10:00 and in the afternoon after 16:00. However, for overcast sky conditions, the c(λ)-corrected irradiance levels are close to those with artificial lighting conditions ($p>0.1$). When we compared the different sky conditions, we found significantly higher c(λ)-corrected irradiances on clear days, between 14:00 and 16:30 in the afternoon than during overcast days and slightly higher between 11:00 and 13:00 ($p<0.1$). Irradiances on clear days were also higher at 16:00 compared to intermediate sky conditions ($p<0.05$). On overcast mornings between 10:30 and 12:00 the c(λ)-corrected irradiance levels were slightly lower than those with intermediate sky conditions between 10:30 and 12:00 ($p\leq0.05$).

DISCUSSION

As expected, we found significant differences of daylight irradiances between the three sky types (Figure 2-4). Our results also showed the variability of irradiances and the spectral composition across working hours between 09:00 and 17:00. Irradiance values for overcast skies are in general much lower than those of intermediate and clear skies, especially between 11:00 and 15:00. Yet higher irradiance values are obtained on clear days, especially between 13:00 and 15:00. The same effects are visible in Figure 3 where we analyzed only the spectral irradiance at 465 nm.

These initial findings visualize the fact that the daylight exposures of occupants in those ADS-equipped office rooms are increasing when the weather outside is improving (i.e. the sky is clear). In other words, the occupants can benefit from nice weather, even while working inside. One could of course argue that glare might occur and visual comfort might decrease when ocular irradiances increase. However, we can assume from this and earlier work that good visual comfort was generally achieved during our experiments [1-4]. The occupants usually “ease” temporarily occurring glare by using the installed window blinds. Glare typically occurs on clear days when there is a high risk of direct sunlight reaching the office. Furthermore, such situations typically occur in the mornings and afternoons when sun elevations are comparably low.

As a matter of fact, the irradiance differences that are apparent in Figure 2 and 4 between 11:00, 13:00 and 15:00 are more important under clear sky conditions than under intermediate sky conditions. Those differences could be the result of closed window blinds on the mornings of clear days. Interestingly, around 09:00 the irradiance levels are similar under all three sky conditions. If our objective would be to add artificial light on overcast days in order to make the ocular irradiances comparable to those occurring on clear days, this would be most easily achievable in the early mornings. Furthermore, the graphs for intermediate and clear skies in Figure 2 visualize the fundamental differences between artificial fluorescent light and daylight: Whilst the fluorescent light spectrum is mainly composed of several distinct peaks (centered on the emitting wavelengths of the applied fluorescence substances) the daylight spectrum is much more continuous and complete: virtually no wavelengths are “missing”.

The comparably low spectral irradiance in the blue range achieved under the artificial blue-enriched light source (Figure 3) might seem surprising at first sight. This can partly be explained by the fact that the “blue peak” of the artificial lamp is at approximately at 436 nm (Figure 2), which had of course no influence on the irradiance levels at 465 nm.

After their experiments in a UK office building, Viola et al. concluded that the lighting situation created by the newly installed blue enriched lighting design was sufficient to improve alertness, performance and mood as well as subjective sleep quality in office workers. The average horizontal work plane illuminance during their experiments was found to be 310 lx. The lighting design in our test office room led to an average work plane illuminance of 383 lx. Thus, the two lighting designs are comparable. Whether we might find the same positive effects in our office occupants in terms of alertness, performance, mood and sleep quality, needs to be tested. We may assume that any other light source which performs at least as well as the two blue-enriched light sources in terms of weighted circadian irradiance E_{ec} could also induce those positive effects. Therefore, on working days with intermediate and clear skies, no additional blue-enriched artificial light would be needed in our ADS-equipped office rooms during very large parts of the working day: daylight almost always creates sufficiently high E_{ec} levels (Figure 4). However, the plots in Figure 4 suggest that additional artificial lighting with blue-enriched polychromatic fluorescent tubes such as “Activiva active” might be useful on overcast days and even before 09:00 on days with intermediate and clear skies, in order to improve the building occupants’ wellbeing, alertness, performance and mood.

CONCLUSION

Our results showed to which extent external sky conditions influenced light exposure of office workers in an ADS-equipped office room for different sky types. We also found that the considered ADS was able to supply natural blue light irradiance levels during large parts of days with intermediate and clear skies, which were much higher than those created by our artificial lighting installation based on two blue-enriched fluorescent lamps. The same is true for weighted circadian irradiance values E_{ec}. It seems admissible to assume that, within this tested ADS-equipped office room at the LESO solar experimental building, complementary artificial lighting with blue-enriched polychromatic fluorescent tubes might are useful on days with predominantly overcast skies and before 09:00 and after 16:30 on all days. Our results suggest that in all other cases, the available daylight is sufficient during this time of year.

Finally, the use of the circadian action function c(λ) has of course several limitations because it does, for example, not account for the length of light exposure and is based on nocturnal melatonin suppression only.

Further research will reveal whether daylight and ADS are sufficient to obtain the described positive effects [9] without artificial lighting and to also investigate objective variables. In particular, we need to quantify how much artificial lighting is required to complement insufficient natural light conditions, especially in the blue range of visible light, in order to optimize circadian biological and behavioral functions of office workers and other populations.

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The study of two different natural light transportation systems using a simulation software

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Abstract

In recent years an increased sense of awareness has been spreading throughout the world on particular problems like carbon emissions, global warming and sustainable design. The planned use of natural light in residential and in non-residential buildings has become of strategic importance. The use of natural light can improve the energy efficiency by minimizing lighting, heating and cooling loads and it can also significantly improve the quality of light in an indoor environment due to its quality, spectral composition and variability[1].

This paper presents the results of the numerical comparison between the performances of two different toplighting systems in a windowless test room. The aim is to analyse the luminous intensity distribution for several sky/sun conditions. The first system is a square skylight whose side measures 0,25m; the second system is a lightpipe, it is 0,5m long and the diameter of the top collector and of the internal diffusive device is 0,25m.

The numerical results are carried out by the ray-tracing program Desktop Radiance that accurately predicts the light levels and that produces photo realistic images of the architectural space in all sky conditions: illuminance values and isolux diagrams are obtained respectively through camera measurements and through reference point measurements. The performances of these two different daylighting systems have been analysed for different months of the year.

Introduction

There are two major ways to deliver daylight to the workplane: toplighting and sidelighting. The decision to use toplighting rather than sidelighting is sometimes based upon design criteria other than the lighting needs of the buildings: for example, in a building whose perimeter surfaces need to be used as work surfaces, in areas where security requirements reduce the desirability of sidelighting or where a view in or out is inappropriate such as in a medical examination room, toplighting may be a good solution; similarly, in a single-story building that is very deep, toplighting may be more appropriate than sidelighting or they may be used together [2].

In this paper two toplighting systems are under test: a skylight and a lightpipe.

They provide a uniform distribution of light across the workplane and, because the light comes from above, they provide good visual comfort.

Numerical simulations to compare the illuminance performances of two different toplighting systems during several months of the year were carried out using Desktop Radiance.

METHOD

Desktop Radiance

Desktop Radiance is a lighting simulation software that uses the ray tracing algorithm to determine luminance or illuminance values which are further processed to produce photometrically accurate renderings.

The lighting software uses an AutoCad-based front end, along with libraries of materials, glazings, electric lighting luminaires and furniture. Libraries are accessible through a graphical user interface and include an editor for user-defined materials.

The overall package includes a simulation control interface, an interactive rendering module that allows quick view and control of the rendered image while it is being computed. It is also possible to change exposure, to generate isolux and false color images, as well as to adjust the image to account for the sensitivity and dynamic range of the human eye.

Finally, Desktop Radiance includes a Simulation Manager that allows management and control of multiple simulation runs. Through the Simulation Manager, it is possible to duplicate and modify prior simulations to explore alternative scenarios with respect to accuracy, time of the day, sky conditions, etc. It is also possible to develop userdefined materials, glazing, luminaries and furniture [3].

The first step in the process of performing a daylighting analysis is the creation of a 3D model, that represents the room under test, using a Graphic Editor program such as AutoCAD.

The dimensions of the test room we chose are 2,6m x 3m x 3m, there are no windows and the walls, the ceiling and the floor have different reflectance values: the ceiling and three walls have the reflectance of 66%, the south wall has the reflectance of 55% and the floor has the reflectance of 46%.

Two 3D identical models of the same test room were drawn.

Skylight simulations

In the first test room model a skylight whose side measures 0,25m was drawn in the centre of the ceiling. From the Glazing Library a glass with a transmittance coefficient value of 88,7% was chosen. Then sky condition (Overcast sky) and geographical coordinates of the test room site (Ancona) were defined. The analysis parameters such as camera views and reference point calculations were defined to carry out the numerical simulations.

Simulations were performed for all the days of each month at 12 p.m.

The average day, defined for each hour of each month as the hourly mean internal and external illuminance value in a month, was then introduced to have a global vision of the internal and external illuminance.

The internal illuminance was measured under the skylight both on the floor and at 0,85m height from the floor, to simulate a working plane. The external illuminance was measured on the laboratory’s roof.

Lightpipe simulations

The lightpipe analysis was carried out in two steps: the experimental monitoring of the lightpipe and numerical simulations of a lightpipe model.

An experimental monitoring of a lightpipe system installed on the roof of a laboratory was performed during the year 2007 to examine the internal illuminance. During this period a database of internal and external experimental illuminance values was created.

The lightpipe under test is 0,5m long and the diameter of the top collector and of the internal diffusive device is 0,25m. The lightpipe consists of a top collector made of an acrylic hemispheric dome, a 99% reflective mirror duct and an internal prismatic diffuser device.

In the laboratory there were two illuminance sensors: an external sensor was located on the roof of the laboratory and an internal one was connected to a data acquisition system. The internal sensor was positioned under the emitter at 0,85m height from the floor, simulating a working plane, to record the illuminance data. Consulting a weather prediction database, the overcast days for each month under test were known. The external illuminance values that matched the external ones obtained by the skylight simulations for the overcast sky conditions were used to analyse the corresponding internal illuminance data.

External and internal illuminance values corresponding to the overcast sky conditions at 12 p.m. were then elaborated to obtain the average day experimental values [4]. Using the lightpipe internal illuminance data, IES files with lightpipe's photometric informations were drawn up for each month [4], [5] and then they were loaded in Desktop Radiance Luminaire Library with a CAD design that represents the lightpipe as an artificial lamp.

The second 3D model of the test room was used to study the lightpipe performances with the same geometrical dimensions and with the same reflectance properties of the test room model used for skylight simulations. Analysis parameters such as camera views or reference point calculations were defined to carry out the numerical simulations.

The internal illuminance was measured under the lightpipe both on the floor and at 0,85m height from the floor, to simulate a working plane.

RESULTS

The simulations of the illuminance results for two different natural light transportation systems were carried out for some average days of the year at 12 p.m.. The reference points were put on the floor plane and at 0,85m height to simulate a working plane.

The systems under test were a square skylight whose side measures 0,25m, and a lightpipe that is 0,5m long with a diameter of 0,25m.

The maximum lightpipe internal illuminance was obtained in a spring month (May):it was 207,09 lux on the working plane and 145,48 lux on the floor plane; in the same month for the skylight simulations we had 103,09 lux on the working plane and 66,53 lux on the floor. In the month of May the percentage deviation between lightpipe and skylight illuminance results is 50,22 on the working plane and it is 54,26 on the floor.

The maximum skylight internal illuminance was obtained in a summer month (June):it was 106,24 lux on the working plane and 68,59 lux on the floor plane; in the same month for the lightpipe simulations we had 128,06 lux on the working plane and 89,53 lux on the floor. In the month of June the percentage deviation between lightpipe and skylight illuminance results is 17,03 on the working plane and it is 23,38 on the floor.

The minimum internal illuminance for both the lightpipe and the skylight was obtained in a winter month (January). For the lightpipe it was 57,01 lux on the working plane and 40,6 lux on the floor while for the skylight it was 48,06 lux on the working plane and 31,02 lux on the floor. In the month of January the percentage deviation between lightpipe and skylight illuminance results is 15,69 on the working plane and it is 23,59 on the floor.

In a winter month (February) the lightpipe illuminance referred to the working plane was 77,19 lux and it was 54,29 lux on the floor, while the skylight illuminance was 61,14 lux on the working plane and it was 39,46 lux on the floor.

In a summer month (August) for the lightpipe the internal illuminance was 151,3 lux on the working plane while on the floor plane it was 106,28 lux while it was 98,22 lux on the working plane and on the floor plane it was 63,41 lux.

The minimum percentage deviation for the illuminance comparison is obtained in the month of April and it is 5,82 on the working plane and it is 13,53 on the floor. The maximum percentage deviation for the illuminance comparison is obtained in the month of May.

Month	Lightpipe (lux)	Skylight (lux)	D%
January	40,6	31,02	23,59
February	54,29	39,46	27,31
March	62,61	49,99	20,15
April	69,96	60,49	13,53
May	145,48	66,53	54,26
June	89,53	68,59	23,38
July	94,83	67,54	28,77
August	106,28	63,41	40,33

Table 1: Internal illuminance on the floor.

Month	Lightpipe (lux)	Skylight (lux)	D%
January	57,01	48,06	15,69
February	77,19	61,14	20,79
March	88,97	77,41	12,99
April	99,48	93,69	5,82
May	207,09	103,09	50,22
June	128,06	106,24	17,03
July	134,73	104,51	22,43
August	151,3	98,22	35,08

Table 2: Internal illuminance on the working plane.

The isolux diagrams of these different natural light transportation systems have the common feature of reaching the highest illuminance values in the centre of the floor and of a progressive decreasing of the illuminance values coming from the centre of the floor towards the walls.

Figure 1 shows the skylight and the lightpipe isolux in the month of February at 12 p.m.. The maximum illuminance values on the floor were respectively 39,46 lux and 54,29 lux.

Figure 2 shows the skylight and the lightpipe isolux in the month of May at 12 p.m.. The maximum illuminance values on the floor were respectively 66,53 lux and 145,48 lux.

Figure 3 shows the skylight and the lightpipe isolux in the month of August at 12 p.m. The maximum illuminance values on the floor were respectively 63,41 lux and 106,28 lux.

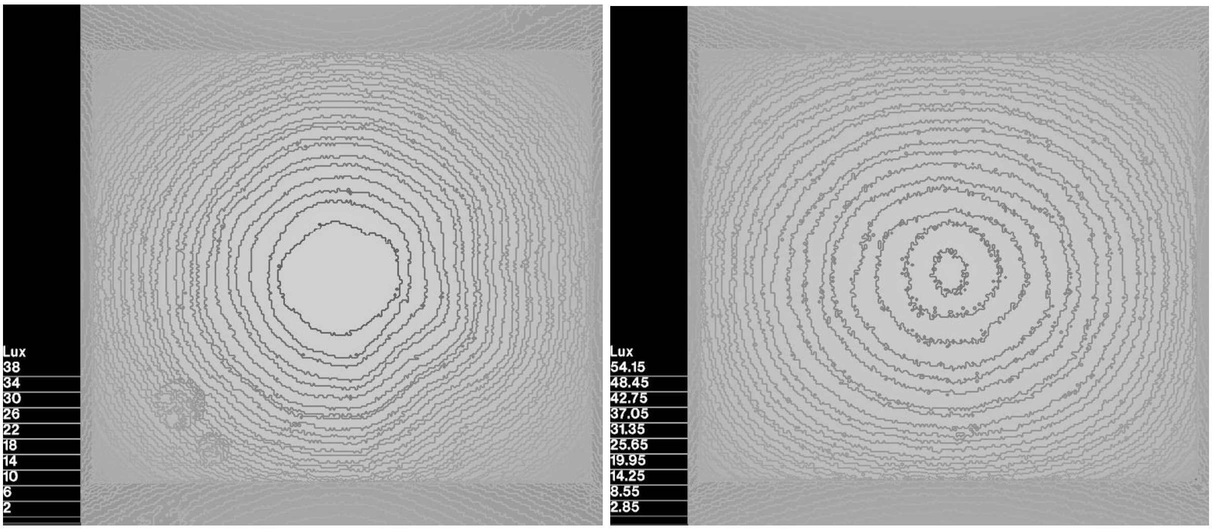

Figure 1: On the left the skylight and on the right the lightpipe isolux on February at 12 p.m..

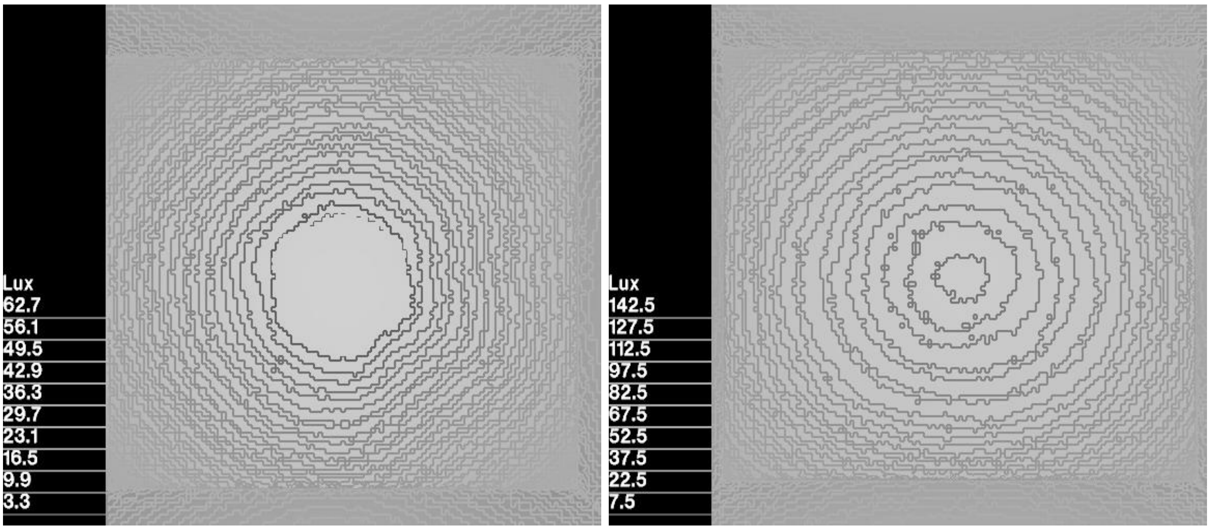

Figure 2: On the left the skylight and on the right the lightpipe isolux on May at 12 p.m..

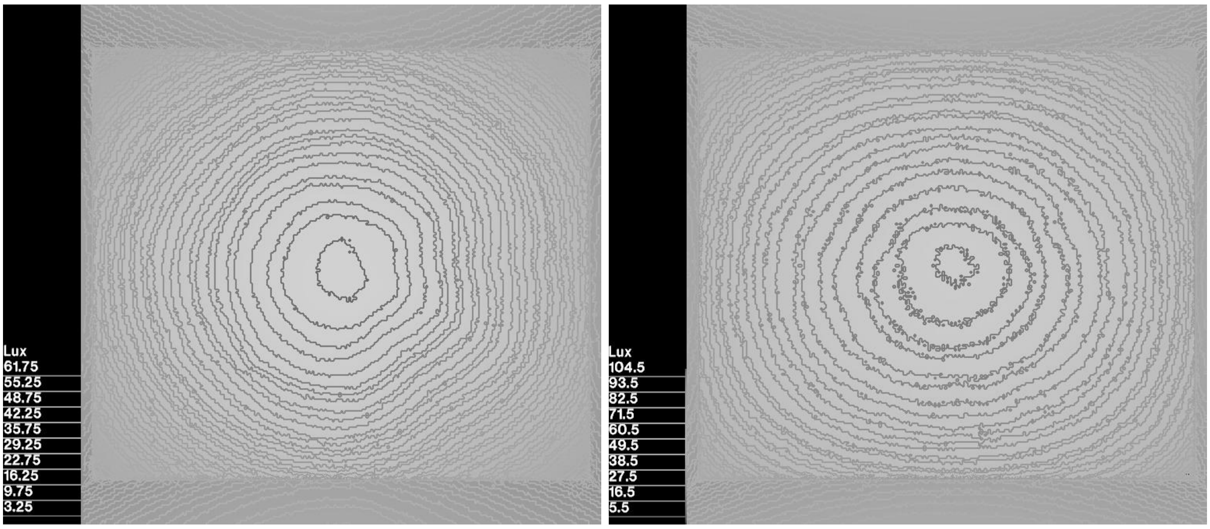

Figure 3: On the left the skylight and on the right the lightpipe isolux on August at 12 p.m..

CONCLUSION

The use of natural light in architectural systems is very important to reduce energy consumption and for a better visual comfort of the occupants.

The natural light transportation systems are studied in order to evaluate the effects of their performances in different configurations of several architectural systems. This paper shows the comparison between the numerical illuminance values of two different natural light transportation systems installed in a windowless test room: a square skylight and a lightpipe.

The skylight's side measures 0,25m; the lightpipe is 0,5m long and the diameter of its top collector and of its internal diffusive device is 0,25m.

A numerical model of the lightpipe system was created and illuminance simulations in some months at 12 p.m. were performed for both the lightpipe and skylight .

The illuminance data of these different architectural solutions were then compared and the percentage deviation between the results was calculated to have a global vision of the behaviour of these natural light transportation systems.

The lightpipe technology improves the capturing of the light rays and their reflections inside the high reflective pipe. So all the light energy coming from the sky and the sun reaches the diffuser, except the very small lost fraction absorbed by the dome and the diffuser, and that lost in the pipe, not reflected at each stroke.

In the period under test the highest illuminance values were obtained in lightpipe simulations runs. The percentage deviations show that the lightpipe is best performing during all the year: from 5,82% to 50,22% and the percentage value depends on the month under test.

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NATURAL AND ARTIFICIAL LIGHTING INTEGRATED SOLUTION FOR BUILDING ENERGY SAVINGS

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ABSTRACT

Due to an increasing demand for improved indoor environmental conditions and a need for energy saving, development of daylight exploitation products has accelerated. Among these products light-pipes, which bring natural light indoors where sunlight cannot reach without generating excessive heat, are one such example.

During the last years several prototypes have been developed and experience has been obtained in daylight collection and transportation; light pipes, for example, represent simple systems to capture and transport natural light inside a room. Nowadays, tubular skylights compete with conventional skylights, particularly in commercial and residential buildings but, due to the system complexity, prediction of the illumination performance and energy saving obtained has always been a difficult task and some tentative studies have been proposed by researchers and some light-pipes manufacturers.

In this paper particular attention is paid to the integration of a light pipe system with artificial light; the combination of the two has led to a research project for the development of an integrated daylight & artificial light tubular system that combines the benefits of natural lighting with artificial lighting.

A sensor detects the illumination intensity on a work-plane with the aim to achieve the required conditions for visual comfort; a home automation system modulates the lighting according to the natural light available and manages the light shaft to control the balance of natural and artificial light provided to maintain a predetermined illumination intensity and achieve energy savings.

The aim of this paper is to provide a review on the availability of tubular light transportation systems made in the world with particular emphasis on Europe and US and to show the first performance results of a system proposed in a specific application both for a commercial and a residential building near Ancona in Italy.

INTRODUCTION

Over the last decade there has been an increased interest in saving energy. This, together with a growing concern for the environment, has promoted the growth of daylight technology in the field of sustainable architecture. Furthermore, several studies have proved that natural light increases human performance and comfort in indoor spaces. The use of daylight appears then as a good strategy to offset artificial illumination and to make a space more amenable, but it also has its design challenges. A variety of lighting devices have been designed and researched to improve penetration of daylight and to increase user acceptance. Of particular interest for this aim is the transport of natural light inside the room without aperture, such as an underground environment, where illuminance levels are not sufficient. Bouchet [1] suggested that as little as 50 lx of daylight may provide significant relief to the isolation feeling of people working in underground spaces. Therefore, in all of these cases, it could be useful to utilize a set of recently developed light transport systems such as light-pipes.

They are simple structures that allow the transmission of daylight from the outside to the inside of a room. They consist of a top collector (often just a polycarbonate hemispheric dome), the pipe itself, and an emitter. In the last years however, the increase of interest in this technology has carried forward a development of new products which are similar but different in their primary operating principles and the kind of light they were designed to utilise. Starting from an overview of daylighting technologies under IEA Task 21, in this paper we firstly considered the up to date models commercially available [2] divided providing an accurate description of their characteristics. The proposed system of categorization was adopted for the review of tubular skylight technologies in order to promote a standard approach to identifying and assessing innovative daylighting systems.
In addition, this paper presents the first results of an experimental study of daylighting performance of a light pipe under the climatic conditions of Central Italy considering its application in a low energy building. The light pipe is a simple and effective daylighting device widely used in North America and Australia but has so far found limited acceptance in Italy (and Europe). One of the main obstacles to its wider application consists in the lack of standardized data regarding real performances and the absence of photometric data suitable for its implementation in a daylighting simulation software.

PRODUCTS AVAILABILITY

Referring to the state of the art, the systems for capturing and transporting natural light can be classified in two categories: fixed and active furniture [3].

- The first systems are lacking in mobile parts and consequently their management is simple and inexpensive. They are more used in residential, commercial and industrial buildings.
- The second systems use active elements for capturing and concentrating solar beams and are designed to be constantly oriented towards sun direction. These are technologically very complex as they demand sophisticated mechanisms in order to guarantee movements precision. The employment of such systems only finds a justification for demonstrative participations or for application on a wide scale; while they turn out inapplicable for standard use because of the high cost of construction, management and maintenance.

Standard light pipe

By the mid-1990s the passive solar light pipe technology was established and gaining popularity commercially. In their application to daylighting, light pipes are variably called sun pipes, solar pipes, solar light pipes, tubular skylights, tubular daylighting devices or daylight pipes. Light pipes, lined with highly reflective material, are used to guide sunlight and daylight into occupied spaces. They allow light to go through complex roof spaces to reach rooms that are not easily accessible to skylights. Today commercial light pipes are available from a number of manufacturers, in straight and bent sections for on-site assembly and installation. A light pipe is normally fitted with a clear top dome which prevents the entry of rain water and dust. Usually the top collectors are glazing skylights manufactured from 3.0 mm clear uv-stabilised polycarbonate with around 85% light transmission. They are resistant against loss of impact strength, excessive yellowing and loss of light transmission. In some cases, polycarbonate secondary glazing is also available to maximise insulation levels along with the use of skylight tube insulation.

With reference to the top collector, some industries added a special part for increasing the ability of capturing the natural light, especially the light coming from the sun. It concerns the models of the Solatube International including the fitting of laser cut panels (LCD) to the collector called Raybender 3000 Technology and a little metal foil called LightTracker Reflector. The aim of these systems is to deliver an Effective Daylight Capture Surface (EDCS) significantly higher than the previous models. Such systems capture, both in refraction and in reflection, low-angled morning and afternoon sunlight and redirect it into the shaft to extend daily daylight penetration.

In winter season, Raybender 3000 Technology captures not only lowangled sunlight on the horizon, but also redirects diffuse light from the sky vault delivering vastly higher light levels. Another way used by SolarSpot for increasing the sun capture is the RIR system (Reflected Interactive Refraction). It consists of a Fresnel lens placed inside the top collector which redirects the sunlight, similar to the previous system. Furthermore the Sunscoop utilizes the system called Light and Sun Deflector (LSD) which intercepts direct sunlight that would otherwise miss the top of the system at both low and high incident angles, reflecting it down to the tube. This system is comparable with the LightTracker Reflector of the Solartube.
Table 1 shows the common products on the market .

Company	**Product**	**Reflecting material**	**R (%)**	**Diameter (mm)**	**Collector optimiz.**
Elite Solar Systems, Inc.	Solar Lighting	MiroSilver anodized	98,0	150-250-400-500-600	
SolarWill	Lumitube Solaire	ALANOD miro silver	98,0		
Solartrading	Solarspot	3M VMF	99,5	250-375-530-650	x
Solatube International, Inc.	Solatube	SpectraLigh Infinity	99,7	250-350-530	x
Fakro	Light Tunnel	-	-	220-350-550	
Sun Pipe Company, Inc.	Sun Pipe	Solar Silver-98	98,0	220-330-530	
Daylighting Technologies	Sun-Dome Tubular Skylights	Alanod Miro Silver	98,0	250-330-530	
Glidevale	Sunscoop	-	-	250-350-530	x
Sun-Tek Skylights	Sun-Tek Tube	Alanod Miro	-	150-250-450	
Natural Light energy systems	Tubular Skylights	ALANOD miro silver	98,0	250-330-450-530	
Tubzz	Tubzzz	Anodized aluminium	-	300-400-600	
Velux	Sun tunnels	-	-	250-350	
Sunlight Direct , Inc	Sunlight Direct	-	-	121	x
Brixia Solar srl	Brixia Solar	Laminated Aluminum	-	-	x
The light pipe company LTD	Light pipe	-	-	250-350	
Almeco	Light pipe Vega 98	Aluminum Vega 98	-	-	
ODL	Tubular skylight	-	-	250-350	x
SkyDome	Skytube	Silvertube	97,0	-	x

Table 1: Available light pipes in Europe and US.

Other companies manufacture their commercial products without optional systems for the optimization of the solar light collector. By contrast, the Velux solar tunnel is made like any vault collector in order to decrease the environmental impact of this component in specific application like that in a city historical centre; in this way it can be mounted with the terminal tube aligned directly to the roof.

Another fundamental element of the system is the pipe itself. It transports the light that comes from collector to the indoor space. Highly reflective materials are placed inside a tube which have a reflectance greater than 95%. They must ensure pure white light with no colour shift, even after multiple reflections down the light tube. Generally anodized aluminium draft is used for the more economic solutions, but it would also be possible to use a silver finish or a covering with detail films such as the VMF (visible mirror film) by 3M.

The tubes can be of several diameters. The choice depends on the amount of light that is desired in indoor environment. Obviously the greater the diameter of the tube, the greater will be the amount of light.
In the final a diffuser fitted to the bottom of the light pipe ensures that light is distributed indoor. There are two main types of diffusers:

- the standard recessed ceiling diffuser for all tube sizes, designed to maximise light transmission. Manufactured from diffused polycarbonate, its translucent surface provides privacy and spreads the light efficiently throughout the room;
- the innovative Skyview diffuser consists of a grid of Fresnel lenses which provides a wider spread of light without excessive losses and enables the sky to be viewed.

They can be rectangular or circular and their diameters depend of the tube installed on top.

EXPERIMENTAL SET-UP FOR RESIDENTAL BUILDING

The research project under development has the main aim to evaluate the on-site performances of a light pipe [4, 5, 6] considering its application in residential and industrial building; this should permit to define the real performances of a light pipe and to give fundamental data and information on how to integrate and manage this system with artificial light fixtures.
Considering the residential application the assessment of the light pipe performances has been carried out considering the so called "Leaf House"; this, as reported on left side of figure 1, is a technologically innovative house built for the environment near Ancona, in the central part of Italy, that represents a laboratory for new clean energy technologies.

The building is composed of six apartments, and each has a kitchen, a living room, two bedrooms, and two toilets where was installed a SolarSpot light pipe fitted with clear top dome, 300 mm in diameter and pearly white diffuser attached to the connection between the wall and the ceiling. The light pipe is more 8 m long giving an aspect ratio of approximately 1:26, and due to the presence of obstacles has three bands. The toilet has no external lighting other than the light pipe. The light pipe was 0.30 m from wall on the left, 1,20 m from wall on the right and 2.3 m from the floor to the bottom of the diffuse.

The illuminance measurements (both indoor and outdoor) were taken with a Minolta Illuminance Meter T-10 equipped with a Minolta Multi-point measurement system. They are based on a silicon diode photocell capable of measuring illuminances in the range 0,01 to 299900 lx with an accuracy of ± 2% ±1 digit of displayed value (based on Minolta standard) and a virtually perfect cosine correction curve. For indoor measurement (right side of figure 1), we considered several measuring points situated on horizontal plane placed 0,85 m from the floor and on the each walls.
External measurements were taken on the same plane of the light pipe’s collector.

The luminance acquisitions (indoor only) were carried out with a Techno Team LMK 98-3 video-photometer with 1380 (H) x 1030(V) pixels array resolution and a 0,1-10000 cd/m^2 as a measuring range; a 50 mm lens is used.

Figure 1: "Leaf House" of LOCCIONI Company and internal measurement set-up

RESULTS AND DISCUSSION

First measurements to check the instruments and to acquire initial data were carried out on 15-16-17th April 2009; the measurements were taken at the same time every 1/2 a minutes and the sky conditions were noted also; the weather was very changeable from clear sky to partially cloudy conditions, which was reflected in the results.
The average illuminance reading over the days for horizontal and vertical points are shown in Figure 2 below. The values are integrated on five minutes average time.

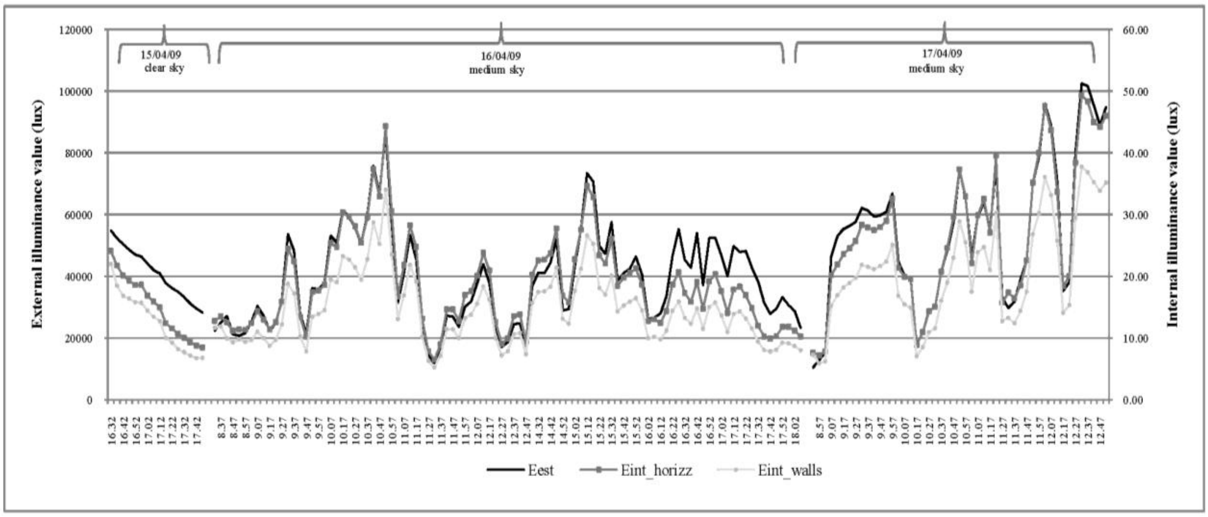

Figure 2: Indoor vs. Outdoor illuminance values throughout the acquisition period.

From the graph above it can be noted that the external illuminance is quite variable reflecting the weather condition; the maximum value of 100000 Lx is achieved at the end of the acquisition period with a corresponding value of 50 Lx for indoor horizontal illuminance.
The internal illuminances, both walls and workplane, show the same pattern of the external value and the ratio of internal horizontal/external illuminance is sufficiently constant during all acquisition period, but low enough, from 0,06% to 0.08%, compared to those reported in many references; this is certainly due to the aspect ratio of the system considered and the presence of several diversions of ducts development.

Moreover luminance images in front of the diffuser were captured and averaged; the data are reported considering the relationship with the external illuminance in figure 3; the pattern, with a sufficient approximation (R^2 = 0.81), could be considered quite linear with the highest value of 3700 cd/m^2 corresponding to 100000 lx of external illuminance.

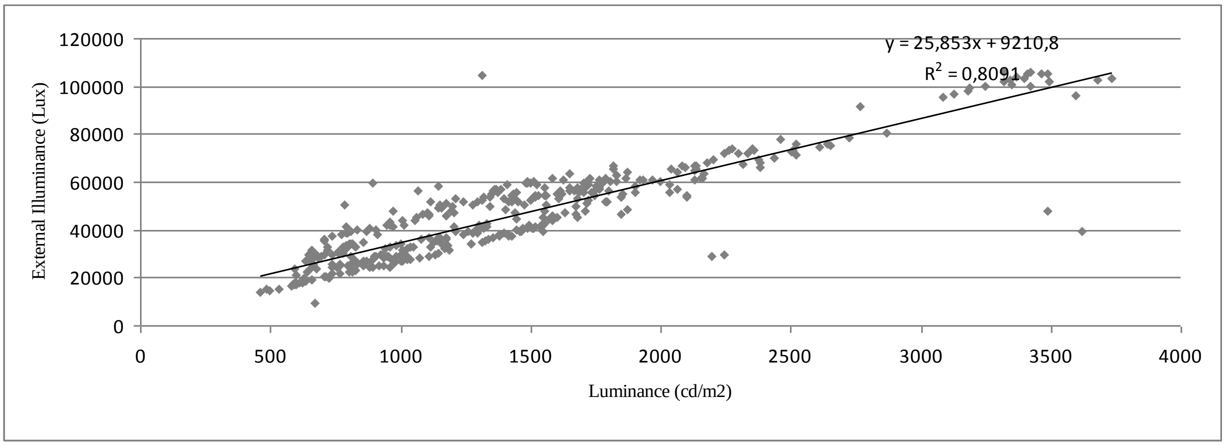

Figure 3: Diffuser luminance vs. external illuminance.

CONCLUSIONS

A review of a common available light-pipes and manufacturer company was given considering the main characteristics employed to optimize system's performances such as top collector optimization or internal thin film coating. The internal ducts usually present diameters values between 121mm – 650mm that permits system installation and sufficient daylight contribution for indoor spaces. The set up of an acquisition system to assess the light-pipe performances for on-site residential building application is described too; the external illuminance was recorded with a maximum value of 100000 lx and a corresponding value of 50 lx on the horizontal work-plane. The ratio of internal horizontal/external illuminance has limited variations ranging from 0.06% to 0.08%. We also considered the influence of the light-pipe diffuser evaluating its luminance distribution with different external illuminance values or sky conditions; with a sufficient accuracy, the luminance has a quite linear trend as the external illuminance changes.

ACKNOWLEDGEMENTS

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DAYLIGHTING METHODS IN IRANIAN TRADITIONAL ARCHITECTURE (GREEN LIGHTING)

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ABSTRACT

Natural light has a great effect on the health, physiology and psychology of humans. Providing natural light in living spaces is the best way to promote a healthy life. A glance at Iranian traditional architecture, with around six thousand years of history, shows the richness of this architecture in many aspects of design including the way it provides natural light for the building. To know these methods and to investigate their designing principles can help to create initiative ideas and methods for offering access to daylight in temporary architecture. In this article 6 main types including 20 different kinds of windows are studied according to the following aspects: the general form of the window, its location on the building, its relation with open and closed space, the kind of specified space and its function, how light is dispersed in the interior, frame and glass, opening inward or outward, aesthetic principles in the interior and façade, its function with respect to other space requirements such as ventilation, landscape, and privacy, construction methods, strength and stability.

INTRODUCTION

Providing enough light for the interior of a building has always been the architectures' concern and architectural history may be known as a history of different methods for lighting in architecture. Industrial age and artificial light technology have made the use daylight in architecture unnecessary, putting it on a lower priority. Living in places without natural light and environmental problems resulting from fossil fuels for providing artificial light on one hand and diseases resulted from natural light deprivation on the other, have reminded architects to give natural light priority again. Using different design ideas in architecture, we may take advantage of natural lighting for the interior. This study examines different window concepts used in Iranian traditional architecture that will make clear the principles of the former, still rich in nature, which can give valuable lessons to modern architecture.

WINDOW TYPES

Depending on the conditions they create in interior lighting quality, windows come in various kinds, named as a function of their location with respect to the interior, their dimension, quality, and ratios. It is worth noting that in Iranian traditional architecture, many of these kinds of windows were known under different names and have been used as a design pattern commensurate with light needs in different spaces. These windows involve door/window, sash window (Orosi), lattice window (Shabak), pavilion, orifice etc.

1 FULL-WALL WINDOWS

1-1 OROSI (SASH WINDOW): Orosi is a kind of window used for main spaces with high ceilings. Orosi is a full-wall window, which covers the whole wall, with lattice, and opens on a vertical rail rather than a horizontal hinge, resting in an overhead space. Orosis windows were mainly built on main halls where there was the most dominance on the yard. The other uses included balconies, and rooms located at the sides of large and high halls.

Orsis have meshed wooden lattice work, which are more condensed at the upper part and less at the base for more light and a better view. Colored glass used in the lattice reduces the severity of the natural light, creating a beautiful glitter in the interior. The lattice work controls the amount of light and supports privacy. This characteristic was the main reason for using the windows on upper floors and in rooms facing alleys in the northern cities where horizontal ventilation is required on hot days. Colored glass and lattice wooden frames were used to prevent unwanted heat transfer and severe light. Orosi height and upper lattice windows make light to go deeply through the hall and at the same time prevent severe light. At times when the hot sun created unwanted heat and light, people used to control the heat and light by hanging white sackcloth on an Orosi façade. Sometimes for very hot days, they provided shade by building a balcony in front of Orosi.

Places with Orosi were capable of being used both in summer and in winter. By opening the ascending windows in summers, an open space with suitable flow of air and a pleasant view appeared. By closing the shutters in winters, the hall turned into a warm place thanks to the greenhouse effect. Therefore Orosi is a kind of window which is used for every Iranian climate due to good capabilities and creating dabbled functional space. In cold weather conditions, Orosis have been built in two layers to prevent unwanted heat transfer. Their wooden frame and lattice work, which reduces the amount of glass surface, is another factor to reduce heat transfer. In hot and arid areas and moderate and humid areas, Orosi was used to supply fresh air and horizontal ventilation in the places with one layer or suction ventilation in the places with funnels.

1-2 SEMI-OROSIS: Orosis are also used for low-ceiling rooms in some cities. In this case, Orosi occupies half of the wall, which provides the necessary flow of air and view for people who are used to sit on the floor and at the same time creates a greenhouse effect in winter. In some cases, the lower part was Orosi-like and the higher part was a separated window. In this case, Orosi covered half the door and provided a view of the yard, light and ventilation.

Orosi is characterized as below: providing a view and protecting privacy at the same time, dispersing light deeply into the rooms, preventing direct sunlight, ventilation and free air flows, heat transfer control, preventing severe light and preserving beauty at the same time. (Fig 1)

2 WALL WINDOWS

2-1 DOOR/WINDOWS: The prevalent kind of tall windows in traditional Iranian architecture are door-windows. Despite being built in the form of a door, this window was not used for passing as a door, but as a connector of the interior with the yard and enjoying the view, providing light, fresh air, and air flows. This window had been used for ordinary rooms in the form of three doors (seh dari) and for halls and larger rooms in the form of five doors (panj dari) and sometimes seven doors (haft dari).

Door-windows have been used in many main and subordinate spaces, all facades, over the main axis or sideways, on ground floors or upper storeys. Three-doors and five-door windows are characterized by low depth of rooms and uniform distribution of windows along the room. Light inside the rooms was, thus, distributed well and all the parts were well-lit.

Every door-window has two shutters, which turn on pivots and open. Brick partitions separated door-windows. In many cases, the lower part of a door-window was made of wood and the higher part from glass. The glass had lattice work, especially on the crown. When the window was closed, heat transfer was controlled and privacy kept and there was a good view and fresh air when it was open. In main rooms with high ceilings, there were large windows over the crown of door-windows for better use of light. Sometimes, there was colored glass to avoid severe light.

Door-windows were used in all climates. In summers, they were covered with white cloth or a mat or with white curtains from the inside to prevent direct sunlight. In hot climates, the door-windows were built 50 to 70 cm inside the external rim of the walls. There was a vertical partition with the same depth between the windows. These partitions were called "Tabeshband" in some

areas which limited the hot sunlight. A combination of a door-window and an upper orifice were used in cold or humid areas where there was a need for a unidirectional air flow because of a location on a slope or because there was only one single window. In these cases, warm air exited through the upper orifice and cool air entered through the lower part. In moderate and humid areas where one-layer spaces were frequently used for producing air flows and horizontal ventilation, door-windows were very common. The wooden frame and little glass controlled severe light and heat transfer.
Door-windows are characterized as below: offering view and privacy at the same time, distribution of light in the interior, control over hot sunlight, easy ventilation, control over heat transfer.

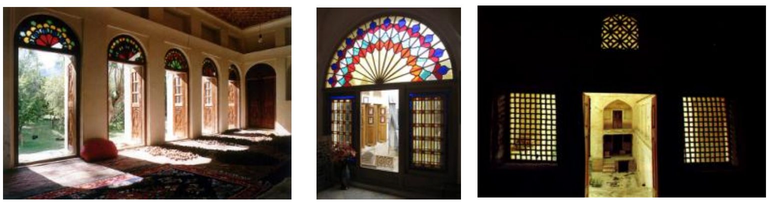
2-2 PACHOLAGHI & PACHANG: A combination of door and window with the door opening at the bottom and the window at the upper part is called Pacholaghi. A window or orifice up above the floor, set at the sides of the door is called Pachang. In mosque-school yards - to protect the privacy of the votaries - the windows surrounding the doors and the upper orifice are covered with wooden or brick lattice works.

2-3 ORDINARY WALL WINDOWS: Ordinary wall windows are a kind of window that like door-windows are very common in Iran, especially in the countryside. This window is up above the floor, going up beneath the ceiling. The window base is near the floor so that those sitting are able to enjoy the view and cool breeze. In humid areas where there is a necessity for natural air flows, wall windows are set on more than one wall so that there are air flows inside the room. On the other hand, this will help better distribution of light in the interior. A curtain on wall windows controlled the light severity and maintained privacy.

2-4 LATTICE WINDOW (SHABAK): Shabak or lattice windows are a kind of window much used in traditional Iranian architecture in summer houses and basements. In humid climates, this window separates two external spaces and maintains ventilation at the same time. For example, the walls propping yard and alley use Shabak for both privacy and air flows. Although the exterior is easily observable through a Shabak during the day, the interior could not be seen through it. Glass was sometimes used for lattice windows. In winters, wooden, earthenware, or chalky lattice windows were barred by greasy papers which were removed in summers. While providing privacy and ventilation, Shabak breaks and adjusts rays of light. A moderate light thus enters the room and creates a spiritual atmosphere. That is why this window was used in religious places. Glitters of light through decorated lattice doubles its beauty. Lattice was sometimes made of ceramics and there were empty spaces between ceramics which acted as ventilation and giving light. Shabak was made of wood, brick, clay, or chalk.

A Shabak is characterized as follows: limited view while keeping privacy, distributing indirect moderate light in the interior, controlling hot sunlight, controlling severe light, capable of ventilation, controlling heat transfer. (Fig 2)

Fig 1. Orosi windows and Tabeshband



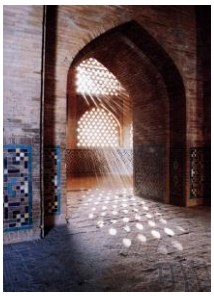


Fig 2. Wall windows and Shabak

3 WALL WINDOWS IN COMBINATION WITH BALCONY

3-1 Balkaneh: In humid areas where air flows are necessary, there were wooden door-like balconies upstairs. A balcony surrounded with windows was called Balkaneh. Some Balkanehs were built as windows projected from the façade and were decorated with colored glass.

3-2 Shenashir and Tarmy: In hot humid areas, due to hot weather, high damp and direct sunlight, Balkanehs were fully covered by wooden elements and a small part was left for light entrance. In some cases, some parts of wooden lattice were mobile, which let light and fresh air in when opened.

3-3 Tarmy: Used in hot humid climates, Tarmy is an all-wooden balcony, placed partially on the facade, which made using air flows possible while preserving from severe light and sunlight. There were small holes on the upper parts of the shield against TARMY to equally distribute light and to avoid severe light at the same time. (Fig 3, left)

4- ROZAN (WALL ORIFICE)

4-1- FARIZ AND KHAVOON: Fariz and Khavoon were placed over the doors and sometimes at their sides for letting in light and fresh air. The orifice was made with wood, chalk, or clay, in which little pieces of glass with all kinds of numeral and non-numeral figures were inserted. Khavoon is a decorative figure, made from scraped pieces of brick or mosaic. For light and air to enter into the rooms, slabs were perforated in which some figures were drawn. The slabs were then set over the doors and windows. In some cases, there were some orifices around and over door-windows. Orifices are small in size, made from wood or clay, and make air circulation behind possible.

4-2- BULL'S-EYE ORIFICE: A circular little window, turning on a pivot, is called bull's eye orifice. It is characterized as below: no view, better light distribution, control over direct sunlight, unidirectional ventilation.

4-3 GOLJAM (FLOWER GOBLET): Little colored glass panes, set inside chalk, put over the highest part of the wall, are called Goljam. With these, light reaches the furthest part of the room and avoids severe light due to colored glass use. Goljam was often used in urban buildings and rich men's mansions because of high accuracy and skill needed for their construction. Goljam were put on top of door-windows, acting as the window crown. The figures drawn on Goljam were mainly roses and vase. That is why they were called Goljam. Goljam exhibit varied figures rather than similar ones. (Fig 3, right)



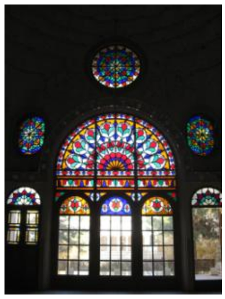



Fig 3. left to right:Tarmi, Shanashir, Goljam, Rozan

5 CEILING WINDOWS (SKYLIGHTS)

5-1 HOOR E NOOR: To use light and the interior ventilation, traditional Iranian architecture used Hoor e Noor. Hoor e Noor was located at the centre of the dome. Since there was no possibility of building a ceiling near the zenith of the dome, they did not fill that part and left it like a hole named Hoor e Noor. Hoor e Noor had no glass and used to light and ventilate places that had direct connection with outer space such as terraces of the domes, entrance porches, corridors, bazaars, porches, kitchens, and stores. That is why their openness did not creat a problem and provided ventilation as well as a slight light through the course. In places where the space under the dome was used as a living place in winters such as springhouses, Hoor e Noor was covered by cone-shaped glass.To equally distribute light through Hoor e Noor, some orifices were considered on the roof of the dome which made better light distribution and ventilation possible. Hoor e Noor is characterized as follows: no view, better light distribution, control over direct sunlight, funnel ventilation.

5-2 PAVILION (ROSHANDAN): Pavilion windows were used to cover circular ceilings in main places such as halls, alcove, galleries, springhouses or dome houses. They had their place in rooms with high ceilings, creating an empty space in the middle of the dome in the form of a circle with 1 to 1.5 m diagonal. Pavilions, usually decorated, used to be placed on hole of the ceiling.

In buildings like bazaars, baths, springhouses, dome houses, and the like, some orifices had been made that passed the light and ventilation in the best way. These windows, known as Roshandan, were built like a pavilion down on Khorshidi Karbandi. Some Roshandans had glass and some had lattice. Roshandan was usually a multigonal. In combination with a funnel, the pavilion window, like Hoor e Noor, improved air suction and was used in summer houses for better air circulation. The pavilion is characterized as: no view, better light distribution, control over direct sunlight, funnel ventilation, ventilation control at cold times.

5-3 HOOR E NOOR AND PAVILION IN COMBINATION WITH NOORANDAZ (LIGHT-SCOPE): In some cases, orifices on dome roofs were prominent, taking a gradient or a semi-arc figure. Direct sunlight hits a light-scope (Noorandaz) wall and indirectly reflects downward. In this case, direct sunlight was deviated from the floor while light and ventilation were distributed. At times, a light and air entrance window is covered by lattice. Noorandaz windows around Hoor e Noor are better ventilators. In some cases, combined with funnels, these windows enhance suction ventilation, creating a pleasant climate in hot summers. (Fig 4, left and middle)

5-4 FUNNEL IN DOME GORGE (CLERESTORY): Sometimes, ceiling funnels are placed in a dome gorge, instead of the dome zenith. In this case, the funnel body is latticed by clay or chalk. Direct light radiates from ceiling to under the dome and runs like shafts of light, creating a spiritual atmosphere.

5-5 UNDER-CEILING ORIFICE (CLERESTORY): Sometimes a funnel sits in the dome wall instead of the dome gorge and lights it by light reflection. The lattices inside the funnel allow ventilation. Sunlight reflection from under ceiling gives a spiritual sense and unequally lights it. At the same time, sun heat is controlled and cools the atmosphere by suction ventilation from under the ceiling in warm weather. When the middle ceiling is covered in the form of a gradient, the window would be placed on the border of the gradient and the roof smooth surface. This is more seen in buildings located in moderate humid climates and springhous roofs. In this case, the window acts as a light shelf, leading reflected light from the roof to the internal ceiling. Thus, reflected light from ceiling lights the space, allowing equal light distribution. An under-ceiling orifice is characterized as: no view, better indirect light distribution, control over direct sunlight, less heat transfer, suction ventilation. (Fig 4, right)

5-6 JAAMKHANEH: Jaamkhaneh was used in domes, public baths, passageways, and bazaars. A Jaamkhaneh, covered by round glass panes, has clay rings and was used for lighting and heat exchange. In summer, panes were taken from their places and the opening used for lighting and ventilation. In winter, the round glass panes were placed in the ring again to provide light and prevent heat escape. A primer-like substance, a combination of clay, wax, and a kind of oil, was used. Much like primer, this substance made putting and removing the glass parts of Jaamkhaneh easier. It may be the most suitable way to light the places where there are cold and warmseasons . A Jaamkhaneh is characterized as: moderate light distribution in the interior, control over severe light, ventilation as necessary, control over heat transfer, direct sunlight prevention, keeping privacy. (Fig 5, left)

6 Atrium in Traditional Iranian Architecture

6-1 Central Yard with Textile Ceiling: When central yards were the place of some special religious or social ceremonies, it was necessary to cover the yard to protect from hot sun or cold weather. The yard was then covered with some temporary ceiling. The covering was often a thick cloth or white burlap to let the suitable light in. The pores on the cloth allowed the dirty air to exit.

6-2 Central Yard with Glass Ceiling: To cover little yard roofs, new materials are used to preserve the yard from unpleasant atmospheres and to create a greenhouse effect, and the space between the rooms can be put to best use, like modern atriums. (Fig 5, right)

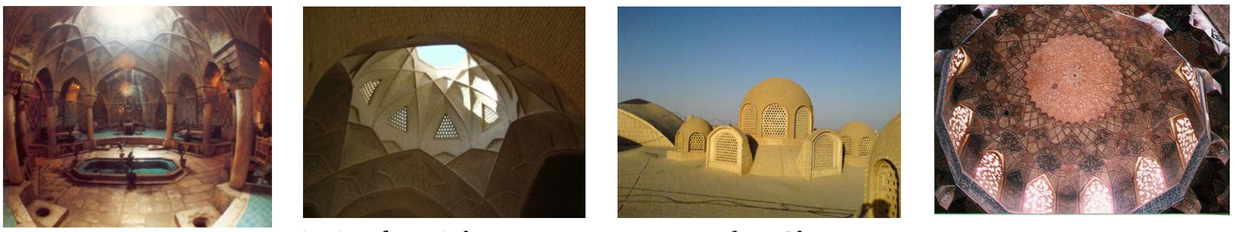
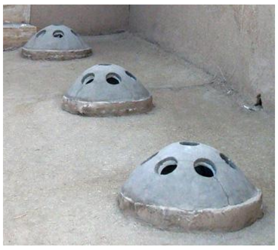


Fig 4.Left to right: Hoor Noor, Noorandaz, Clerestory



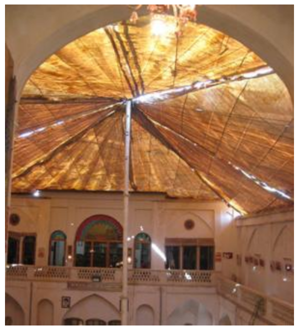



Fig 5.Left to right: Jaamkhaneh, Atrium with textile

Summary

As studied, every place in Iran had its own windows which provided conditions like ventilation, light, view, privacy, heat transfer control and etc. Different types of Iranian traditional daylighting methods were introduced as: 1- Full wall window such as Orosi (sash windows) 2- Different kinds of wall windows such as door-windows, ordinary windows, lattice windows (Shabak). 3- Wall windows in combination with a balcony such as Balkaneh, Shanashir and Tarmi. 4- Rozan (Orifice windows) with a great diversity in Iranian architecture such as Goljam (flower goblet). 5- Ceiling windows (Slylight) with a diversity of Hoor-noor, Roshandan and combination of these two called Noorandaz (light scope), Clerestory windows around the tambour or under the rib of the dome, and Jamkhaneh (Glass goblet) 6- Atriums where the small central yards were covered with textile. This study revealed that Iranian traditional architecture, having a civilization history of many thousand years, has contributed to climate-friendly architecture and presented a variety of windows, each of which can inspire our contemporary architecture.

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DAYLIGHTING PERFORMANCES OF DIFFERENT ADVANCED GLAZING SYSTEMS: TEST CELL MEASUREMENTS AND ANALYSIS

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ABSTRACT

The influence of daylighting on the energy performances of buildings is widely recognised, as well as its benefits on human comfort and health. The research aims at demonstrating the potentialities and the limits of advanced glazing technologies compared to conventional solutions, in order to spread out the penetration on the market of more efficient components and systems. The performances are evaluated by an experimental campaign, carried out installing different glazing systems in three outdoor test cells. The cells are identical in geometry, used materials and dimensions of the windows. Different glazing systems were tested: electrochromic glazing units, interpane fixed reflecting lamellae, internal moveable venetian blinds with lamellae with high regular luminous reflectance, capillary transparent insulation with a diffusing layer. A standard glazing and internal blind was installed as reference condition.

Each room was equipped with a number of illuminance sensors in order to evaluate the luminous climate on the basis of daylight availability, also the external global horizontal illuminance was measured with the same time step. The monitoring was carried out during the spring equinoxes, the measurements were taken with a time step of six minutes along all the day. Sunny and cloudy days were monitored in order to have a complete set of data to assess the advantages of each system and to make reliable comparison respect to conventional transparent systems.

According to the results, the dynamic systems have good performances in terms of lighting levels and uniformity with respect to the standard solutions. The static glazing units, even if they show a good behaviour in several climatic conditions, cannot ensure the optimal luminous quality always, their performance being affected by the characteristics and the design of the transparent and reflecting components.

INTRODUCTION

Ensuring good daylighting in the built environment is a crucial point in modern buildings[1]. These are often characterised by large glazed surfaces with associated risks for daylighting control in terms of uniformity of the indoor light distribution and, in case shading systems are used, in terms of daylight availability. Beside luminosity issues, many others are affected by daylighting: energy, sustainability, health of the building occupants [2]. The selection of the glazing systems has, in particular, a strong impact on the overall energy performance of the building, affecting the heating and cooling demand, as well as the energy consumption for the artificial lighting.

Many instruments can calculate the daylighting in a built environment but often several restraints apply. The calculations are performed in a given time, hence many calculations have to be performed for a complete assessment of a product. Most of the available tools do not deal with complex transparent systems and, if they do, with high uncertainties in the input data quality and in the calculation routines. The motivation was to stimulate the market penetration of advanced solutions hence it was important showing that such materials exist and can be installed in our building. For such reasons it was decided to have an experimental campaign with real products installed in real rooms. The tests were performed on three identical cells, one was used as a reference with conventional glazing and blind installed, the other two were used for the advanced transparent system installation.

This study was carried out in the framework of a large project funded by the Ministry of Industry. Among the various objectives of the programme, one was the evaluation of the glazing system influence on the electricity consumption of Italian building. This study presents part of the results related to the daylighting analyses.

EXPERIMENTAL

The experimental activity was carried out between the end of February and the beginning of March, within the four weeks prior and subsequent to the spring equinoxes, as defined in [3]. This period included sunny and cloudy days, hence the test configurations could be tested under different climatic conditions. Following the main contents of the experimental set up are described.

The Test Cells

The three test cells are placed in the southern outskirts of Milan (lat. 45°28´N and long. 9°12´E), all of them with the same geometry. The internal length is 5 meters, the width is 2.80 meters and the height is 2.80 meters, so that it can be assimilated to a small cellular office room. Five of the six façades are built with a concrete load-bearing structure 10 cm. thick covered with a 5 centimetres external thermal insulation. The last façade is south oriented and it is made of 10 cm-thick expanded polystyrene, in order to easily change its characteristics. The cells have the unobstructed view to the south front, while a building projects shadows from south west in the evening. Each room was painted for the experiment, the estimated luminous reflectance coefficients are: 0.3 for the roof (dark grey) and 0.7 for walls and ceiling (non perfectly covering white). The outside view of the cells is in figure 1. The axis beams mounted to simulate the overhang and fins 10 centimetres deep can be observe in the same figure

Figure 1: outdoor view of the test cell. The reference room is in the middle

The Glazing Systems

The openings on the south façade of the cell have the same size and geometry, as well as the thermal break aluminium frame. The transparent part is made of 4 units, the 2 above are

85x90 centimetres, while the lower units are 55x90 centimetres. The sizes were chosen in order to dedicate the lower window to the view outside and the upper part for the application of advanced solutions that might obstruct the view. As inferred from the Figure 1, each window consists of four glazing units, described as follows:

C0 Low-e double glazing unit, luminous transmittance 80%, coupled with a tissue diffusing blind, luminous transmittance 12%. This internal blind worked in two positions: fully open or fully closed, according to the standard office worker behaviour.

C1 The glazing system is as above, but a special internal venetian blind system was used in this case. This Hunter Douglas product is characterised by a high luminous reflectance (higher than 80%) and mirror behaviour on the convex side and a diffusing behaviour on the concave side (30% reflectance). The venetian blind was always kept on during the test.

C2 The two lower glazing units are the same of C0. The upper holes are equipped with the Okalux glazing system by Okalux. It is a double glazing unit, the air gap is filled with an element made of translucent capillary slab covered with diffusing glass fibre tissues on both sides. The system has a luminous transmittance of 36%.

C3 The two lower glazing units are the same of C0. The upper holes are equipped with the Okasolar Retro O glazing system by Okalux. This is a louver system integrated into an insulating double glazing unit. The outer part of the slat is designed to reflect away the solar radiation, the inner part has an almost horizontal concave shape to redirect part of the solar radiation to the ceiling. The slats are 20 millimetres in width and placed in a 30 mm air-gap. This system is very sensitive to the angle of incidence of the sun, so it the beam light transmittance of the system varies a lot, while the diffuse transmittance is 29%.

C4 The four units consist of solid state electrochromic glazing by Sage. The lower units were kept always clear during the experiments. The upper panes were coloured when the illuminance on sensor 1 was higher then 3 kLux and bleached when it got lower than 1 kLux. The systems works in two states only: coloured (transmittance 3%) and bleached (transmittance 60%).

Figure 2: Internal view of the test cell equipped with C1 and C4.

Figure 2 shows the indoor luminous environment of two test rooms equipped respectively with C1 and C4. The picture were shots late in the morning, with the sun entering directly into the test rooms. The visual inspection is sufficiently clear to stress how different glazing systems affect the potentiality of the selected samples in terms of control of the entering light, illuminance distribution, glare control.

The Monitoring Instrumentation and Procedures

The three test cells were equipped with 4 luxmeters placed in the middle of the room along the depth axis. The distance between two adjacent sensors was 95 centimetres, the same distance was set between the first luxmeter and the window, as well as the last sensor and the back wall. The sensors were mounted at 80 centimetres, typical value for horizontal visual task in office buildings. The indoor and outdoor illuminance values were measured every six minutes.

The data logging system was set up in order to start the measurements at 9 in the morning and close the session at 6 in the evening, in order to cover the whole working day according to typical national schedules. The measured data were downloaded weekly and the comparison analysis among the test cells was carried out on daily basis.

RESULTS AND DISCUSSION

The monitoring lasted several weeks, in different climatic conditions and several glazing systems configurations. The large amount of data is not presented here for obvious reasons, while some the most interesting outcomes are discussed below.

Figure 3 presents the comparison of the C0, C1 and C2 comparison during two sunny days. The x-axis numbers represent the position of the sensors respect to the window, the green light is 500 lux and the red line is 350 lux, the minimum acceptable mean illumiannce. It is evident from the right diagram how the illuminance values are not acceptable for un-shaded glazing systems, being the average illuminance close to 10 kLux on sensor on a daily basis. Different results are shown in the left diagram, when the standard glazing is coupled with the standard blind. The illuminance values decrease, while good results are registered for C1 and C2, with sufficient daylight on sensor three.

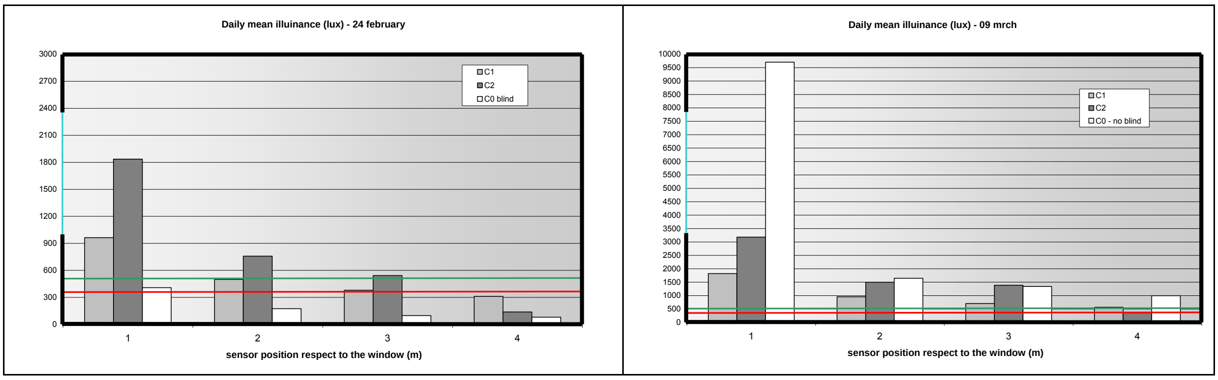

Figure 3: Internal view of the test cell equipped with C1 and C4.

We focused the attention on five sunny days in February to understand how the systems worked. The cumulative distribution of the illuminance values on the first sensor give some useful indications and are summarised in Figure 4. When the shading system of C0 is activated, the illuminace on Sensor 1 is lower than 500 lux for the 60% of the time and lower than 350 lux during the 40%. This implies that use of conventional blind lead to probable large use of electric lighting. C1, mirrored high reflective lamella systems, are in the same conditions for respectively 20 and 10% of the time, mainly during the late evening hours. This system suffers of high illuminance (higher than 3kLux) only for the 10% of the time. The capillary system suffers instead of this problem, since illuminances higher than 3 kLux are found in the 60% of the time. It was found that the systems ensure a good uniformity of light, but glare problems arise in presence of direct sun.

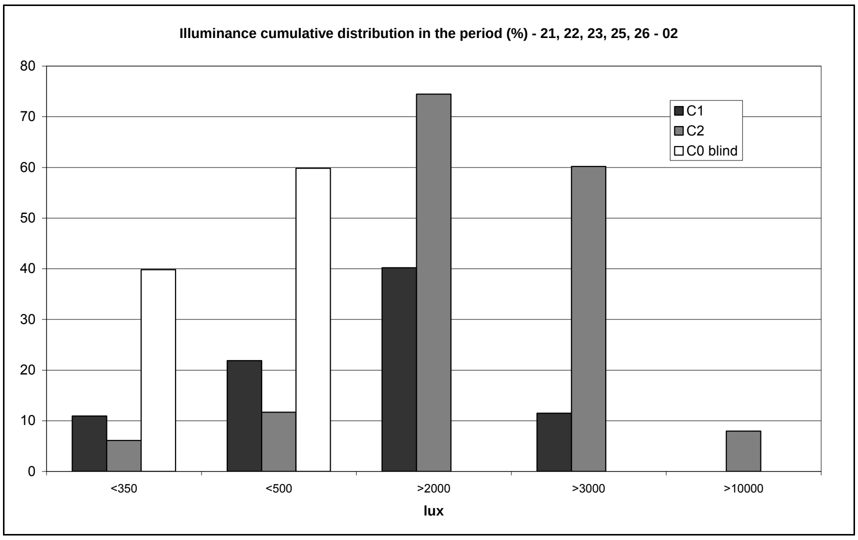

Figure 4: Illuminance cumulative distribution for C0 with blind, C1, C2.

Some results related to the electrochromic units are in figure 5-left, where C2 is compared with the standard glazing with and without blind. The data comes from two sunny days in April with very similar luminous conditions. It is stressed how the electrochromic performs in terms of shading, ensuring enough daylight availability up to sensor 3, slightly below a mean illuminance of 500 Lux. On the contrary, the standard glazing suffers for a too bright (above 6 daily kLux on sensor 1) or too dark luminous environment (lower than 350 Lux on sensor 2). The performance of C2 are strictly dependant of the control strategy. In this case the colouring was activated whenever 3 kLux were reached on sensor 1 and the bleaching started below 1 kLux.

Figure 5-right presents the results for the Okalux lover system collected during the same days of the case above. The main advantage of this system is the good distribution of the indoor illuminance, in fact the daily 500 Lux are reached deep into the room on sensor 4. The 2.5 kLux on the first sensor stress that glare problems can arise close to the window, in fact values above 5 kLux were registered in may hours during the monitoring period.

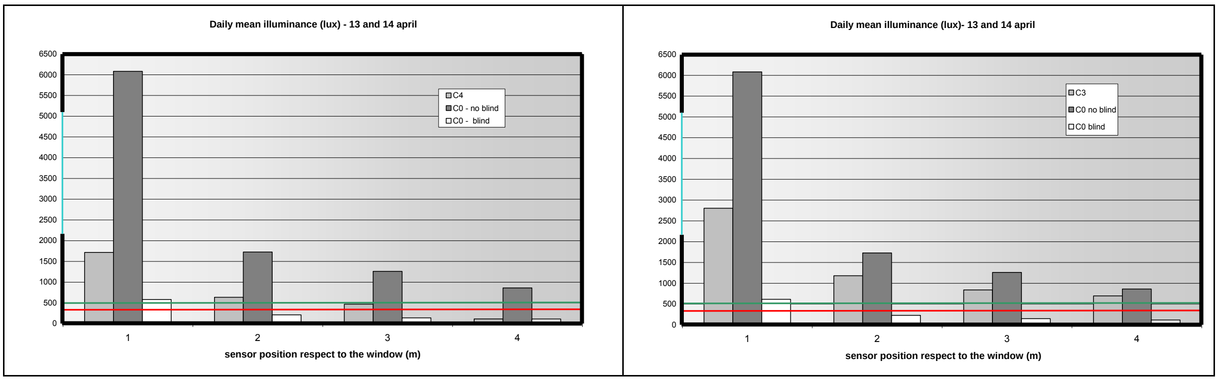

Figure 5: Internal view of the test cell equipped with C1 and C4.

The cumulative distribution analysis of these systems is summarised in Figure 6, referring to the results collected during 4 sunny days in April. The reference data are the daily mean illuminance values measured on Sensors 1 and 2 in the three test cells. The graph shows the occurrence of 2 standard values: 350 and 500 Lux, being the standard room with the blind activated. The diagram shows that C0 does not ensure adequate daylighting on Sensor 2 for almost all the monitoring period. C4 does not reach the 400 Lux on Sensor 3 for the 40% of the time, while C3 does for the 25%. On the other side, values exceeding 350 Lux are measured in the 90% of the time for both systems. To be noted that C0 does not reach 500 Lux on sensor 1 for the 60% of the monitoring.

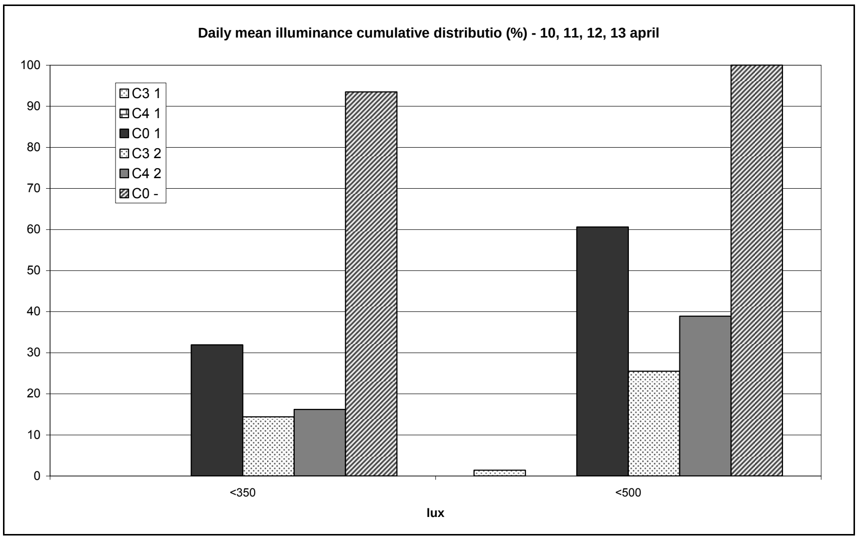

Figure 6: Illuminance cumulative distribution for C0 with blind, C3, C4.

CONCLUSIONS

The daylighting analysis performed in this monitoring campaign stressed how innovative systems can affect and improve the luminous conditions of the built environment. This is a partial aspect only, which needs to be integrated with energy analyses as well. The main outcomes are:

- The solar protection with conventional shading systems leads very often to dark indoor spaces in need of artificial lighting.
- Dynamic glazing systems optimise the façade luminous performance. Electrochromic systems ensure an excellent shading protection, but mirrored venetian blinds ensure a better indoor daylighting distribution, using the illuminated ceiling a secondary light source.
- Advanced static transparent components often improve the conventional solutions, even if this does not apply in all situations. An accurate design of façade configuration and space use is needed for calibrated applications. If not additional shading must be provided even for short use.

The activity will go through a second phase during the summer 2009, with planned luminance measurements using a new video-photometer combined with illuminance monitoring.

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Indoor and Outdoor Environment Quality and Health

INSITU MEASUREMENTS TO EVALUATE THE REAL ENERGY SAVINGS OF HUMIDITY SENSITIVE VENTILATION IN MINERGIE BUILDINGS

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ABSTRACT

Humidity sensitive ventilation is a proven technology offering a controlled passive stack, hybrid or mechanical air change and indoor air quality for residential dwellings. Inlets and outlets airflows are adjusted according to inner relative humidity. The system performance was evaluated on a Minergie refurbished building in Geneva where a standard natural stack ventilation system was transformed to humidity sensitive one. The results show a 30-39% reduction of final thermal energy and even more, considering primary energy taking into account the fans energy consumption. CO_2 measurements in a bedroom showed that in a passive stack ventilation system mean concentration is around 650 ppm with picks never exceeding 1500 ppm. This demonstrates the efficiency of such a system regarding IAQ. A questionnaire before and after refurbishment showed that complaints for cold draughts present before refurbishment have almost disappeared after refurbishment. Cost was reduced from 5'000 € for a heat recovery system with 60-70% effective recovery down to 322 € per apartment for the humidity sensitive passive stack system. This makes the system a particularly relevant solution for social housing where cost constraints very often limit the efforts for energy efficiency measures.

INTRODUCTION

Humidity sensitive ventilation adapts airflow rate to real needs, offering high indoor air quality and high energy efficiency in residential buildings. Although modern ventilation reduced airflow rates to strict necessary, a constant airflow should be dimensioned to satisfy a pessimistic occupancy scenario. Today, Minergie standard considers ventilation rates for residential buildings at 0.8 to 1 m^3/m^2h in mechanically ventilated dwellings and Swiss norm SIA 380/1 at 0.7 m^3/m^2h (Swiss norms consider heat reference area as the total area within thermal envelope, including walls and staircases). A flowrate of 0.7 m^3/m^2h corresponds to 0.3 ACH for a dwelling of 2.8 m inside height. Instead of providing this minimum constant airflow and trying to recover heat through a heat exchanger, humidity sensitive ventilation reduces ventilation (down to 0.25 - 0.3 m^3/m^2h average, depending on the dwelling surface) when dwellings are not occupied, and increases flow rate up to 2 - 2.5 m^3/m^2h during high density pollution emission (cooking, bath or showering). This strategy offers very good indoor air quality because pollutants are evacuated faster during polluting activities. On the energy side, efficiency results from reduced average airflow during the major period when the ventilation needs are low (low occupancy). So the question we try to answer in this article is: what is the global resulting airflow during heating season with humidity sensitive ventilation?

Adapting airflow to occupation density becomes more and more a pertinent energy saving strategy due to recent changes in social structure and habits: Swiss Federal Statistics office, reports that occupation density passed from 0.79 inhabitants per room in 1970 to 0.59 in 2000 [6]. Occupation scenarios have changed also, as single parent families and rising rate of professionally active mothers increases the percentage of empty apartments during the day.

HUMIDITY: A RELEVANT INDOOR AIR QUALITY INDICATOR

The control parameter adjusting airflow must be representative of ventilation need, must be physically measurable and easily exploited to regulate apartment air change. We can show that humidity is linked to most of pollution “sources” in the dwelling.

Pollution generated by human activity like cooking, showering, cloth and dish cleaning etc. emits mainly humidity and a variety odorant agents. Although this pollution is not a danger for human health, it deteriorates seriously olfactive comfort and generates a high potential risk for buildings (condensation and appearance of fungi on cold bridges). Human activities that generate high density of pollutants (10 minute shower generates 350 g of vapour) need boost ventilation in order to limit the level and duration of pollutant presence. Pollution generated by human metabolism (breathing and transpiration) generates essentially humidity and carbon dioxide. This fact confirms the need for an airflow adapted to the emitted humidity that is directly in relation with the number of present people and with the level of their physical activity. **Various research projects have proved that humidity is a good indicator of pollution generated by human activities and human metabolism [1, 4, 7]**.

HOW HUMIDITY SENSITIVE VENTILATION WORKS

Sensor principle

The humidity sensor is made of polyamide textile strip shrinking and expanding according to relative humidity, operating a dumper mechanism opening and closing air inlets and outlets.

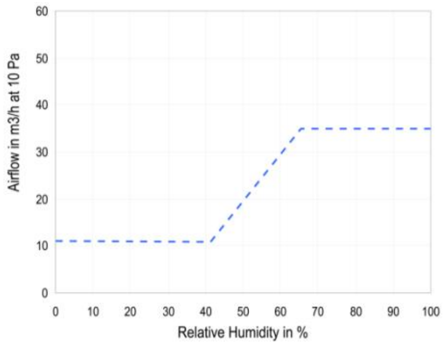
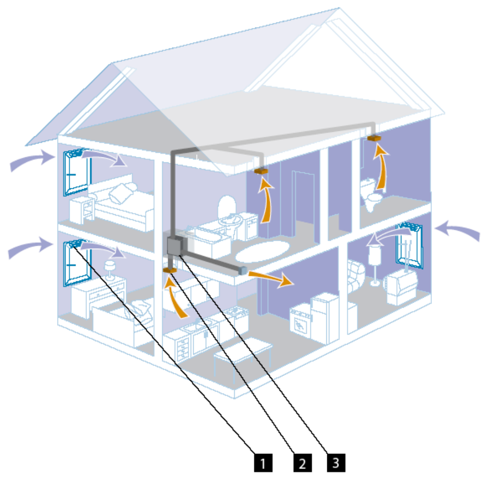


Figure 1: humidity sensitive sensor of an air inlet made of polyamide textile and resulting airflow as a function of relative humidity

The system does not need electricity or battery to operate. Tests performed on devices installed since more than ten years confirmed systems high reliability. The system simplicity limits divergence or damage risk. The technology based on polyamide strips offers an analogue operation with continuous regulation of airflow avoiding binary or discontinuous operation observed with other technologies.

Operation of the humidity controlled ventilation terminals

As shown on Figure 2, the airflow extracted by the extract units from the wet rooms (kitchen, bathroom and toilets) defines the air change rate of the whole dwelling. The air extract units adapt the airflow in response to the amount of humidity in each wet room. An additional boost rate either manual or automatically triggered by presence detection can complement the humidity-driven airflow. The extract units dispatch the available airflow generated by the fan’s (or stack) pressure in the various wet rooms. Humidity sensitive air inlets, in turn, dispatch fresh air in the various dry rooms (living room, bedrooms) according to their relative humidity. Such a setup constitutes a typical extract-only system, where fresh air enters into the less polluted rooms (dry rooms), and is extracted from the most polluted wet rooms. As a result, the pollution generated in the wet rooms does not spread into the dwelling. Besides, the same air is used to ventilate the dry rooms and then the wet ones, which limits the amount of energy required to heat the incoming "cold" air.



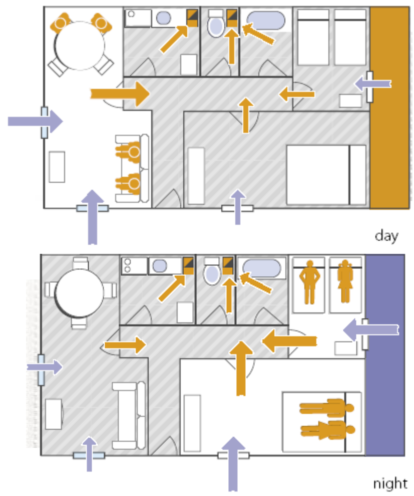


Figure 2: Airflows and humidity sensitive components in a single-family-house mechanical ventilation system. Typical day and nighttime dispatching of airflows within the dwelling.

A humidity controlled ventilation system provides a regulated dispatching of air inside the dwelling. Humidity sensitive inlets and outlets provide air in relation to real needs. Heat losses are thus limited in vacant rooms and occupied rooms are ventilated as needed. During daytime (Figure 2 – top right), air inlets in the living room (occupied) provide more air than those in bedrooms (vacant). At night time (Figure 2 – bottom right) the reverse happens.

If the need for ventilation increases in the kitchen for example, the extract unit will open up, thus increasing the whole dwelling air change rate. Part of the pressure will then be transferred from the extract unit to the inside of the dwelling, thus increasing the airflow admitted through the air inlets, until the extracted and incoming airflows are balanced.

On the other hand, if the demand (humidity) increases in a sitting room or bedroom, the air inlet will go from a standard minimum free section of e.g. 5 cm² (required to ventilate VOCs) to a higher free section. A partial transfer of pressure will occur from the air inlets towards the extract units. This, added to the humidity coming from main rooms, will increase the total air change rate. Dispatching of airflows between the kitchen, bathroom and toilets will depend on their respective states of pollution. The whole system is therefore able to manage the whole dwelling in a consistent and combined way, from air supply to air extract.

We have seen that the various rooms inside a dwelling have different needs that are handled by the humidity sensitive system. Similarly, different dwellings have different needs and these needs are time-dependant. In a multi-family house (Figure 3), humidity rise in the most occupied dwellings induces the opening of air inlets and extracts units, thus increases the air change rate. In less active and occupied dwellings, smaller openings contribute to energy savings on heating.

Stack effect tends to create more pressure in lower dwellings whereas higher ones can suffer from insufficient pressures. Humidity control of ventilation reduces and balances the airflow differences between floors: where the pressure is higher for a dwelling, humidity is extracted faster, so that the extract units go back to low/normal opening. More pressure is then available for the other dwellings.

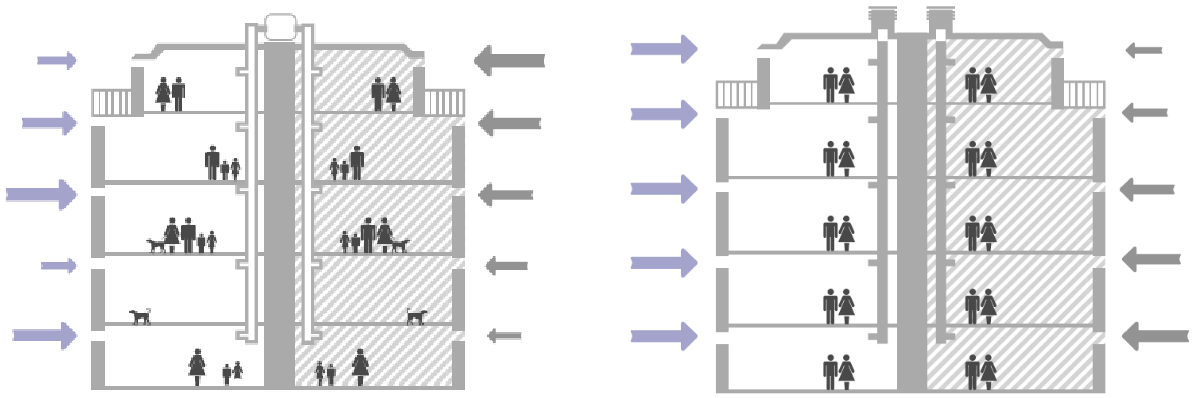


Figure 3: Dispatching of airflows between dwellings as a function of occupation and stack height. On the left, humidity sensitive ventilation, on the right standard extraction ventilation.

IN SITU MEASURMENTS AND ENERGY SAVINGS EVALUATION

The refurbishment of a 62 apartment building (4050 m² of heat reference area) according to Minergie standards, finished in 2008, gave us the opportunity to perform measurements and simulation of energy savings due to ventilation.

Social housing standards conditioned the refurbishment project to low cost solutions: 16 cm of thermal insulation, new windows with U value 1.2 W/m^2K, roof insulation of U value 0.2 W/m^2K and transformation of existing “fixed” passive stack ventilation into humidity controlled passive stack ventilation. The initial project planned a heat recovery ventilation but the cost of 5’000 € per apartment (300’000 € for the whole building) was prohibitive. Refurbishment of the existing ventilation system and transformation into humidity controlled one costed only 322 € per apartment (20’000 € for the whole building)

The existing ventilation system is the most common in Geneva on buildings of the period 1930 – 1960. A vertical concrete duct starts from the basement and goes up to the roof passing through a wet room (kitchen, toilet or bathroom). Each wet room has its own duct. The duct is cut and stopped at 30 cm from the floor. An inlet ventilation louver is fixed on a 10X20 cm hole. Another hole is opened at 30 cm from the ceiling where the outlet ventilation louver is installed. Air enters from basement, passes through the first part of the vertical duct and enters in a wet room. Polluted air is extracted from the top part of the duct towards the roof. Ventilation driving force is stack effect. This system ventilates only wet rooms while main rooms are supposed to be ventilated through infiltration and window opening.

Transformation of the existing system was very simple. The duct from the basement to the apartment was cancelled. A humidity controlled air inlet was installed in each bedroom and living room window. The exhaust ducts were cleaned and a humidity controlled air outlet was installed in kitchens and toilets.

Swiss norm SIA 380/1 considers a normal ventilation flow rate at 0.7 m^3/m^2h (0.3 ACH). A usual hypothesis of old buildings with deteriorated windows presenting cold droughts and without controlled ventilation is valued at 1.7 $m3/m^2h$ (0.7 ACH). Corresponding ventilation heat losses for Geneva climate are 68 and 165 MJ/m^2y (59% less ventilation energy losses). However, these values do not consider effects of airflow rate control and adaptation to real needs. Minergie considers 0.8-1 m^3/m^2h for ventilation without adaptation airflow to use and 0.7-0.9 m^3/m^2h for controlled ventilation adapted to use according to apartment density.

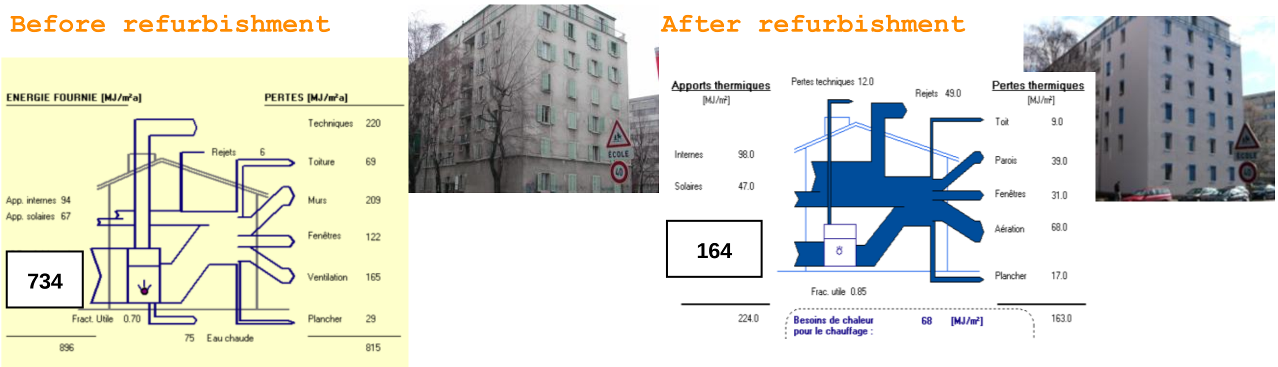


Figure 4: Before refurbishment, the building consumption for heating and hot water is 734 MJ/m^{2}y (class G). After refurbishment, energy consumption according to standard conditions is reduced to 164 MJ/m^{2}y. Although after refurbishment airflow is drastically reduced, the part of ventilation losses, according to standard conditions, represents 41% of total losses.

Experimental setup and calculations

The main question is to determine the real airflow rate in dwellings during a whole heating season in multi-family residential buildings. To evaluated this quantity in an environment with so many non controlled parameters we applied the following method:

1. We measured airflow through ventilation terminal units for various temperature, wind and internal humidity conditions measuring air velocity through a known circular section. We verified measurements by using at the same time the concentration decay method [8]. We raised CO2 concentration to 2500 – 3000 ppm and we measured concentration decay.

3. We measured CO2 concentration and relative humidity of some dwellings during several days. Concentration decay periods just after dwelling became empty informed us on the real airflow under real conditions with a known relative humidity. We checked coherence of three different measurement methods.

4. We compared measured CO2 concentrations with the ones simulated with SIREN software, to validate this predictive model. SIREN software was developed by CSTB to calculate airflow and indoor air quality in dwellings with humidity controlled air inlets and outlets. We simulated the year airflow under Minergie normal conditions and we compared the calculated airflow rate with the one considered by Minergie standards.

RESULTS

CO2 measurements showed a good correspondence between measured values and SIREN simulations. SIREN shows 7 to 40% higher airflow rates than the measured ones. However, SIREN pessimistic values are considered for energy saving calculations taking into account that in reality people may open the windows.

Measured CO2 concentrations are within INT 2 air quality standards although the building has no fan installed. Mean CO2 concentration is 650 ppm with punctual pick values <1500 ppm. Mean relative humidity is around 33% showing that condensation risks are under control. A survey about indoor environment quality showed that indoor air quality is clearly better. Before refurbishment, 9/34 answered that they are bothered from cold draughts and 8/34 from bad smell. After refurbishment, only 12 people have answered to the same questionnaire, and cold draughts or bad smell bothered only 1 person.

Airflow rates of humidity controlled ventilation simulated with SIREN are 31-39% lower than the ones considered by Minergie standards for constant air extraction

(percentage depends on the apartment typology). This 31-39% difference does not take into account extra savings due to absences, vacancies, low density occupation. This reduction of ventilation losses represents 25-32 MJ/m^{2}y.

According to Minergie calculations, the considered building ventilated with simple extraction ventilation system generates a thermally active airflow of 1 m^3/m^{2}h while a 70% heat recovery system is valued at 0.4 m^3/m^{2}h. SIREN calculates for the considered configuration 0.7 m^3/m^{2}h. This value could be improved again, taking into account the unfavourable hypothesis of a dense dwelling which has been chosen. A standard dwelling, with a more representative higher surface, would give better results for humidity controlled ventilation.

DISCUSSION

Although studies have demonstrated that humidity controlled ventilation offers good indoor air quality and reduces considerably energy consumption in low energy buildings, resulting energy savings are not recognised by official standards in Switzerland. The relative lack of knowledge and evaluation tools is probably responsible of this situation. With the most pessimistic hypothesis, humidity controlled ventilation presents half the thermal efficiency of a heat recovery unit. Additional energy benefits should be considered for electricity savings, especially when the system is used in passive stack ventilation. Mechanical extraction according to Minergie standard spends 7.6 MJ/m^{2}y of final electric energy and a heat recovery unit 15.2 MJ/m^{2}y. **Considering a primary energy factor of 3 for electricity instead of 1.3 for fossil energy, global energy performance of passive stack or hybrid humidity controlled ventilation becomes comparable to heat recovery systems.**

Results are in accordance with another study conducted in 2008 by the Fraunhofer Institut Bauphysik (Germany) has shown that a specific humidity sensitive MEV system's energy performance was comparable with an 80% heat recovery system, yearly consuming only 1070 kWh per heating period more. This represents much less than the cost of the annual filters change that is compulsory on the HR units to maintain their level of performance.

SIREN simulation software has been proved a credible tool to predict humidity controlled airflow. It has been used for the studied building and showed considerable energy savings according to standard values. **This tool is available for estimating a standard thermally active airflow rate to use in certification calculations.**

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OCCUPANCY EVALUATION OF SUSTAINABLE ENERGY HOMES THAT ARE TARGETING THE UK ZERO CARBON ERA: THE BASF HOUSE.

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ABSTRACT

In the UK, money and resources are ploughed into the development of sophisticated technologies, materials and control systems with the aim of improving energy efficiency within the Built Environment. Technical systems often demand that the occupant is educated in their use; and as systems become more sophisticated, this is too frequently overlooked. In order for a building to perform to its potential, users must understand how the building works and how they can control it. This is of particular importance in a house/home as, with no facilitating body, users are left to tailor their own surroundings to make themselves comfortable [4].

This paper aims to review the specific control systems and the implementation of renewable energy technologies employed in the BASF house [1], Nottingham, UK during the first period of occupancy, concentrating on space and water heating during wintertime 2009. This ongoing research is evaluating the energy performance of the implemented technologies and ascertains probable conclusions as to what extent user behaviour demands specific knowledge of technologies and user control.

The energy performance of technologies is analysed along with the user's dairy of events, in order to understand occupant's comfort and energy performance to reach the expectation projected for BASF house.

It is hoped that the insight gained from this study will highlight the requirement to consider user behaviour in modern residential building.

Keywords: occupancy evaluation (OE), energy performance, renewable energy technologies.

INTRODUCTION

The BASF House

The BASF house is part of the Creative Energy Homes (CEH) Project at the School of the Built Environment, University of Nottingham. CEH is a research and educational showcase of seven low or zero carbon houses. This house has been designed to promote sustainable development and has been built after the German 'Passivhaus' Standard in Europe [2] and to reach Level 4 in the UK Code for Sustainable Home [3]. The house is designed to function as a conventional home and act as a prototype for new housing in the UK.

Since June 2008, the house has been occupied by 3 adults; one of them, the main author of this paper is studying the occupant's comfort as the performance of the renewable energy technologies, whilst monitoring every aspect of the house's performance and daily events related to it. The house employs a monitoring system of 50 meters. It has a touch screen in the kitchen which acts like a control panel and informs on energy usage and indoor climate. The system enables the occupier to control which spaces require heat, light, ventilation, etc. The system also allows the conditions to be automated and controlled via internet from anywhere in the world. For research and assessment purposes the data is being logged into a computer as *.csv files. The results presented here are based on the analysis of the recorded data by this system and the user's dairy of events.

Besides the mentioned control system, the BASF house bases its success mainly on passive design such as a South oriented sun space (figure 1), a well insulated envelope, small fenestrations on North façade, excellent airtightness. Its energy demand is projected to be ≤15 kWhr/m²/year. It also possesses many other renewable energy and low carbon technologies and materials to enhance the energy performance.

Figure 1 BASF House, South Façade, sunspace(left) and plant room (right).

Some of the renewable energy technologies (figure 1) includes: a ground-air heat exchanger, a biomass boiler, a solar power system, a water conservation & rainwater harvesting system. For construction materials BASF has provided: insulation solutions for ground floor and walls, sustainable concrete solutions, structural insulated panels, phase change materials (pcm) and smart board, permeable paving among others.

METHOD

The Hybrid Water and Space Heating System of the BASF house.

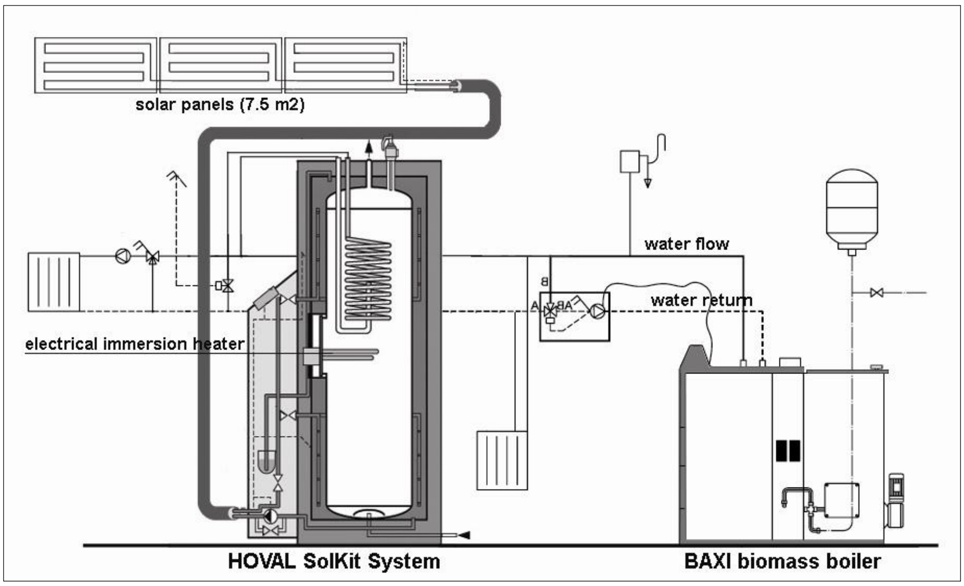


Figure 2 Schematic of Water and Space Heating System installed in the BASF House [5].

For this paper the accent has been set on the space and water heating systems (figure 1). A period of 4-weeks, 30/01/09 to 26/02/09, has been analysed. On one hand, the biomass boiler efficiency will be calculated, for this the energy delivered will be contrasted with the energy consumed (electricity and biofuel). On the other hand, the energy consumption of the biomass boiler and the other electrical appliances, immersion heater of the solar system and local electrical fan heaters will be compared.

Efficiency Comparison between the Two Systems: To calculate the efficiencies for both, the biomass boiler and the immersion heater when being in use in the house, an empirical test was carried out in Dec. 2008. We considered the technical features (see table 1, below) and the readings given by meters from both technologies.

BAXI Biomass Boiler	Nominal output: 15 kW, fuel consumption: 3.4 kg/h, working temperature: 80°C
Masstock biofuel	Energy yield by Rape Seed Oil Pellets: 22 MJ/kg (Specified by Masstock)
Immersion Heater	3 kW

Table 1 Technical Data from Technology Manuals [5]

So, working at nominal output (which corresponds to the manual recommended working temperature of 80°C) the biomass boiler produces 1 kW-h of energy in about 4 minutes, consuming approximately 230 g of BAXI biofuel (Masstock Rape Seed Oil Pellets). By contrast, the immersion heater delivers energy of 1 kW-h in about 20 minutes.

It could be measured the following: Water heating using the immersion heater: in 1 hour, the temperature of the top third of the tank raised 12.3°C, from 35.4 to 48.1°C. Empirically, 4.18 kJ of energy are required to raise the temperature of 1 litre (1 kg) of water in 1 degree Celsius.

Since the tank contains 470 litres of water, the total amount of energy needed to produce the measured temperature raise is equal to:

$$Q = 4.18 \text{ kJ/kg °C} \times 470/3 \text{ kg} \times (48.1 - 35.4) \text{ °C} = 8.3 \text{ MJ} \tag{1}$$

The total energy delivered by the immersion heater in 1 hour is equal to:

$$E = 3 \text{ kJ/s} \times 3{,}600 \text{ s} = 10.8 \text{ MJ} \tag{2}$$

The efficiency of this type of heating, immersion control, is therefore 77%.

Water heating using the biomass boiler: with the boiler set at a temperature of 80°C, the temperature of the upper third of the water tank raised from 34.2 to 52.6°C (a total of 18.4°C) in 30 minutes. The rate of heating was rather constant, of about 3 degrees per minute.

The energy necessary to produce this heating is 12.0 MJ.

At a power of 15 kW (the temperature of the boiler varied between 78°C and 73°C while heating the water), the total energy consumption in 30 minutes should have been about 27 MJ (corresponding to approx. 1.7 kg of fuel). The efficiency of this type of heating, biomass boiler, appears to be then about 44%.

When the biomass boiler is set to a temperature of 65°C, and lit for a longer period, as in the first week of the 4-week measuring period, the efficiency proved to be surprisingly lower, about 13%, this can be observed in detail on table 4 under the result section.

Biomass Boiler Output Heat: To obtain the output heat the biomass boiler is delivering it was needed the volume of water flow in litres and the water temperature, flow and return water temperatures from the boiler to the tank. To calculate de average of the ΔT in degree Celsius for a given period of time (periods of 30 min.) the raw values for the calculation were given by the monitoring system. These were multiplied by the Specific Heat of Water, 4.186 (kJ/lt-°C).

Biomass Boiler Output Heat (kJ) = Water Specific Heat (kJ/lt-°C) × Water Flow (lt) × ΔT (°C) (3)

With this value the energy yield in kW-hr for the biomass boiler (bmb) was obtained. To understand the results obtained from the analysed data, the different values were contrasted with the annotations made by users in the diary of events. The biomass boiler was subjected to a different pattern of use, as it can be appreciated in table 3 as it follows:

GENERAL WEEKLY OBSERVATIONS FROM USER'S DIARY ANNOTATIONS
Week 1. 30/01/09 to 05/02/2009: this was the first week the logging system was generating reliable data. Also the bmb needed to be fixed due to the wrong set up. BAXI recommended for the bmb to be "on" at all times (24/7) and to set it at 65ºC as the maximum temperature. The hopper was filled at noon on the first day with 69.5 k of biofuel made of rape seed oil pellets (Masstock), which was fully consumed by the seventh day; at 4 pm the bmb was turned off. Biofuel consumption rate **9.7 k per day.**
Week 2. 06/02/09 to 12/02/2009: this was the coldest week of the month, there was no biofuel to feed the bmb, therefore the use of the immersion and electrical heaters were needed for water and space heating. The heating produced by the bmb for space and water lasted for 1.5 days after it was turned off. The biofuel supply arrived at the 6th day of the week. After cleaning the bmb it was lit at 6 pm and the hopper was fed with 80 k of pellets (Biofuel consump. rate: **15 k per day**). On the 11th we did a deep cleaning of the bmb, it took 4 hrs.
Week 3. 13/02/09 to 19/02/2009: the external temperature increased much so the bmb was turned on and off as demanded, almost every night for 10 hours approx. Therefore some days the use of immersion and electrical heaters was needed, due the temperatures will be very low at nights, especially the fourth and fifth day of this week. This irregular situation made the efficiency of the bmb go even lower than the first and second weeks and the consumption of biofuel was also 15 k per day, like the second week.
Week 4. 20/02/09 to 26/02/2009: the external temperatures increased much so the bmb was lit at nights mostly to secure warm water for the morning showers. Especially when there was not sun during the day, that week it was mostly overcasted. Also it was realised when the temperature of water reached over 45˚C, it lasted for two days and it will maintain if we had a sunny day. At this point we realised as well that we have never turned the bmb in a "lockout" mode, therefore it was always consuming some electricity.

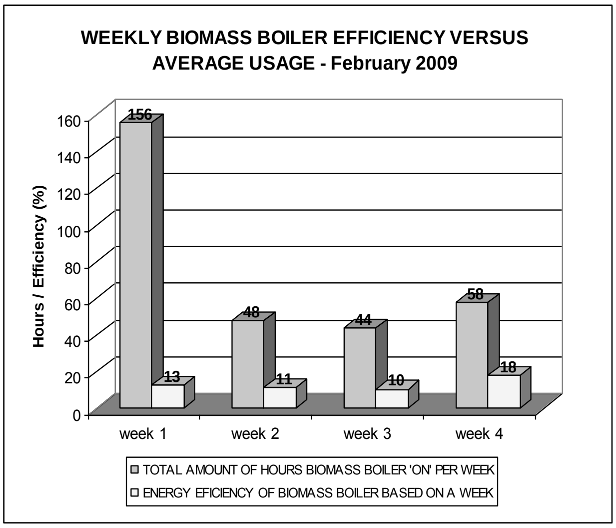
Table 2 Summary of observations annotated of the diary of events from the BASF house.

RESULTS

A summary of the weekly calculated values and the average temperature is shown on table 3 below. It is important to mention that we are not including for this study a carbon emission analysis. Given the fact that biomass boilers are being highly promoted by governmental officials as low carbon emission technologies, especially if we compare their use to the use of technologies that relies on high carbon emission fuels, biomass boilers are in fact low carbon emission technologies; especially the ones that operate with pellets. However, the use of biomass boiler for domestic use varies much therefore the emission factor will also vary in accordance to the scale of use and size of the technology [6].

WEEK	WEEKLY BMB* ENERGY DELIVERED	WEEKLY BMB ENERGY CONSUMED	WEEKLY OTHER ELECTRICAL ENERGY CONSUMPTION	WEEKLY BMB-FUEL CONSUMPTION (Oil seed rape pellets)	TOTAL AMOUNT OF HOURS BMB 'ON' PER WEEK	ENERGY EFICIENCY OF BMB BASED ON A WEEK	WEEKLY AVERAGE OUTDOOR TEMPERATURE	WEEKLY AVERAGE INDOOR TEMPERATURE
units	kW-h	kW-h	kW-h	kg	h	%	ºC	ºC
week 1	53	413	0	63	156	13	1.1	21.3
week 2	15	136	81	30	48	11	0.5	19.2
week 3	14	133	24	28	44	10	5.8	19.8
week 4	30	166	10	36	58	18	7.6	21.3
Month total	**112**	**848**	**114**	**157**	**306**	**13**	**3.8**	**20.4**

Table 3 Summary table for the period of 4 weeks, from 30/01/2009 to 26/02/2009.



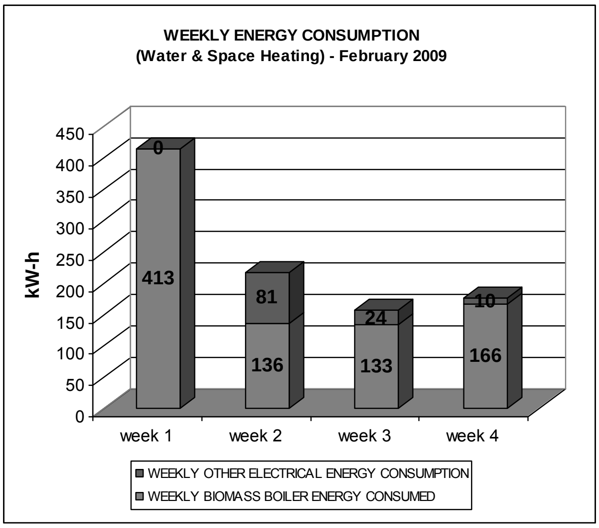


Figure 3 (left) Weekly Biomass Boiler Efficiency versus Average Usage. And Figure 4 (right) Appliance's comparison of weekly energy consumption for water and space heating.

For week 3 and 4, the outside temperature increased much (table 3, most right column); it could be observed that the demand for water and space heating is reduced abruptly (figure 3).

On figure 4 the column two depicting the second week of the studied period, on one hand, the energy consumption of the biomass boiler, which includes the biofuel plus the electricity consumed during 2 days (48 hours) was calculated as 136 kW-h. On the other hand, the energy consumption of the immersion plus the electrical heaters during the rest of the week, 5 days, was calculated as 81 kW-h. It is obtained that the biomass boiler consumption is four times bigger than the use of alternative heaters to heat space and water in a day roughly. For the biomass boiler the daily consumption is 68 kW-h per day while for the heaters is 16,2 kW-h per day.

DISCUSSION

The annual demand of energy in kW-hr/m² for heating for the BASF house cannot be extrapolated by using the month of February readings only, because the data is not divided between the energy used for space heating and water heating, they need to be logged separately. And based on observations and the experience of living in the house, it can be estimated that from the 848 kW-h monthly energy consumption (Table 3) about 70% was for water heating, roughly 600 kW-h, which needs to be confirmed in the future.

There is another very important aspect in regard to the biomass boiler for domestic use that needed to be discussed. There is not smaller model available in the market, and this particular model is not automatic, so it required to be lit when needed, which need some expertise, in case of a family with children, the safety issue has to be considered. Also, it requires continuous maintenance due to the characteristic of the biofuel. The cleaning of it involved to remove 16 fire tubes that collect hard tart from the oil of the pellets. It was supposed to be done every 6 weeks, but the cleaning lasted only for 17 days and it took 4 hour/person to clean it. This process produces much fine fire dust which is very toxic and it remains in the nasal ducts for couple of days after the cleaning. In case one machine is going to serve many houses, maintenance needs to be specified.

One of the most important learning from this analysis is that the energy efficiency of the biomass boiler is far lower than the expected one and from the indicated by BAXI as “Very high efficiency (87%-90%) with a variety of fuel types” [5]. The nominal output of 15 kW indicates that given the thermal characteristics of the BASF house the biomass boiler is oversized for the demanded heating needed for the house. It is not the appropriated technology for it, we are not analysing the quality of the technology here. Also, it has been demonstrated through the analysis of the data that in regard to energy consumption for water and space heating, the biomass boiler consumed four times more than the electrical and immersion heaters together.

The house proved to be low in demand for space heating, the heavy insulation, airtightness and the conservatory contribute greatly for an excellent thermal performance, and the main demand of energy is to heat up the water. Just by the everyday observation, it could be stated that the solar system works excellently for water heating when is not overcast; few hours of winter solar radiation produced enough energy to warm up the water for the daily demand. However, the tendency of the climate in UK is to be overcast during the winter season. It is recommendable for space and water heating to review other technologies more appropriated to the thermal characteristics of the house, the biomass boiler technology needs to be replaced, beside the energy efficiency problem, the maintenance and operation of it is not user friendly at all, not for a single family house.

With all the available knowledge and technology for this matter nowadays, many unexpected results can be predicted; however the above facts raise some important reflexions:

· Integration of technologies: The use of renewable technologies for residential application in UK needs to be widely tested, technology cannot be installed solely for assessment purpose and to reach new regulation targets, the effort of its usage should focus on the contribution for a better quality of life as well as energy performance.

· Knowledge and environmental education: Professionals involved in the home production industry need to update their knowledge in regard to all energy efficiency aspects, such as design, materials, technologies, physics of buildings, etc. Otherwise the application of technologies becomes a fashion or a mere respond to regulations.

· Users and environmental education: It is included in the UK code the need for provision of a “Home User Guide” [3]. This aspect seems extremely important, in our own experience, being one of the current occupants of the BASF house, the use of this home has been far from being simple. This fact brings a very crucial question: are sustainable homes for everybody? Beyond the possible answers, we must be certain that sustainable homes should be for any type of user.

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PERCEPTION OF AIR POLLUTION AND COMFORT IN THE URBAN ENVIRONMENT

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ABSTRACT

This paper presents the results of a study, aiming to enhance our understanding of the connection between human perception and actual environmental quality, focusing on the sensory awareness of polluted air and particulate matter (PM). Microclimate, noise and PM were monitored during field surveys with 260 questionnaire-guided interviews on the UC San Diego campus. Overall comfort was determined primarily by the thermal environment, with no correlation between comfort and sound or PM levels. About 50% of the interviewees considered the air to be dusty or burdened with higher PM counts. The other half of the respondents considered the air quality to be good. Overall, as the concentration of PM increases, the number of 'clean' and 'good' votes decreases, whereas the number of 'dusty' and 'poor' votes increases. The similarity between the overall air quality and how dusty it feels suggests that visual clues of PM, such as dust, affect the evaluation of air quality and pollution.

INTRODUCTION

In the context of sustainable cities, personal perceptions of air quality and other environmental factors are a key factor in the 'liveability' of an urban environment. In 2007 for the first time in the history of mankind the urban population exceeded that of rural areas across the globe, while in Europe that figure is over 80%. Urban populations are particularly vulnerable, as a result of the Urban Heat Island effect and poor air quality. In particular, traffic-induced air pollution causes increased mortality and morbidity.

Chronic exposure to outdoor air pollution from traffic is believed to have even larger impacts on mortality than acute exposure [1]. Studies of long-term impacts [2] have shown that living in a relatively polluted city for a prolonged time, leads to a shortening of life expectancy. This vulnerability to chronic exposure will increase further under climate change, as increased temperatures are often associated with higher pollution concentrations. Understanding the human assessment of air quality through the integration of physical and psychological processes could inform strategies to protect the population from such exposure.

There is a wealth of research focusing on the impact of air pollution in the urban environment, but there is a significant lack of information on the way people perceive and evaluate air pollutants. A recent review of the air pollution perception literature [3] showed that in the body of evidence available, publicity about air pollution has been an important factor in influencing public awareness of air pollution. Thus it was not possible to identify whether people were independently sensing polluted air in their environment, or whether their perception was biased by media coverage.

In a climate change context, external public spaces are expected to play an important role in urban living. The outdoor urban environment is notoriously complex, due to the spatial and temporal variability, as well as variety of human activities. How could human perception be relied upon to evaluate environmental conditions in complex settings? Recent research in the outdoor context, revealed a range of physical and psychological factors that affect human perception, assessment and evaluation of microclimatic conditions [4] and demonstrated the importance of microclimate for activities in urban spaces. Expanding this approach could then be entrusted to provide useful information on some of the complex questions surrounding human perception and evaluation of exposure to meteorological conditions and air pollution.

This paper highlights how people perceive and evaluate air pollution and environmental quality in the urban environment. The aim is to evaluate whether people can be relied upon to perceive and evaluate actual environmental quality in the urban environment, by focusing on the sensory awareness of polluted air and more specifically particulate matter (PM).

METHODOLOGY

The University of Bath and the University of California, San Diego (UCSD) collaborated in a pilot project to evaluate the relation between the concentration of PM and the perceived state of individuals. The UCSD campus (32.88ºN, 117.24ºW) was used as a case study, as there are various construction projects, hence elevated PM levels could be studied. Furthermore, UCSD has established a unique network of stations to monitor environmental conditions for Decision Making using Real time Observations for Environmental Systems (DEMROES) project [5] that provided the microclimatic information and monitoring infrastructure for this work.

The field surveys involved questionnaire-guided interviews with users of two sites on the campus; a key node for vehicular traffic and public transportation (TS) and a road construction site (CS). The surveys were conducted by UCSD students in summer 2008. Concurrently highly time-resolved monitoring of microclimatic, noise and air quality parameters the interviewees were experiencing. An enhanced mobile DEMROES station, mounted on a 2m high tripod, was installed at the survey sites, equipped with a sound level meter, an anemometer and wind vane, a temperature and relative humidity probe, and a pyranometer. A Shinyei PPD20V particle counter sensitive to particles with a diameter larger than 1 μm was used to determine PM10. Based on a detailed chemical characterization of particulate matter at a nearby site [6] we expect the majority of the particles in the >1 μm range to be sea salt and local dust from the wind shear created by vehicular traffic and construction.

Since the aim of this study was to test the overall concept, the number of interviews was relatively small. To maximise the effectiveness of the data collected, both transverse and longitudinal surveys were used. The transverse study included students and staff, selected at random, from the area under investigation. The longitudinal study involved a control group of students with the aim to minimise personal variation between different surveys. Six days of surveys were carried out with 260 questionnaires completed, 79 of which were by the control group. Meteorological and air quality variables were recorded every 2 seconds.

The questionnaire was developed by merging questions on microclimatic and noise similar to the RUROS project [4] with air quality from studies on indoor climate. The questionnaire asked for gender, age, smoking status, perceptions about the thermal and acoustic environment, environmental quality, and health and well-being. Health symptoms and past medical history information was also requested. The interviewees reported their evaluation of different environmental parameters on a 5-point scale and preference on a 3-point scale, as well as their assessment of their overall comfort state.

RESULTS

Environmental conditions

Weather conditions in San Diego are strongly affected by proximity to the ocean resulting in a diurnal sea breeze circulation, with a small diurnal temperature range and high humidity [7]. The range of air temperature over the measurement periods was small (20.6 ºC - 24.4 ºC) with a mean of 23.1 ºC. Relative humidity was moderate to high (mean at 79%) with a narrow range, 71%-85%. All survey days were sunny. Wind speeds were low, varying between 0.3-3 ms^{-1}, with a mean value of 1.5 ms^{-1}. Both sites are open and exposed to the wind.

Particulate matter was measured in number of particles per litre. Since international health standards and PM measurements are usually reported in μgm^{-3} a conversion factor was needed to allow better intercomparison of the reported PM concentrations. Given that the sensor is sensitive to particles between 1μm and 10 μm and assuming a typical PM size distribution, the average aerodynamic diameter would be around 3 μm [8].

Air quality varies significantly between the two sites. CS is clearly more burdened from an environmental point of view, as the PM count distribution has a long tail towards higher values (Fig. 1). The minimum values are fairly similar for both sites (around 53 part/l), but the maximum value is 3 times higher at CS (2868 part/l as opposed to 967 part/l, or 80.3 μgm^{-3} as opposed to 27.1 μgm^{-3}). The mean value is 4 times higher (806 part/l as opposed to 216 part/l, or 22.6 μgm^{-3} as opposed to 6.1 μgm^{-3}). The measurements reflect the higher pollution load of the CS, which we attribute mainly to dust loading. However, given that the campus is open and well ventilated in an otherwise clean area, the absolute values are considered rather good.

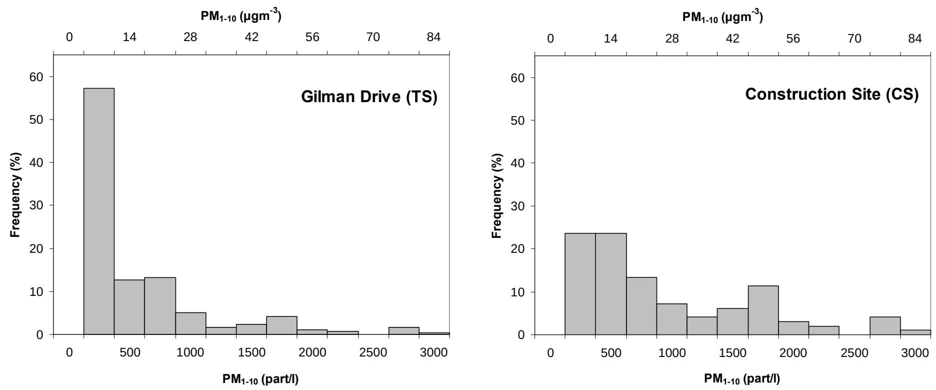

Figure 1: Frequency distribution of the PM data for the two sites during the surveys (left: CS; right: TS), in particles/litre and μgm-3 (estimated).

Sound pressure levels (SPL) are higher for the CS. Although both sites have a minimum SPL around 62 dBA, the maximum value of the CS is 87.5 dBA, as opposed to 77.1 dBA for TS. The acoustic environment is not very good for either of the two areas, with an equivalent sound pressure level of 78.6 dBA and 68.9 dBA, for the CS and TS, respectively. These values represent the noisy activities taking place (construction activities/heavy machinery in the former, high level of vehicular traffic and buses in the latter).

The majority of the interviews took place at TS (163 or 62.7% of the 260, as opposed to 97 or 37.3% at the CS), as more people could be found there, given the nature of the site, an important public transportation hub for the campus. The control group accounts for about 30% of the total interviews. 63.3% of the interviewees were male, (86% for the control group). Age is biased towards younger people with 67% in category 18-24 and 19% in 25-34. This is not surprising, given that both sites are on a University campus, where the majority of the population is students. Ethnic groups appear well mixed. In terms of activities, 80% of the people were either walking or standing, reflecting the nature of the sites, with 20% seated.

Perception of environmental conditions

Regarding thermal sensation (Fig. 2), the conditions are perceived as warm (48.3%). In response to their overall comfort 87.7% voted comfortable. People seem to prefer no change (58.1%), or desire cooler conditions (39.2%) and only 2.7% voted for warmer conditions. Regarding wind conditions, nearly 70% prefer no change with 22.3% asking for more wind. Thermal vote is strongly correlated with thermal preference (r=-0.399), implying that respondents who felt warmer preferred to be cooler. Overall comfort is only correlated with air temperature (r=0.158). No significant correlation exists between the comfort vote and sound or PM levels.

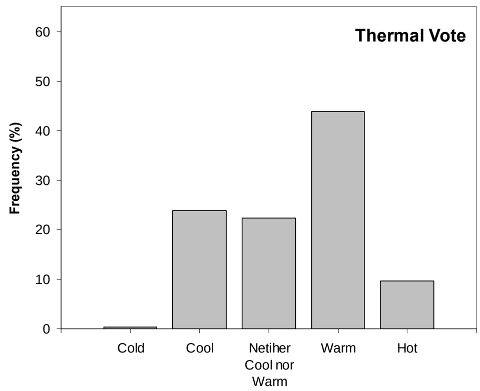

Figure 2: Frequency distribution of the thermal sensation.

More than 50% of the participants consider the air to be clean. 25% consider the air to be neither clean nor dusty and 22.3% dusty (Fig. 3). Examining the two sites separately, most people consider the air to be clean at TS (67.5%) whereas, as expected, about 50% of the interviewees at the CS consider the air to be dusty. Air quality vote distribution (Fig. 3) is practically identical to that of clean/dusty air vote, with similar complaints for the two sites.

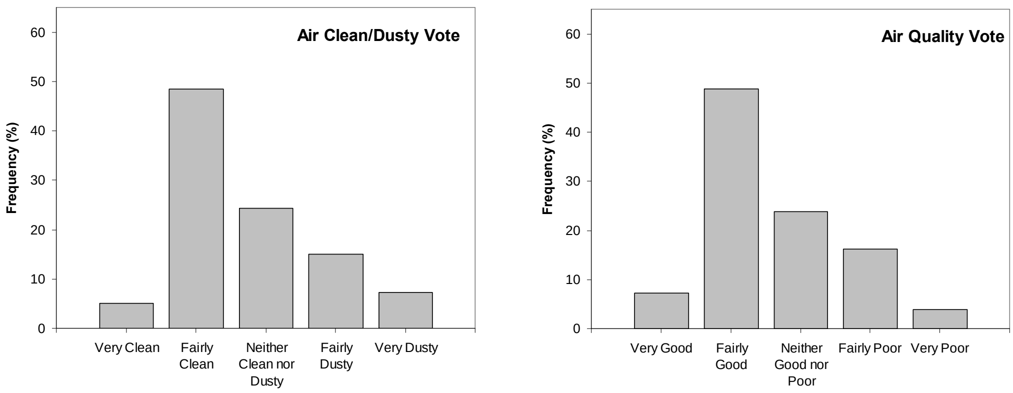

Figure 3: Frequency distribution of the Air Clean/Dusty (left) and Air Quality (right) votes

Air clean/dusty vote has a very good correlation with air quality vote (r=0.797). Both votes have good, statistically significant, correlations with PM count (r=0.310 and 0.298) and surprisingly with solar radiation (r=-0.305, -0.274). This could mean that the way people perceive PM related air quality is through the visual effect of particles, which inevitably becomes more noticeable under low irradiation conditions, resulting in negative Pearson correlation coefficients for solar radiation. The control group provides air cleanness and air quality votes which are better correlated with the PM10 levels, when compared to the All Data case (r=0.345 and 0.331 respectively), as is also the case for the correlations with solar radiation (r=-0.850 and -0.349, significant at 0.01 level).

Stacked bar-charts of the cumulative percentage of votes visualise the distribution of votes at different levels of PM (Fig. 4). Both Air Clean/Dusty and Air Quality votes demonstrate that as the number of PM increases, the number of ‘clean’ and ‘good’ votes decreases, whereas the number of ‘dusty’ and ‘poor’ votes increases. The bar on the far right of each graph, corresponding to 3000 particles/litre stands out, not following this trend. Examining this along with the frequency distribution of the PM data (Fig. 1), it becomes apparent that there is little data for the high pollution loads; hence the respective cumulative frequencies are not reliable.

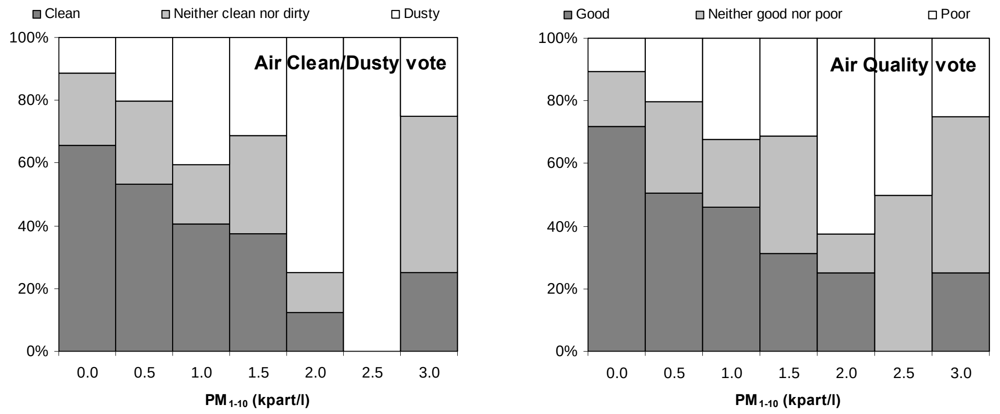

Figure 4: Cumulative frequency distributions for the votes of Air Clean/Dusty (left) and Air Quality (right) for different levels of PM (N=260).

The overall impression of the acoustic environment is of fairly noisy, as 56% voted for one of the noisy categories. Considering each site separately, it becomes clear that the CS is noisier than TS, with 81.3% of the votes on the noisy side of the scale, against 40.5%. This matches the SPL profile of the two sites. Regarding the personal evaluation of noise pollution, there is a significant correlation between the acoustic environment vote and the recorded SPL. Control group members vote for the acoustic environment in a way that is better correlated to the actual sound levels (r=0.629) than the rest of the interviewees (r=0.485).

Focusing on the predominant noises on site, traffic and construction are the major sources of annoyance. Considering each site separately, as expected, in the CS, construction is the single most dominant annoyance factor (64%) followed by construction related activities, e.g. machinery, trucks, etc. In TS traffic is the only significant annoyance factor.

CONCLUSIONS

We have presented the results of a study aimed at enhancing our understanding of the connections between perception and evaluation of environmental quality to actual exposure to meteorological conditions, particulate matter and noise. Questionnaire-guided interviews aimed to evaluate environmental quality were conducted together with highly time-resolved physical measurements, to link objective and subjective parameters. Since our sample size is relatively small (260 interviews), the results should be regarded as indicative of the trends in perception and evaluation of pollution and the relative importance of various other factors.

The meteorological conditions were generally sunny, warm, moderately humid, and light winds, whereas the acoustic environment was noisy. PM concentration was generally low, but the CS was burdened with higher PM counts (presumably from dust) and higher sound levels.

Overall comfort was determined primarily by the thermal environment, with no correlation between comfort and sound or PM levels. Overall air quality is considered to be clean by more than 50% of the participants. Air quality vote distribution is strongly correlated to the Air Clean/Dusty votes, and both of these perception votes are correlated with the PM count. Overall as the concentration of PM increases the number of ‘clean air’ and ‘good air quality’ votes decreases, whereas the number of ‘dusty air’ and ‘poor air quality’ votes increases.

Surprisingly, these perception votes also present a significant negative correlation with solar radiation, suggesting that the way people perceive PM is through the visual effect of particles that inevitably becomes more noticeable under low irradiation conditions. Hyslop suggests that impaired visibility is the result of air pollution due to light scattering on particles or more extreme cues such as smoke from chimneys or car motor exhausts [9].

This work shows promising results but the confidence is affected by the small number of responses. An extensive study investigating different levels of air pollution in different urban settings would help us to disentangle the effect of these parameters. Furthermore, it would help us to identify threshold levels that different air pollutants need to reach for them to be perceived by individuals, while investigating the means by which these pollutants are being perceived. An in-depth analysis of the human parameter will open new horizons for evaluating the use of physical intervention through urban and built form in urban design to improve environmental quality and increase adaptive capacity to climate change.

ACKNOWLEDGEMENTS

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BRINGING HYGIENE, USER COMFORT AND ENERGY EFFICIENCY REQUIREMENTS IN HOT WATER SYSTEMS ALTOGETHER TO THE POINT OF PRACTICAL ACCEPTANCE FOR A NEW BUILDING CODE

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ABSTRACT

A new building code for hot water systems in buildings is currently being developed by the Swiss Society of Engineers and Architects (SIA). Optimisation of hot water systems becomes increasingly important due to several reasons. The first part of the new standard, devoted to the requirements, has reached the public enquiry stage. This paper highlights some of the new aspects dealt with. Results of new laboratory measurements are reported, which were necessary to support the new requirements. These topics are: (i) the draw-off lag after opening the tap until hot water is available; so far, this lag has been underestimated by planners by a factor of 2 or even more; (ii) the internal counter-flow circulation which takes place in a hot water distribution line under stagnation when its lower end is warmer than its upper one; this flow has been filmed under different geometrical arrangements; it causes major heat losses in hot water systems and can be prevented by heat traps. The standard defines energy requirements for hot water stores, distribution lines, heat traps, circulation pumps, heat generation (if separated from the space heating system), as well as for the hot water system as a whole. It will have consequences for the spatial distribution of the hot water taps as well as for design, construction and installation of hot water systems.

INTRODUCTION

A new building code for hot water systems in buildings is currently being developed by the Swiss Society of Engineers and Architects (SIA). Optimisation of hot water systems becomes increasingly important due to several reasons: (i) the drastic reduction of space heating energy demand as a result of building envelope improvement in the past decades; (ii) the corresponding increased need for summertime cooling if technical systems (e.g. hot water distribution) loose too much energy indoors; (iii) numerous claims from hot water users as a result of too long draw-off lag after opening the tap until hot water is available; (iv) increased attention required by hygiene in hot water systems to prevent the multiplication of the *Legionella pneumophila* bacteria. The first part of the new standard, devoted to requirements, has reached the public enquiry stage.

THE HYGIENE ISSUE

In accordance with the health authorities [1], requirements have been set to prevent the multiplication of the *Legionella pneumophila* bacteria in hot water systems. They regard design and maintenance. Water stagnation at medium temperature (25-50 °C) for longer than about 1.5 day shall be avoided, especially when the pipe or store inner surface is not clean (limestone deposition, etc.). 1.5 day is a conservative duration, considering the fact that this bacteria's growth rate in different environments still needs research efforts until it is known in all details. This guideline implies, e.g., that limestone and other sediment is periodically removed from the system and unused pipe work is entirely separated from the distribution lines in use (instead of being just closed at one end after being put out of operation). Too large hot water storage volumes must be avoided as well. Another guideline is the provision for "temperature disinfection": systems must be designed in such a way that the hot water drawn off at any tap has been heated up for at least 1 h at 60 °C within the 24 hours having preceded the draw-off. Depending on the building use (from single-family houses to special hospitals), three risk levels are defined and the requirements have to be considered either as mandatory, in a number of cases, or as recommendations in others. More in [1].

THE DRAW-OFF LAG ISSUE

Especially when hot water is not drawn off at short intervals, users must first wait after opening the tap until the flowing water can be considered as hot. In the new standard the minimum temperature for hot water to be considered as usable has been defined as 40 °C. Hence, per definition, the waiting time ends up when water reaches this temperature at the tap. The required maximum draw-off lag that can be accepted depends on water usage; in kitchens the proposal is to adopt a smaller upper limit than elsewhere. The definitive values will be set up after the public enquiry.

Measurements of the draw-off lag have been performed in the laboratory, using a typical set-up (materials, geometry) of pipe work and fittings that reproduces situations of the practice. It turned out that the current design practice, which considers the time interval the pipe content needs to be expelled and replaced by hot water from the hot water store or the heat generator, systematically underestimates the draw-off lag. The discrepancy can be of a factor of 2 or even more. The reason is that both pipe and tap have non negligible heat capacitances. These materials absorb large amounts of heat energy and delay the temperature rise at the tap. Two examples are given in Figure 1. Calculations confirm the origin of the reported discrepancy. Curiously, the recent European standard EN 15316-3-2 still neglects the heat capacitance of pipe and fittings [2]. The new SIA standard will have to find a simple way to get a realistic

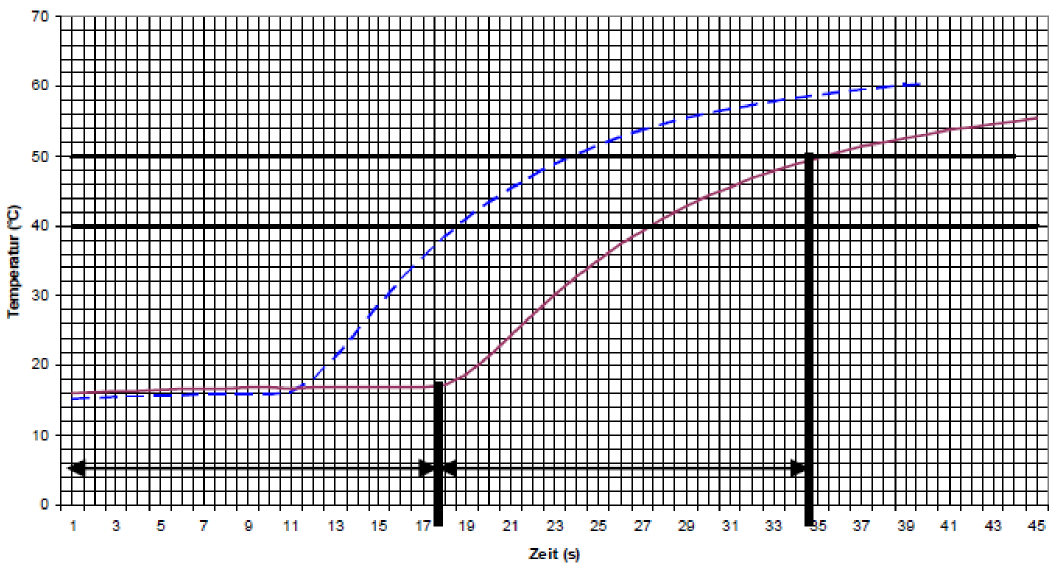

Figure 1: Laboratory measurement of the temperature rise after opening a hot water tap in a hardware configuration that simulates a typical situation in a dwelling. Dashed line: 9 m pipe length. Solid line: 15 m pipe length. Two phases are visible: first, expulsion of the pipe water content at ambient-temperature; second, warming-up of pipe work and fittings. Horizontal solid lines: two possible threshold temperatures for the definition of the draw-off lag. [3]

draw-off lag on the basis of the easily calculated duration of phase 1 (expulsion).

ENERGY CONSERVATION IN HOT WATER SYSTEMS

To limit the heat losses from hot water systems, a set of separate requirements is defined for storage devices, distribution lines and heat generators. Another requirement is defined for the pump of the circulation loop, if any, to save electricity. In addition, a global requirement is defined for the whole storage and distribution system, in order to prevent the distribution lines to become so long that they could even annul the savings obtained by means of the separate requirements' set. The global requirement should be considered by the architect and his team at the beginning of the design, when the room geometry and disposition may still be adapted.

THERMAL INSULATION OF STORES

Data available from the testing laboratory since the enforcement of the legal requirement imposed on heat losses of factory-insulated hot water stores, have been analysed (Fig. 2).

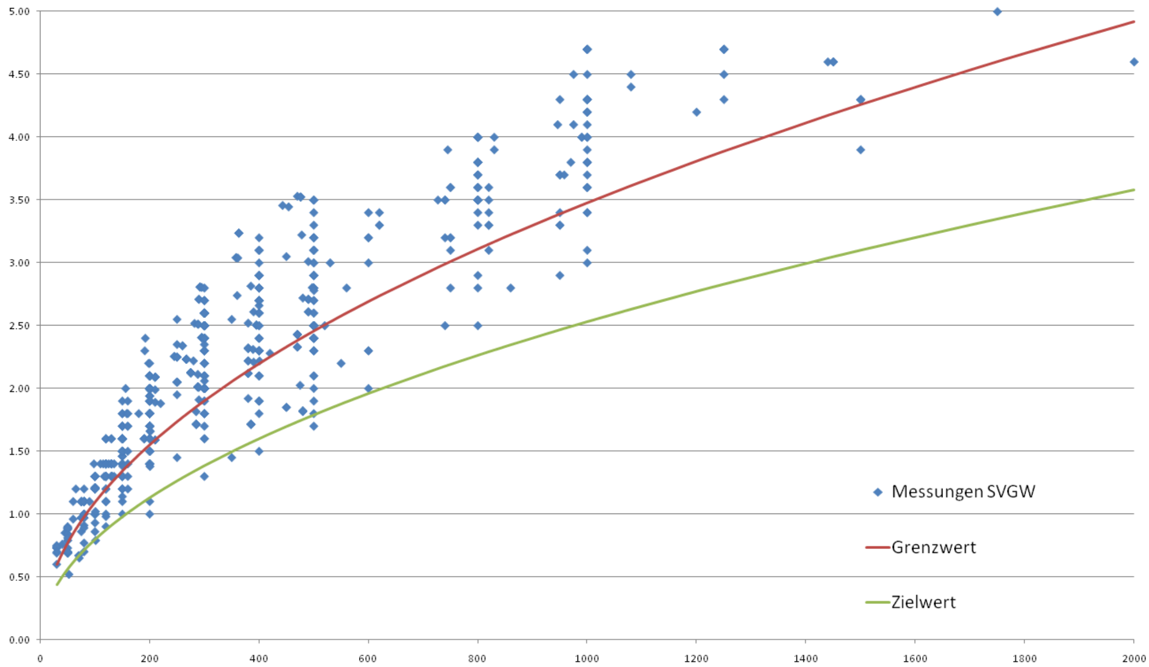

Figure 2: Overview of the heat losses of factory-insulated hot water stores, measured in the testing laboratory since the beginning of the mandatory tests (1992) imposed by Swiss legislation. The heat losses recorded within 24 hours under a 45 K temperature difference between store water and store surrounding air is plotted, in kWh/24 h, as a function of the nominal store size, in litres. Each of the 776 tested stores is represented by one data point [4]. From 200 to 500 litres, 0.1 kWh/24 h and 100 l of tank content have been subtracted from the measured value, and 0.3 kWh/24 h in the range 500-2000 litres, this in order to eliminate the additional heat losses caused by connection pipes (assumption: 0.1 kWh/24 h for each additional connection pipe; base case: 2 connection pipes as in the range < 200 l). Also shown are the proposed curves for threshold and target values of the heat losses, respectively. They imply 2 connection pipes in the whole size range.

New threshold and target values are proposed in the standard, as a function of store size, corresponding to the state of the art. They are more severe than the current legal requirements and should become the new reference. About 20% of the stores tested to date, lie below the suggested threshold line. A significant improvement in the reduction of heat losses has been observed since the beginning of the tests as a result of the publication of the product characteristics. The suggested threshold and target values should be increased by 0.1 kWh/24 h for each additional connection pipe (base case: 2 pipes).

For on-site insulated stores, threshold and target values for the thermal conductivity of the insulating material, divided by the thickness of the insulating layer are suggested, which lead to similar heat losses as in the case of factory-insulated stores. Defining the limiting values in this way (instead of insulation thickness at fixed thermal conductivities), has the advantage of already considering future improvements in insulation technology.

THERMAL INSULATION OF DISTRIBUTION LINES

Distribution lines that are maintained at a temperature near to that of the store by means of a circulation loop should be entirely insulated, including all fittings, wall passages and manifolds. The required thickness of the insulating layer is defined as a function of its thermal conductivity and nominal pipe diameter. A table is available with commonly used values of both parameters.

Contrary to usual practice, manifolds should be insulated as well. Otherwise, the required maximum draw-off lags cannot be obtained.

End-use distribution lines connecting the individual taps to the warm manifolds should cool down to ambient temperature after draw-off for hygiene reasons. No requirement is put separately on their heat losses. The latter are included in the global requirement (see below).

HEAT TRAPS

If a hot water distribution line under stagnation (absence of draw-off and of forced circulation in the pipe) has its lower end warmer than its upper one, an internal counter-flow circulation takes place. Water that has cooled down in the pipe is aggregated in the gutter formed by the lower internal surface of the pipe, and falls down to the warm end (a store, a manifold or a part of the circulation loop); as a result, hot water is sucked into the upper part of the pipe, and this establishes the counter-flow circulation. This circulation, which was mentioned 1983 for the first time in Switzerland, can be blocked by heat traps [5]. Detailed experiments have been recently performed and general rules for the geometry of heat traps established [6]. Heat traps are short pipe sections with a warm end at the top and a cold one at the bottom (Fig. 3). A short video movie of a counter-flow circulation experiment is presented at the conference [6].

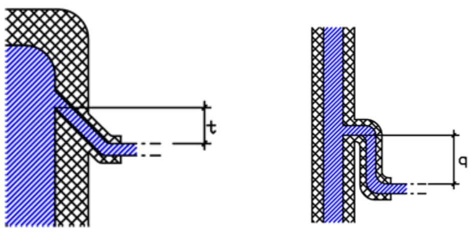

Figure 3: Two examples of heat traps to be installed between a hot water store (left) or a warm distribution line (right) and an end-use distribution line that has to cool down after draw-off. Minimum vertical heat trap extension: t > 7 cm (left), q > 12 cm (right) [6].

Counter-flow circulation causes massive heat losses in hot water systems [5]. Therefore, heat traps are required by the new draft standard, to clearly separate the lines, manifolds and stores maintained at service temperature from those which have to cool down. In this way, the energy efficiency of the hot water system increases and hygiene is improved, due to the fact that (i) end-use lines are less exposed to intermediate temperatures favourable to *Legionella* growth, and (ii) circulation lines are maintained at a higher temperature.

POWER OF CIRCULATION PUMPS

For hygiene reasons, circulation pumps shall be continuously running, day and night, 365 days a year. Electricity savings can only be achieved by limiting the installed electric power of circulation pumps. Only the most efficient pumps available on the market place (Europump energy label category A) will be able to meet the target set by the new draft standard. The suggested threshold value is somewhat less stringent. These limiting values depend on the pipe work length.

HEAT GENERATION

The new standard only considers heat generation for hot water by a separate device, i.e., that is independent of heat generation for space heating. In the case of combined generation, standards for space heating systems shall apply, which are also relevant for all cases of heat generation by a burner. Two cases are treated in the new standard:

- An electric heat pump that supplies heat to a hot water store, with or without integration into the storage device: minimum threshold and target values are specified for the mean annual coefficient of performance.
- A solar water heater with electricity as back-up energy source: no special requirement is defined for the heat generation. The whole system simply has to meet the global requirement (see below).

OVERALL HEAT LOSSES OF HOT WATER SYSTEMS (GLOBAL REQUIREMENT)

The overall heat losses of hot water systems shall be limited, in order to improve energy efficiency and prevent high indoor temperature in the summertime. The approach suggested in the new standard puts a requirement on primary energy consumption to cover the sum of stores' heat losses and distribution lines' heat losses.

First of all, reference conditions are defined for the usage of the system, in accordance with European standards and national reference documents: tapping programme, daily draw-off volume of hot water. Here, a distinction is made:

A) For residential buildings, the net daily consumption of 40 litres per person is assumed, after subtraction of the hot water losses due to the draw-off lag (see above)[1]. To convert this water consumption to an energy consumption related to the building's conditioned area, the statistical occupancy of housing (number of persons per housing unit, as a function of the housing unit's conditioned area) available from the most recent national census is used and a temperature rise of 50 K in the heat generator is assumed.

B) For non-residential buildings, standard hot water energy consumption figures per m^2 of conditioned area are taken over from other national standards and converted to net consumption figures by subtracting energy losses due to the draw-off lag. Here also, a tapping programme is needed. There are two main groups of non-residential buildings: those with a low hot water consumption (schools; office, commercial and industrial buildings; stores; meeting rooms), and all others with a high hot water consumption (hotels, hospitals, sport buildings, swimming pools).

Then, for these reference conditions the yearly heat losses from stores and distribution lines – both those maintained at service temperature and those cooling down after draw-off – are cal-

[1] Usually, hot water losses due to the draw-off lag are not separated from the effective (useful) hot water consumption. The usual measurement procedure delivers only the sum of both quantities.

culated. The different contributions are split according to the respective energy carriers, multiplied by the corresponding primary energy factors and summed up. The resulting sum shall be smaller than a threshold value and preferably near to a target value. The corresponding overall primary energy efficiency figures suggested in the new standard are given in Figure 4.

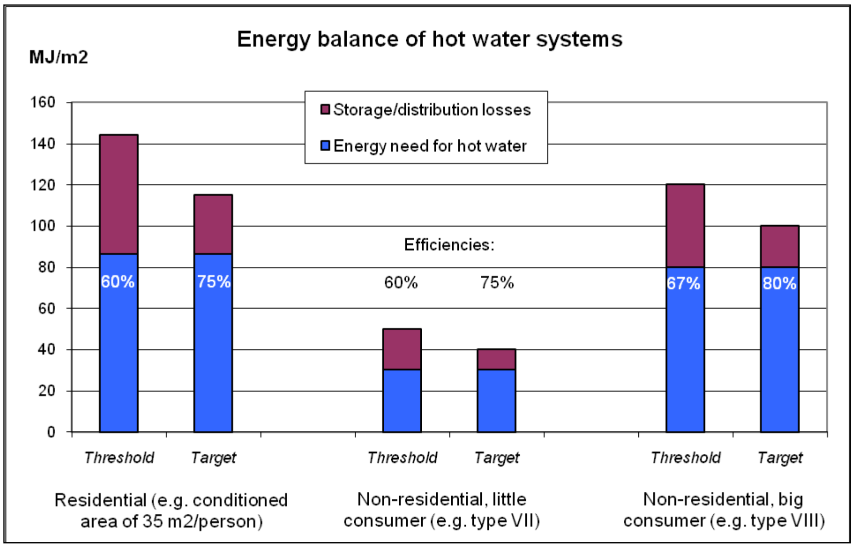

Figure 4: Suggested overall primary energy efficiency of hot water storage and distribution systems, for three building categories (residential, non-residential with low hot water consumption, other non-residential). Typical examples according to SIA standards. Left-hand bars: threshold values. Right-hand bars: target values.

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AN ASSESSMENT OF INDOOR AIR QUALITY IN NEWLY BUILT ENERGY EFFICIENT HOMES IN THE NORTH EAST OF ENGLAND, UK

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ABSTRACT

The objective of this study is to monitor indoor air quality of newly built energy efficient homes in the north east of England, UK and to compare results to accepted standard guidelines. Air temperature (°C), relative humidity (RH%), and carbon dioxide (CO_2) were monitored. The results showed that the indoor thermal environment conditions in the five mechanically ventilated homes had a mean air temperature and relative humidity of 20.5 °C and 47% respectively in winter time. The mean CO_2 levels were in the range 420 to 1471 ppm and followed a pattern that rising during morning and evening in response to human indoor activity; also there was an inverse correlation between CO_2 and air temperature ($r=0.31$, $p<0.05$). Detailed analysis of CO_2 at four periods during the day showed that afternoon times contained lower values of CO_2 compared with morning, and evening. We conclude that two homes meet thermal targets and 4 homes meet relative humidity targets within acceptable levels for thermal comfort. Indoor air quality (IAQ) is indicated to be not fresh enough, suggesting that the ventilation systems are not working satisfactorily in winter time.

INTRODUCTION

The Building Energy Analysis Unit (BEAU) in the School of Architecture at the University of Sheffield was working with a Housing Developer (the Accent Group), their Architects (the Goddard Wybor Practice) and along with their M&E Consultants (Mott MacDonald) to evaluate and modify the designs with the goal that they are environmentally friendly and low energy users within the UK climate. As a result of this team effort of research and development, the first generation of newly built energy efficient homes were built in Bradford in July 2006 and occupied by social tenants from August 2006; which are also currently being monitored by BEAU to establish if the energy efficient homes are low energy low carbon homes as designed, and if the user satisfaction is highly as desired. The designs include a range of advanced systems such as renewable energy technologies to provide both space heating and hot water in these social homes.

The indoor environment is an influential factor to environmental quality. People spend a majority of their time in buildings, the average Western person spends up to 85% of their life in a building, or in a vehicle conveying them from one building to another [1]. The housing environment is the main setting for many; consequently certain conditions of this environment can have a profound effect on the quality of the environment and the public's health. Studies have highlighted that at present many people live in conditions that are considered 'unhealthy' because of high levels of mould growth, damp and dust mite concentrations. Approximately 20% of all dwellings in England suffer from mould growth and dampness to some degree [2].

United State Environmental Protection Agency (EPA) studies of human exposure to air pollutants indicated that indoor air levels of many pollutants may be two to five times higher than outdoor levels [3].

Oreszczyn and Pretlove point out that a key parameter in house dust mite survival and mould growth is relative humidity. Relative humidity is a function of both moisture and temperature, which are dependent on many other inter related factors of the indoor environment, including fabric insulation, occupants activities within the home (number of occupants, hours of occupation, ability to pay fuel bills and amount of moisture generating activities), the heating system (efficiency, control and distribution), ventilation and external climate. Using these factors they have developed a model to identify the risk of mould growth in dwellings [2, 4].

A study by Carrer et al. showed that the concentration of many air pollutants were higher indoors than outdoors in an urban environment. Pollutants found indoors include CO and NO_2 as well as dust, volatile organic compounds (VOC) and radon. The sources of these pollutants vary depending on the type of pollutant, but studies have shown that common sources can be the external environment, building materials and household products [1].

Increasing the attention to indoor air quality has contributed to the awareness of poor health associated with a poor indoor environment. Two types of illnesses related to poor indoor air quality have been identified: sick building syndrome (SBS) and building related illness (BRI). While the definition of SBS varies slightly in the literature, SBS can be defined as the discomfort or sickness associated with poor indoor environments with no clear identification of the source substance. BRI is defined as a specific recognised disease entity caused by some known agents that can be identified clinically [5, 6].

The objective of this study is to monitor indoor air quality and to investigate conditions and performance within the newly built energy efficient homes in the north east of England, UK and to compare results to accepted standard guidelines.

METHOD

A measurement programme of internal environmental parameters was undertaken for a two weeks period (12 February - 26 February) 2009.

Indoor air temperatures and relative humidity levels were measured at the six homes using HOBO U12-012 data loggers. Indoor carbon dioxide levels were also recorded in the five energy efficient homes using Telaire 7001 CO_2 meters. Although CO_2 is not toxic it is commonly used as an indicator of air quality. High levels of CO_2 indicate inadequate ventilation in a space.

All equipment was placed in the living room in each home, specifically in the breathing zone of a person sitting on a sofa (approximately 1.5 m above the floor) and away from open windows. In addition, participants were requested to behave as normal within their homes during the monitoring period in order to obtain realistic data.

The objectives of monitoring indoor air quality were to gain an insight into conditions within residents' homes and to compare indoor environmental conditions i.e. air temperature (°C), relative humidity (RH), and carbon dioxide (CO_2) to accepted standards guidelines. Average levels of each variable were collected in 15-minute intervals over a 24-hour period for periods of two weeks.

RESULTS

The data collected from the indoor monitoring equipment were statistically analysed to investigate the condition of indoor air quality in winter within the five homes.

Our results have been compared to published standard guidelines. Figure 1(a, b and c) shows the average indoor air temperature (°C), relative humidity (RH) and carbon dioxide (CO_2) for each of the monitored dwellings in winter time.

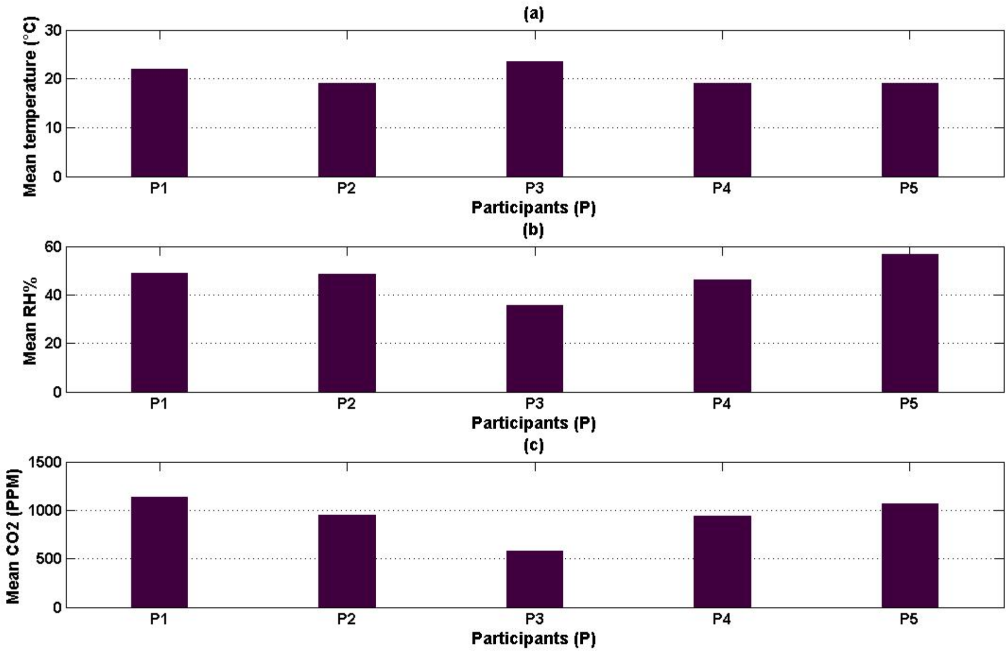

Figure 1: Mean temperature, relative humidity and carbon dioxide for each home

Average temperatures ranged from a low of 17.7 °C to a high of 24.8 °C, with an average of 20.5 °C in winter period. Average relative humidity ranged from a minimum of 30% to a maximum of 59%, with a mean value of 47% for winter.

In comparison with the UK's Chartered Institution of Building Services Engineers (CIBSE) recommendations (Environmental Design, CIBSE Guide A) [7] it is clear that 3 homes out of 5 did not comply with the CIBSE recommendation for the range of winter internal temperatures (22-23°C) in living rooms and are below the value of 22 °C table 1 and figure 1(a). An acceptable range for RH is 40% to 70% and table 1 and figure 1 (b) show that only four homes have acceptable mean values of RH for winter.

Indoor relative humidity fell when the temperature was rising and minimum values were recorded at maximum temperature. The most significant value of RH was 70%, which occurred in P5 at 19:05 in the evening.

Currently, there are no UK CO_2 standards for indoor air, although the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) recommend an acceptable indoor air carbon dioxide concentration of less than 700 ppm above the outdoor concentration. The average indoor CO_2 levels were measured in 5 homes and their values ranged from 420 to 1471 ppm, which indicates inadequate ventilation during the monitoring period for four homes table 1 and figure 1(c).

Participants	**Mean temperature (°C)**	**Mean CO_2 (PPM)**	**Mean RH (%)**
P1	22	1133	48.8
P2	19	948	48.4
P3	23.5	582	35.5
P4	19	939	46
P5	19	1063	56.5

Table 1: Overall means from all the measured data for every home

Mean daily indoor air temperature and mean daily CO_2 were correlated with statistically significant results ($r = 0.31$, $P = < 0.05$). Figure 2 shows this inverse relation. These results may indicate that warmer dwellings have higher air ventilation rates and therefore CO_2 levels are lower.

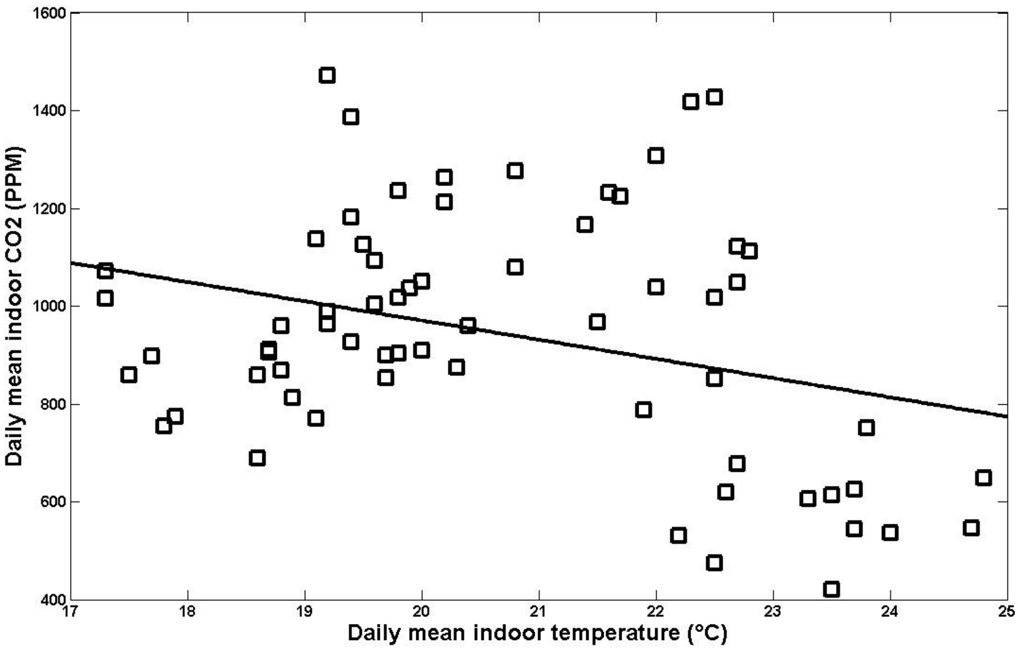

Figure 2: Correlation of Daily mean carbon dioxide and daily mean temperature of five homes

(17/02/09) was chosen at random to plot its CO_2 concentration against time to investigate the behaviour of carbon dioxide during that day. Figure 3 indicates that the indoor CO_2 level followed a pattern in the three homes. Levels were seen to rise during morning period and drop afterwards, later rising and falling at evening time and again at morning time.

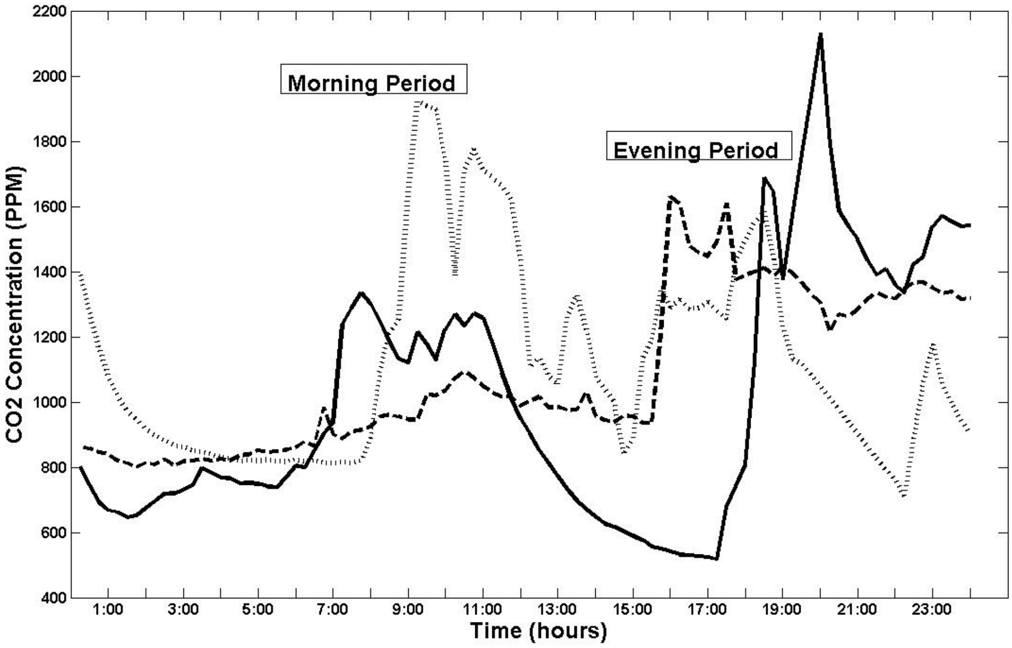

Figure 3: CO_2 concentration of three homes for one day.

Weekend and weekday data was separated into two groups. This allowed the comparison of their mean values of temperature, relative humidity and carbon dioxide. From table 2 it can be seen that P1, P3, P4 and P5 has mean values of indoor temperature, relative humidity and carbon dioxide which are slightly higher at the weekends than weekdays, except for participant P2.

Participants	**Indoor temperature (°C)**		**RH (%)**		**CO_2 (PPM)**	
	Weekdays	**Weekends**	**Weekdays**	**Weekends**	**Weekdays**	**Weekends**
P1	22	22.2	50	47	1112	1185
P2	19.8	18.2	48.2	49	995	833
P3	23.3	23.9	36	34.5	567	619
P4	19.4	19.6	46.8	45	926	972
P5	18.7	19.5	56.8	56	961	1319

Table 2: Mean value of temperature, CO_2 and RH for every participant in weekends and weekdays.

CONCLUSIONS

This study aimed to investigate the internal air quality of newly built energy efficient homes in the north east of England, UK and to compare measured values to accepted standard of temperature, relative humidity, and CO_2. The conclusions from this study are acknowledged to be based on a limited number of samples (five homes). To further describe the indoor air quality and generalise the results, it would be necessary to do more sampling on a larger population. From this limited data, measured values in winter of temperature, and CO_2 have been found not to comply with standard guidelines. In a previously conducted study [8] it was found that there was a proportional relation between indoor temperature and CO_2 levels which reflected the dilemma of achieving proper ventilation and indoor thermal comfort. However in this study the relation between temperature and CO_2 is inversely proportional which may be due to the mechanical ventilation systems employed in the buildings. The study shows that the rising pattern of CO_2 is in the morning and evening sessions which may be due to the increase of indoor human activity.

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LIVEABILITY AND ENVIRONMENTAL COMFORT APPROACH IN URBAN RENEWAL: A CASE STUDY

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ABSTRACT

The municipality of Nuoro, a small city in Sardinia (IT), last year called for bids for building and urban renewal of public buildings and urban spaces located in the city centre.

The bid called "Pratzas de Janas" (the fairies squares) is organized into four paths trough the city centre joining squares, streets, widening and viewpoints (14 urban spaces and 4 buildings). All the places have a particular meaning for their inhabitants.

The bid considered the environmental sustainability aspects dealing in particular with the materials choice as well as the technological and plant solutions research (15/80 marks).

Integration in the urban context (15/80 marks) as well as observance of the largest accessibility principles (10/80 marks) - in terms of designing choices and solutions adequate to improve paths used by people – were both required.

This paper introduces the approach adopted by the winning project for renewal of urban open spaces, in order to reach a social and environmental sustainability. The proposed project has always been coping with environmental and thermal comfort improvement on one side, and space use and pedestrian activities analysis, which have to be kept aside from vehicular flow and parking lots, on the other hand.

THE BID "PRATZAS DE JANAS"

In December 2008 the bid, named POLIS-*Progetto di qualità - Gli itinerari della cultura – Pratzas de Janas* (POLIS- quality design- the cultural paths- fairies squares) was closed. It was called by the the Municipality of Nuoro. It deals with squares, small squares, streets and alleys renewal, and the renovation of some ancient buildings located in the historical city centre, considering 18 different design actions in coordination and integrated among them, characterizing four thematic paths: figurative arts path, literature, artefact and folklore, and the last one, the landscape value path.

According to the size, the economic magnitude, the supposed timing of the building process, the delicacy of the urban context involved, and the perspective designing capacity, this project represents a special changing occasion for the city of Nuoro as well as the first very important technical and administrative public commitment.

THE SUSTAINABLE URBAN RENEWAL APPROACH

Vitality and liveability of urban spaces are the success key of a city, in particular for those cities which want to be considered sustainable.

In order to reach this goal the conventional way to tackle the project has to be change. We need a new approach giving priority to the users needs. Users needs deal with three categories of needs: the aspect of the spaces, the space use, and the environmental comfort (thermal and visual in particular). Sometimes users express them in a unconscious way.

This immaterial sphere interfaces itself with the space physicality, that is material, touchable. The environmental behaviour, i.e. the performances of the urban space, allows activities can be done. It is very important that the urban space design takes into account the materials, shading devices and vegetation choice, since the first steps of the project. They actually are those element that can improve the microclimate and then define better environmental comfort conditions. The Definition of the location of users activities (settled and moving ones) it is also fundamental. The activities location takes priority over the vehicular traffic, and has to be defined according to the climatic variability based on daily and seasonal cycles.

THE METHODOLOGY IMPLEMENTED

In case on urban renewal, before starting the design, it is fundamental to observe users behaviour, in order to understand the favourite areas for staying, the more used paths, that often don't consist with the design propose. These observations related to the space use, together with some simple evaluations represent the first design indication.

The pedestrian and vehicular flow analysis as well as the settled activities, combined with the design shade analysis of a specific urban space, represent a work in progress design evaluation. The design has to be change so far we don't find the better relationship between car and pedestrian, as well as the suitable relationship between space environmental behaviour and urban furniture which allow the activities to be played. The proposed method to analysed the space use (Gehl architects) put in evidence that the activities follow daily (taking into account the different periods of time in the day) and seasonal rhythms. A further analysis considers the sun/shade paths in three different period of time - morning, lunch time, afternoon - for the whole urban space. The proposed projects were tackled starting with the environmental condition analysis of the urban spaces. In the first phases, the existing analysis, was done with a field survey, i.e. microclimatic measurements (during the hottest day of the year, 6th of August) and people behaviour observation, and also trough sun/shadow analysis trough sun-path diagrams and shadow masks evaluated with the Heliodon software.

Therefore the main effort of the project was to balance the car and pedestrian. The urban design always tackled with the environmental improvement, i.e. with the comfort conditions from one hand, and with pedestrian paths and settled activities areas from the other hand. They have to be separated as much as possible from parking lots and vehicular roads.

Some simulations in dynamic regime allowed us to estimate thermal comfort conditions of the design proposed.

The design, in terms of environmental issues, mainly focused on shading devices (vegetation in particular) and pavement materials with high thermal capacity and not too much clear, in order to avoid the reflected radiation on people, responsible of glaring and thermal discomfort.

The vegetation choice often rebounded on the typical and already used species. In particular small, deciduas and suitable for urban environment species have been selected. The perceptive vegetation impact has been evaluated too, taking into account the seasonal assets of the species that are in the same urban space.

A CASE STUDY

The case study presented in this paper represents one of the squares redesigned for the competitive exam, included in the Literature Path. The urban space presented is piazza Asproni.

The public library faces the square in the south side and the old "Casa Buscarini", nowadays the Sardinian section of the library and the archaeological museum, is in the east side. Although ever and ever reached, this square is just a path, where people pass by not stopping themselves. They frequent the space but they don't "live" it, they don't identified themselves in it. People cross this square in order to reach the library and the few dwellings in the area.

Figure 1: Piazza Asproni, nowadays a parking area (view from the library, from the north)

They cross the north side to go towards the cathedral and Corso Garibaldi (the main pedestrian street of the city).

The environmental analysis

The square is irregular shaped reminding an isosceles triangle, in which the short side is north oriented. The environmental analysis has been done evaluating the solar path obstructions through the shadows mask that allows us to understand when, during the day and the year, the square is sunny or shaded. The first consideration deals with a morphological analysis: due to the limited high of the buildings and then the reduced dimensional ratio (H/D), the square is for long time quite sunny, during the whole year as well as the day.

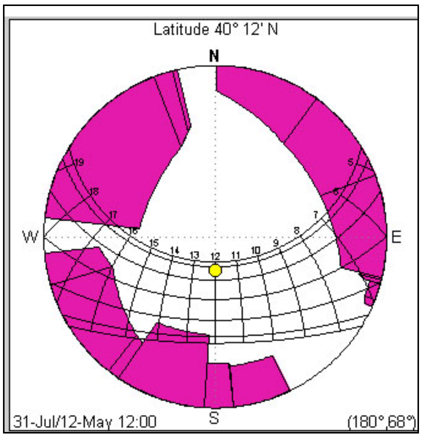

Figure 2: The shadow mask shows periods of time in which the square is sunny or shaded

During the coldest months, when the sun is quite low to the horizon, the square is shaded from the lunch time and in the afternoon. During the summer the squares is shaded only from 5 p.m.. This means that in order to encourage the people presence in summer we need to make for shading device at least in some areas for the morning and the lunch time.
A more careful analysis, made with the microclimatic measurements, allowed us to verify that the situation can be very critical in terms of both air temperature and surface temperature (linked to the mean radiant temperature and then to the comfort conditions).
The field survey were done with the aim to evaluate the thermal balance, i.e. comfort conditions, with the calculation sheet Comfa+.
In the most critical moment, at the lunch time, for a person under the sun, the thermal balance is about 209 w/m^2. If we consider acceptable comfort conditions not higher than 50-70 w/m^2, we realize how impossible it is to propose the use of this square not considering improving strategies, in terms of vegetation, shading devices and suitable materials (i.e. able to avoid overheating as well as accumulate heat and give back after some hours).

Microclimatic survey	Morning	Lunch time	Afternoon
Air temperature (°C)	35.8	39.2	30.8
Global radiation (W/m^2)	472	630	51
Diffuse radiation (W/m^2)	54	20	35
Relative humidity (%)	27	30	58.8
Luminance (lux)	87.7	112	29.4
Surface temp - Building east	25.2 (shaded)	41 (sunny)	36 (partially shaded)
Surface temp - Building south	27.6 (shaded)	33 (sunny)	29.4 (shaded)
Surface temp - Building west	39 (sunny)	37 (shaded)	32 (shaded)
Surface temp - Building north (library)	27 (shaded)	33 (sunny)	41 (sunny)
Surface temp - Pavement	39 (sunny) 25 (shaded)	63 (sunny)	40 (shaded)

Table 1: Microclimatic data measured August the 6th in the central point of the square. In particular, air, surface temperature and solar radiation

The design process

The project has the aim to get identifiable the sense of belonging of piazza Asproni to the whole historical urban system. It is possible when the urban space is free from cars arrogance and the space is organized around the Sardinian sector of the library, the building on the east side. The project tackles with the back garden and let imagine that the library entrance could be a sort of gallery that keeps them connected. From here originates the new urban quality with its new dimension coming from the constant and productive dialog among the different composing parts, and from them and the rest of the territory. The environmental analysis of the existing space gave the first designing indications. The aim of the project developed itself with the proposal to realize a usable space for citizens in every moment of the day and the year in environmental condition close to comfort as much as possible.

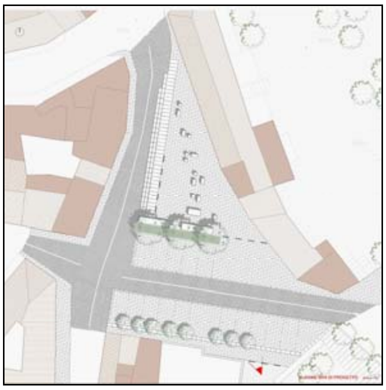


Figure 3: The last version of Piazza Asproni project

In this part of the work particular care has been taken to the summer comfort conditions, particularly critical and able to discourage the potential use of the urban space. The square irregularly shaped needs to keep a number of parking lots and vehicular flow.
The preliminary design (Project cod. 975XZAB – Eng. C. Manca), were changed in order to meet the administration needs. The need to separate the two flows oriented the project and then, the area for the settled and moving activities for people in the east side, along the building, has been considered. The pedestrian area is about 400m^2.
The "Casa Buscarini" building and its façade in the east side of the square represent an important scenario that can be used occasionally for special events and projections. This aspect limits the possibility to provide more shading devices, and for this reason the square, even after the design, has some sunny areas so far the afternoon. From mid afternoon the square get in shade and can be completely used. Shadow is provided by a group of small globoid trees that shade in the central hours the benches below.

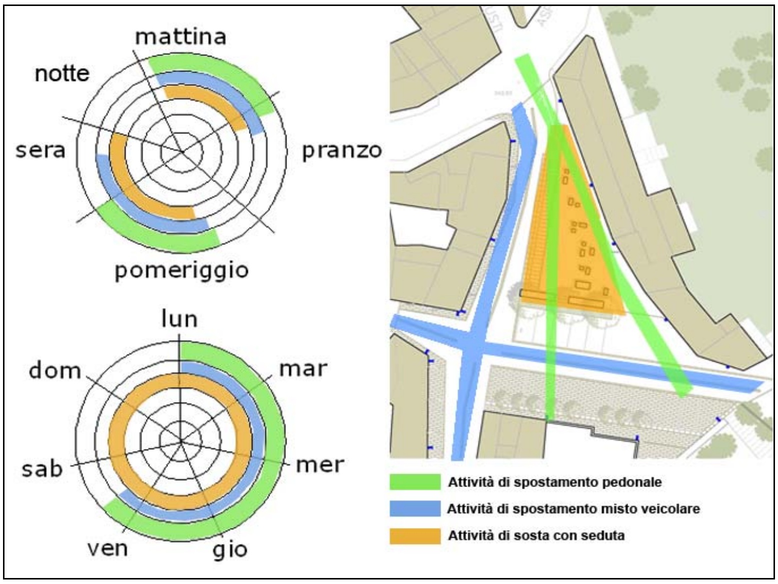

Figure 4: The use of space analysis through the representation and the timing of the car flows and pedestrian areas (green: pedestrian path; blue: vehicular path; area for settled activities)

The trees are catalpa *bignanoide bungei*, named "dwarf" because of the reduced dimension. The crown is about 5 metres. They are deciduous trees so that allow the sun to pass by and reaches the benches in winter.

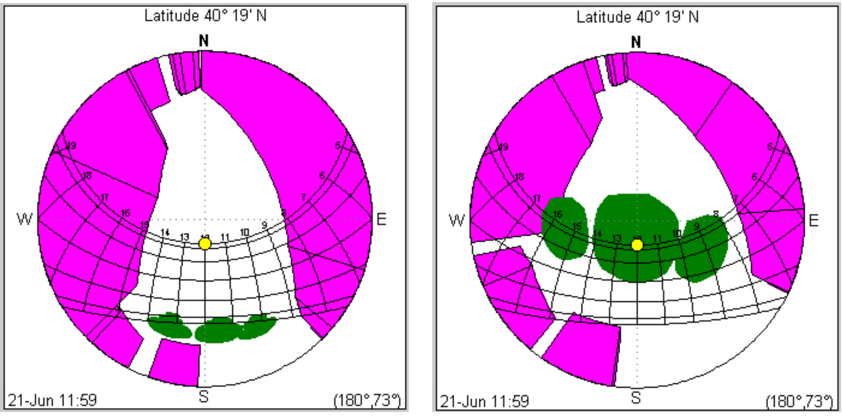

Figure 5: the shadow analysis trough the shadow mask of the design proposal, in the central point of the square and under the trees

The flower-bed under the trees is constituted by a covering shrub, the *cotoneaster dammeri*, 50-70 cm tall, that separates, also in visual terms, the sitting areas from the parking lots. Another row of small trees, *pseudoacacia umbraculifera*, with 4-5 metres of crown playing a role of wing in the north side will be provided. The other buildings façades of are not object of intervention, while pavement will be completely renovated.
The proposed material is the granite for different reasons: first of all it is a typical local material, widely available in the area. This material satisfies the requirements of a material with an average albedo value and high thermal capacity.
At this point it is possible to evaluate the proposals effect, calculating again the thermal balance through Comfa+.
The evaluation were done in the same point as before, the point now provided by the trees. the proposed situation put in evidence a clear improvement.

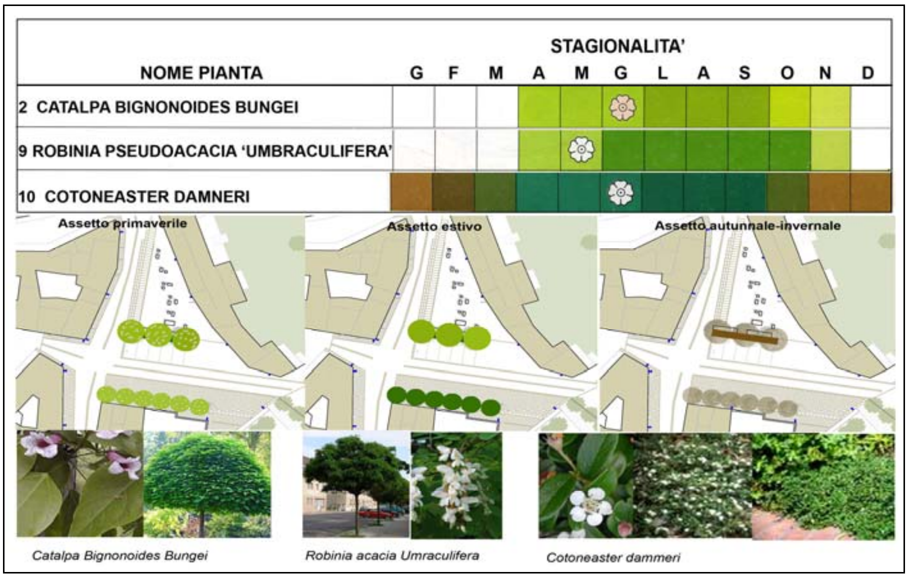

Figure 6: The seasonal asset of the vegetation proposed for piazza Asproni

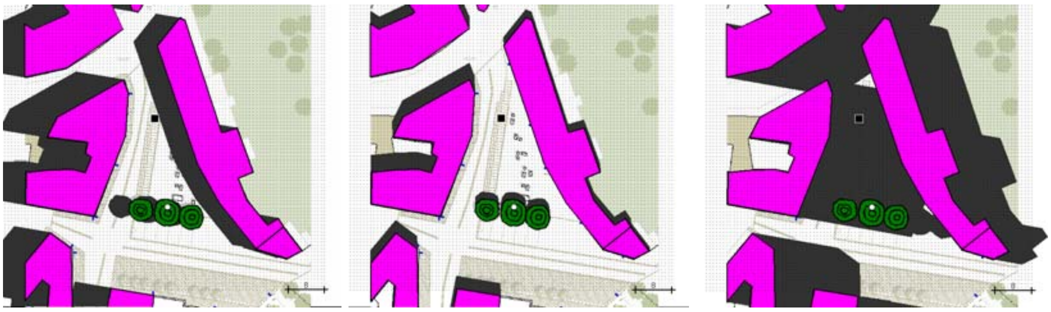

Figure 7: The shadow analysis trough the shadow brought by the buildings

Actually the thermal balance at 2 p.m. is decreased to 73,4 w/m^2. This values is just out of the range of comfort. Nevertheless this conditions can be considered acceptable. Neither the fact that we are considering the most critical moment of the year has to be neglected. It is therefore reasonable to think that during the main part of the summer people can sit, pass by and stand in the protected areas in the central hours of the day in comfort conditions.

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SUSTAINABLE REHABILITATION OF THE SOCIAL HOUSING DISTRICT "SEMICERCHIO" IN THE TOWN OF SESSA AURUNCA (SOUTH ITALY)

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ABSTRACT

The social housing, aimed to satisfy the requirement of living for the poorer social classes, nowadays adopts requirements such as comfort, usability, well-living and ecosustainability. All starts from the desire to give a new configuration to the social houses. A configuration that avoids low quality buildings, just enough good for primary needs, and decay phenomena in our suburbs. The house is not in search of fixed standards, that brought in the past to a minimization of quality levels, but it finds to identify the economical and environmental opportunities of the site, allowing thus to reach the highest and better living conditions.

For supporting this new social housing concept, more often new laws, such as that regarding the Energetic Certificate, are issued in Italy with the aim of pushing the social housing towards these goals.

Talking about social housing means to satisfy the individual, and community needs, but it means also to protect the natural and human environment, through the energy, water and material saving. Such aims must be achieved in new buildings as much as the existent ones.

The paper deals with a design concerning the rehabilitation of a social housing district in the town of Sessa Aurunca (CE).

Through the study of natural and human systems, the aims of well-living, usability and ecosustainability have been defined, and all the project has been developed according to them.

INTRODUCTION

Our towns, which host more than two thirds of the world population, employ big amount of resources, such as prime matter, energy, water. Our environment has been arranged in order to satisfy a number of requirements, which not always happen to be efficiently established, and often the provision of one facility produce more refusals and toxically emission than actual services. As far as the thoughts of a number of scientists and philosophers are concerned, the carrying capacity of earth ecosystem depended on the actual requirements of a population, but should also be compared with the speed with which the consumption of resources and the production of refusals occur.

The aim of sustainable design should be achieved according to the two main principles outlined by Hermann Daly (one of the fathers of Ecological Economics), i.e.: 1. renewable resources should be consumed at such a speed allowing the nature to recuperate strength (principle of sustainable efficiency) and 2. the good production should not produce refusals and pollution which could not be absorbed by the system within reasonable times; there should not be storing effects (principle of absorbing capacity).

Towns have been included in the category of open systems, which, in analogy to living organisms, exchange with the environment a number of physical entities and chemical phenomena, thus providing the effect of increasing or decreasing the entropy of the system itself according to the quantity of refusal output or resource input. [Pulselli, Tiezzi, pag. 21]

Our research started from this point of view and tends to demonstrate that a different way of approaching the design of housing arrangement in the town can help to reduce the entropy of the system, thus allowing a longer and more favourable life on earth for citizens. Therefore a new relationship between the development and the environment should be tested, in which the comfort as well as the health of the inhabitants was taken into account by means of various tools, such as the participation, the ergonomics, the environmental psychology.

Our idea is that this new design approach should begin from the avoiding of constructing and reconstructing the areas, which is an human action, that more than others consumes big amount of resources, and mainly the soil; the sole big change in design should be that of rehabilitating existing buildings, both in the historical centres and in the suburban areas, naturally accompanied by energy saving, good accessibility to public transportation, but mainly trying to improve social cohesion and quality of life for the whole community.

The last includes strongly the minor income population which has to be provided with social housing settlements, both of new construction and as rehabilitation of existing ones.

Social housing definition has today exchanged into a word that includes, among the others, also the respect of requirements such as comfort, benefit, usability and eco-sustainability. It is not expected that the new social dwelling would satisfy fixed and unique standards, which had brought to minimize quality levels, but on the contrary it should be in harmony with the site potentialities, both economical and environmental, which will allow to achieve higher grade of life satisfaction.

We present as case study the requalification of a public housing stock in Sessa Aurunca (South Italy), called the Semicerchio (half-round), built in the 60s and presently decayed and little liveable, from both the point of view of landscape and settlement.

THE REQUALIFICATION HYPOTHESIS

Through the study of natural and human systems, the targets of comfort, usability, well-living and eco-sustainability are defined, so to use, in a better way, the site opportunities both in the urban and building design.

In the district distribution none of the buildings creates shadow on the others. The orientation, instead, is unfavourable, except for some buildings located at the north of the area. Here we find the Roccamonfina Volcano, while the East side is closed by the mount Massico; nevertheless these mountains let the winds Libeccio (south-west) and Maestrale (north) to pass.

The existing green areas, clearly lower than the inhabitants needs, are mostly neglected and degraded; moreover the original design of these areas has completely disregarded the climate.

Thus, in our project, the green areas requalification has been thought with the principal aim of blocking the Maestrale, cold winter wind; some evergreen trees have been located in the West side of the district, in a non-built zone (Fig. 1).

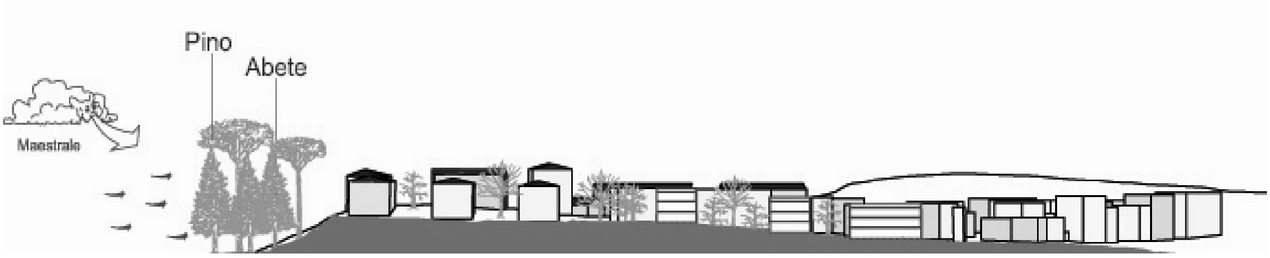

Figure 1 - Longitudinal section of the district with the green planning

In the internal area of the district, instead, there are deciduous tree, for shadowing the houses and the linking paths in the summer. The morphological and typological analysis shows that the streets are characterized by a mixed circulation, both pedestrian and vehicular, that makes disagreeable, for the users, to walk through the district. Moreover very few are the car-parking zones, so it is frequent to see cars parked on the sidewalks, that cannot be exploited by the pedestrian. The sidewalks, further, have no protection from the rain and the sun. The asphalt street paving, finally, does not drain well and accumulate too much the heat.

Therefore the design proposes a vehicular circulation scheme with massive use of one way streets. The reorganization of the internal viability has, furthermore, the intent to slow the vehicular speed and to reduce the acoustic pollution due to the traffic, through some interventions that aims to narrow the driveway like: sidewalks widening (choker), urban design elements installation, green areas, different colouring and texture of the materials used for the paths.[1]

Moreover, the present street paving has been changed with a new one made in Porphyry, disposed in fan-shaped, which results more draining and soundproof of the present asphalt. The parking areas are protected from solar rays through diffused trees and the parking paving is made up by ecological polypropylene.

The pedestrian paths, separated and clearly distinguishable for the use of a different type of paving (made with basaltic stone and earth), are conveniently protected, through artificial or natural elements, from the rain and the summer sun.

The pedestrian areas are divided in two different zones, in which a small football field and a public garden are located, so as to create a space completely closed to the vehicular traffic. The two described areas are linked together by an existing narrow street, which is characterized on a side by the presence of a long and continuous sit, protected by a bower that supports some photovoltaic panels that provides energy for the public lighting of the pedestrian areas (Fig. 2).

[1] For slowing the cars that entry in the district, the design has reduced the street width: 3,5-4,5 m. for the one way streets, with parking on one side; 5-6 m. for the two-way streets, 7-9 m. for the two-way streets, with parking on one side.

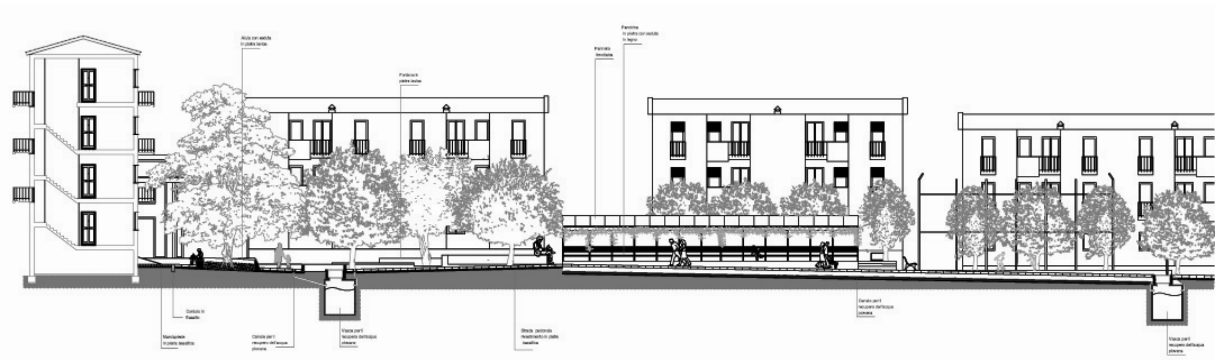

Figure 2 - Longitudinal section of the pedestrian area

The introduction of a fountain in the little square helps, together with the presence of the trees, to create a pleasant microclimate in summer (Fig. 3).

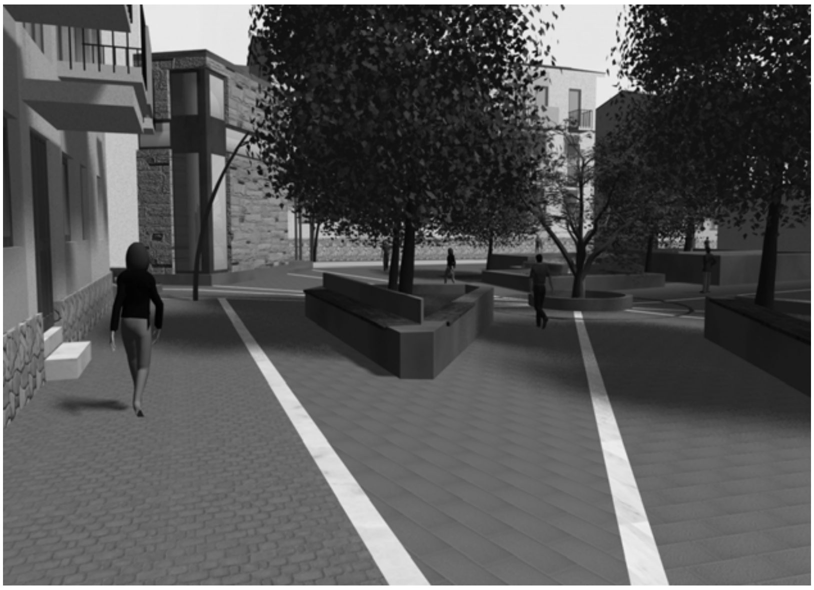

Figure 3 - The little square

The care for saving and reusing water has led to a design strategy that takes into account the recycling of superficial water.

So, exploiting the existing ground slopes, the rainwater is conveyed into specific channels and collected in some underground pools. The water, so collected, is used for the gardening and for domestic use (toilet and wash-machine).

The district has been built by the INA Casa in the 60’s. So all the buildings are made in yellow tufa (a local stone, with volcanic origins), and the typology presents a central stair that serves 3 or 4 dwelling for each floor. The height of the buildings changes from a minimum of 10 meters to a maximum of 15, some with flat roof and others with pitched roof. The area of the dwelling, instead, varies from 70 to 90 squared meters. The bioclimatic analysis has shown that almost all the dwellings have a bad orientation. The buildings have no sun-shading devices and no elements that can reduce the external traffic noises. The windows have simple glass and no attention is given to the internal ventilation.

The building chosen for the rehabilitation, has an East-West orientation (Fig 4).

Figure 4 - A picture of the building chosen for the rehabilitation

For improving the orientation, the internal spaces have been reorganized, moving all the main functions on the South-East side, closing the windows at the North and reopening it at the South.

For improving the exposure of the spaces used during the day, a rotation of the South-East façade has been adopted, so as to align the windows to the exact South, with the aim of gaining much solar heat during winter (Fig. 5).

Figure 5 - Axonometric view of the rehabilitated building

To protect the south-east façade, instead, a green wall made of Ivy has been designed. Another solution proposed for thermal and acoustic insulation is the roof garden, that at the same time guarantees a longer durability (Fig. 7).

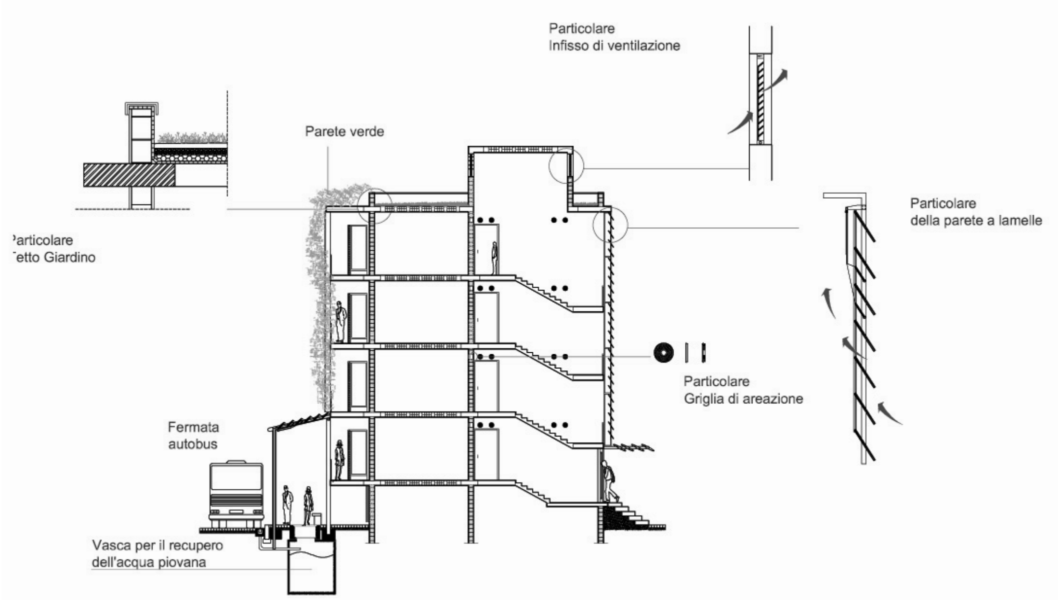

Figure 6 - Technological section of the rehabilitated building

The space that contains the staircase helps to improve the natural ventilation of the building, in fact every dwelling has an aeration grid on this space, and through it the hot air can exit, since, at its top, the staircase presents some openings on the North-East and South-East sides. On the South, a double-skin façade, which is also a photovoltaic wall, allows a continuous circulation of clean air, an higher thermal and acoustic insulation, and an higher protection for the bearing walls.

CONCLUSIONS

The project here presented, which has been object of a graduation thesis[2], aims at the sustainable rehabilitation of the district, trying to maximize the energy, material and water saving, through the knowledge of the site environmental potentialities. The targets of such a rehabilitation are the users' comfort and well-living, and thus the aim is to satisfy the individual and collective needs, promoting at the same time a better social living.

The urban design avoids the fragmentation and the privatization, aiming at developing a unique public space, through the creation of green areas, pedestrian paths and relax spaces built with the minimum environmental impacts. The housing design aims at satisfying the users' demands with new needs of comfort and well-living, considered as users' rights. The correct strategy for reaching such targets is represented by the bioclimatic study and by the consequent eco-sustainable choices, which are able to develop an harmony between physic, social and economic aspects.

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THERMAL COMFORT BETWEEN PERCEPTION AND EVALUATION BY THE BIOCLIMATIC TECHNIQUES OF ANALYSIS

- CASE OF OFFICE BUILDINGS IN THE ARID REGIONS WITH HOT AND DRY CLIMATE -

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ABSTRACT

Comfort is a global concept: heat, cold, light, noise, landscape, water, greenery, prestige and others, are several elements illustrating different climatic, aesthetic and psychological parameters of comfort. Comfort is also *a subjective* feeling which does not exist lonely. It is only by discomfort that one can appreciate comfort. This appreciation is varying in different groups and from an individual to another in the same community. Researchers start to reject the theory of universality. According to them, non-consideration of cultural, social, economic and climatic dimensions in the evaluation of comfort, leads to an exaggeration in the calculation of the heating and air-conditioning needs. Often, a significant thermal discomfort is perceived by subjects, because of a universal application of the thermal comfort evaluation methods [1]. So there is no perfect combination of comfort conditions since those are not related with the context. This relation of the feelings and differences of appreciation vary between individuals, and from a community to another. However, the theoretical definitions of the comfort concept agree all on the importance of thermal comfort. This one constitutes the subject of this study. Indeed, recent works on the concept of adaptive comfort proposes the individual variations according to place and time, conducted by personal strategies, which can belong to physiological, psychological, social, cultural and behavioral nature. In inverse of the physiological answers, which can be measured in *objective* ways, the determination of the *subjective* answers depends of the self evaluation of the person in interaction with a given environment. This evaluation is not single but varies with the individuals, and also for the same individual according to various periods [2.3]. Between *objective* and *subjective*, the finality of this work is the determination of the thermal comfort notion and to improve the evaluation method of thermal comfort by the analysis of the various intervening parameters quantitatively and qualitatively [1]. With an approach under "single condition" with regard to the thermal comfort of the interior environments, significant cultural, social and contextual factors are ignored and can lead to an exaggeration of the needs for air-conditioning [4]. Therefore, the focus will be on the strategies of real thermal comfort evaluation in office buildings of various types and in a zone concerned by an extreme climate, with an aim of adopting accessible solutions for the architects, with an easy to understand method.

Key Words: Bioclimatic strategies of evaluation, thermal comfort, perception, thermal indexes, semantic differential scales, thermal comfort, Re-humanization**,** thermal simulation, Climate Consultant 04.

INTRODUCTION

Comfort and wellbeing are today in the center of concerns of each user, consumer of products or services, and the building universe does not escape the rule. Today the competition in the field of energy services is hard. Today, better knowing the individuals' needs of comfort in buildings is paramount, particularly with regard to thermal conditions. Nevertheless, this task is very complex: there is not a single customer but a multitude, having often contradictory opinions, attitudes, and behaviors [5]. For more than eighty years, the study of thermal comfort has mobilized the scientific community: physiologists, physicists, ergonomists, sociologists and others trying to predict the reactions of the individuals under given climatic conditions. The majority of last and current researches in building techniques are based on a whole of standardized criteria, which are defined for a "standard individual». These standardized criteria are the result of physiological and physical considerations in interaction with environment. Comfort is often associated with an «*absence of discomfort* ", "*an absence of feelings*" or with «*neutrality inside thermal environment*" [5]. However these criteria are not exact enough to differentiate or qualify environments in term of thermal perception.

PRINCIPALS: *how to evaluate the quality of thermal environment*

The human body is a complex thermal system, regular to all climatic conditions, with an intern temperature close to 37°C. To guarantee this homoeothermic temperature, the thermal equilibrium of a human body must be balanced, between the heat which it produces and thermal transfers with the environment. The thermal quality of an environment can then be evaluated starting from these thermal assessments and thus all the phenomena which make it up. The entire heat produced by the human body, or metabolism, depends on the activity of the subject, of the context, and its clothing behavior [6]. Many indices are available to calculate in advance the thermal sensation of one individual according to the variables quoted previously. Most known are the **PMV** (Predicted Mean Vote), and the **PPD** (Predicted Percentage of Dissatisfied) [7]. They will be used with precautions. From the data of: the air temperature (T_a), its velocity (v) and its rate of turbulence (T_u) , Draught Risk or (percentage of dissatisfied people of the air movement) [7], can be evaluated by the following formulation:

$$DR = (3.143+ 0.3698 .v .T_{u}). (34 -Ta). (v-0.05)0.6223 \qquad [1]$$

These indices depend exclusively on the data quoted above and do not consider the mechanisms of thermoregulation which the human body generates according to the climatic constraints. Particularly in hot climate, where the appearance of sweat for example can allow thermal balance, it is essential to evaluate these phenomena [6].

METHOD

The application of the bioclimatic tools on all the cases led to an approximate and indistinguishable evaluation of the real thermal comfort perceived by the occupants of conditioned offices buildings, and consequently the suggestion of inappropriate strategies of thermal regulation to the real perception of this comfort [1]. This study consists in evaluating, for three typical conditioned office building, the thermal qualities perceived by the occupants with measurements of the real thermal conditions. Moreover this research will permit to establish the relation between the thermal comfort perception and the level of its evaluation by bioclimatic analysis techniques on the same environmental conditions. The comparative method between the three selected cases is applied for two months (March and June) between the calculated thermal comfort (*bioclimatic techniques)* and the perceived thermal comfort (*perception* evaluated by the *semantic differential scale).* The techniques of the bioclimatic analysis are used at the base of the traditional psychrometers and the thermal simulation software **(CC04)**

Case Study

In this research, the choice of **Biskra** as a case study permits us to measure the perception of comfort in the conditioned office buildings and to compare it with that achieved from the *bioclimatic analysis tools* in a zone concerned with extreme climates, in order to adopt partial or global architectural solutions to obtain consequently proposals appropriate such regions and such places.

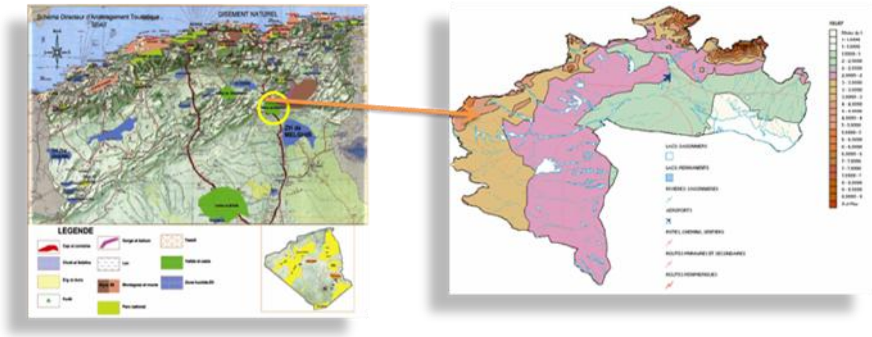


Figure 1: charts expressing the micro region of ***Biskra*** *(Realize by Health Mapper Release 4.1)*

Table 1 shows the three typical conditioned office buildings adopted as a test case (*see table 01*), located in Biskra (Algeria) which is selected for its representation of the arid regions with hot and dry climate.

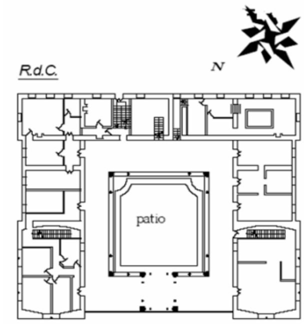
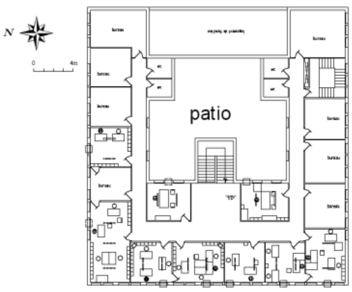
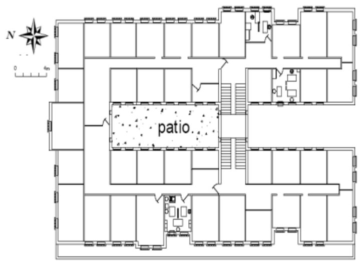
1st example: A.P.C	2nd example : TAXES's office	3rd example : D.P.A.T
		
		
Colonial building "1800's"	**Post colonial building "1960's"**	**Recent office building"1990's"**

Table 1: studied cases, extract from [1].

RESULTS

1- Comparison between perceived thermal comfort and that achieved from *Givoni's Psychrometric Chart;*

After the evaluation of thermal comfort in the studied cases, the comparison between the rates of satisfaction of *global* thermal comfort and the predicted comfort achieved from bioclimatic analysis tools will be made at the base of percentages acquired by questionnaire (investigation) for the first variable, and the limits of comfort determined by Givoni's Psychrometric Chart for the second variable. The evaluation of the perception (the rate of satisfaction) provides the real occupant's thermal comfort needs, instead of the needs mentioned from the bioclimatic diagrams.

Therefore, inside the office buildings, satisfaction is evaluated on a semantic scale of five values " -2 -1 0 +1 +2 ", which correspond respectively to «very satisfied, rather satisfied, satisfied, rather not satisfied, and at all not satisfied»:

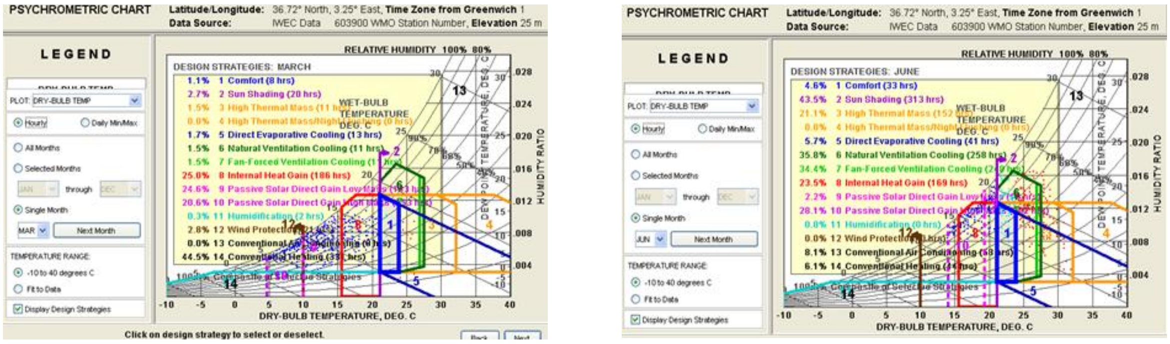


Figure 2: Givoni's Psychrometric Chart, For March, and June extract from CC04.

For March: some 30% of the days of March are integrated in the thermal comfort zone following Givoni's diagram, while the percentages of the occupants satisfaction set out again as follows: 56.60% of people consider their offices comfortable which coincides with value **0** of the Osgood's semantic scale, however only 11.67% of the subjects declare their dissatisfaction by value **+1** of the scale which corresponds to «rather not satisfied».

perception	very satisfied -2	rather satisfied -1	satisfied 0	rather not satisfied +1	at all not satisfied +2
Percentage %	**0**	**31.67**	**56.60**	**11.67**	**0**
Givoni's Psychrometric Chart -Number of days-	**0**	**40%**	**Comfort Zone 30%**	**30%**	**0**

Table 4: comparison between perceived thermal comfort and that achieved from the Psychometric Chart, March

For June: Some 35 % of the days of March are integrated in the thermal comfort zone following Givoni's diagram, while the percentages of satisfaction set out again as follows: 10.84 % of people consider their office buildings comfortable which coincide with value **0** of the Osgood's semantic scale, 45.80 % of the subjects declare their dissatisfaction by value **+1** of the scale which corresponds " rather not satisfied " and 43.33% of the subjects judge their dissatisfaction by value **+2** of the scale.

perception	very satisfied -2	rather satisfied -1	satisfied 0	rather not satisfied +1	at all not satisfied +2
Percentage %	**0**	**0**	**10.84**	**45.80**	**43.33**
Givoni's Psychrometric Chart -Number of days-	**0**	**5 %**	**comfort Zone 35%**	**35 %**	**25**

Table 5: comparison between perceived thermal comfort and that achieved from the Psychometric Chart, June.

2. Comparison between perceived thermal comfort and that achieved from the method of Novell: After the evaluation of thermal comfort in the studied cases, the comparison between the real comfort perceived by the occupant and the comfort calculated by the bioclimatic analysis will be based on the thermal comfort perception obtained by the questionnaire and the method of Novell [9].

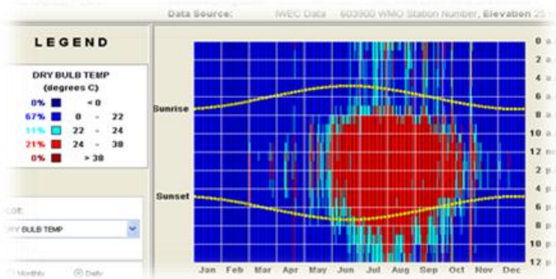


Figure 3: time table plot, extract from ***Climate Consultant 04 CC04***

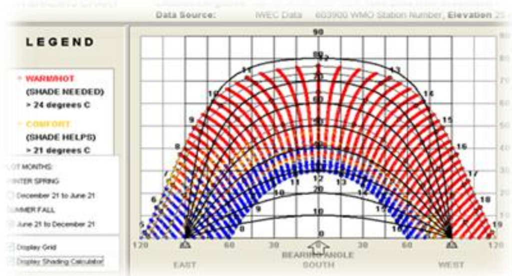


Figure 4: sun shading chart extract from ***Climate Consultant 04 CC04***

For March: The perception of thermal comfort measured in the investigation is relatively close with the thermal comfort calculated (respectively 37 % and 28 %) with a difference of 9 %. However the " cold " lasts less long according to the occupants' perception than according to bibliographical calculations (24.53% against 32%) with a difference of 8 %, while perceived «heat» lasts longer but almost equalizes that evaluated by the bioclimatic tools (respectively 38.47% and 40%) with a difference of 1.53 %.

perception	Excessively cold	Very cold	cold	Slightly cold	neutral	Slightly hot	hot	Very hot	Excessively hot
value	-4	-3	-2	-1	0	+1	+2	+3	+4
%	0	0	8.63	15.90	37	23.80	5.9	5.9	2.87
∑	24.53				37	38.47			
Novell's method	32				28	40			

Table 5: comparison between perceived thermal comfort and that achieved from the method of Novell. March.

For June: The perception of thermal comfort measured in the investigation is considerably different with the calculated thermal comfort (respectively 7.5 % and 28 %) with a difference of 20.50 %. However the "cold" lasts as less long according to the perception of the occupants during June than according to bibliographical calculations (0% against 32%) with a difference of 32 % while perceived "heat" lasts also longer and with a great difference than that evaluated by the bioclimatic tools (respectively 92.51% and 40%) with a difference of 52.51 %.

perception	Excessively cold	Very cold	cold	Slightly cold	neutral	Slightly hot	hot	Very hot	Excessively hot
value	-4	-3	-2	-1	0	+1	+2	+3	+4
%	0	0	0	0	7.5	12.5	26.67	25.84	27.5
∑	0				7.5	92.51			
Novell's method	32				28	40			

Table 6: comparison between perceived thermal comfort and that achieved from the method of Novell, June.

3-Comparison between the perceived thermal comfort achieved from the questionnaire and that evaluated by the thermal indices (PMV and Top – the operative temperature):

The comparison will be based on percentages obtained by questionnaire and the thermal indexes (PMV and Top). According to the simulation and the thermal index: The analysis of the thermal comfort shows that for March all the office buildings attain a certain comfort for the reason of their orientations and their built envelopes, while for June the western and southern west directed office buildings (the unfavorable orientations) suffer from a considerable discomfort and an unpleasant thermal environment.

For March

Predicted mean vote PMV	-1 < PMV < 1	82%
Operative temperature (Top)	Top for summer: 22.5c°< Top < 28c°	72%
	Top for winter : 20c° < Top < 23.5c°	/

Table 6: comparison between perceived thermal comfort and that achieved from the thermal indices, March

For June

Predicted mean vote PMV	-1 < PMV < 1	58%
Operative temperature (Top)	Top for summer : 22.5c° < Top < 28c°	43%
	Top for winter : 20c° < Top < 23.5c°	/

Table 6: comparison between perceived thermal comfort and that achieved from the thermal indices, June

CONCLUSION

This study showed the significant dissimilarities between thermal comfort evaluated by bioclimatic analysis tools and that perceived by the office building's occupants, in the arid zones characterized by a hot and dry climate. These results are the real representation of thermal comfort perception in the arid regions as **Biskra**. They express in reality (not in the bibliographical references) the rates of thermal environments satisfaction, cold, heat and comfort perceived by the occupants of office buildings. The results of the investigation reflect the values of the actual necessities in thermal comfort for the subjects. Thus, *predicted comfort* and *perceived comfort* are different and the techniques of evaluation are not adapted to the case of study [1]. From the comparison between the two thermal comforts (perceived and measured) the following is deduced:

1. A disagreement between calculated thermal comfort and the real comfort perceived by the occupants explained by the fact that:
   - The temperatures of comfort vary from a study to another.
   - The limits of comfort accepted for a population can be considered differently (too cold or too hot) for another.
   - No consideration of subjective dimensions in the thermal comfort evaluation. Indeed, two people of different cultures and socio-professional regions automatically do not perceive space and its components in the same way and do not adopt the same attitudes.
   - The recommendations released by the traditional bioclimatic tools are insufficient and too general for the arid regions characterized by a hot and dry climate.
2. The thermal comfort perceived by subjects is different from the evaluated thermal comfort. This does not mean that the recommendations deduced by these last are invalid any more, but they are universal and so too general. They are applicable at the same time for various climates and in various regions. Whereas there are differences in conditions of each region and city, according to its social, cultural, economic and climatic particulars.
3. Perception represents the adapted technique for the thermal comfort evaluation for a given population, which will make it possible to suggest the necessary strategies and adequate hydrothermal regulation. This technique will permit also the determination of the thermal comfort limits, with synchronic On-Site measurements by sophisticated instruments.

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TENSILE MEMBRANE STRUCTURES AND THE INDOOR ENVIRONMENTAL QUALITY

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ABSTRACT

The present work reports a part of a research, lasted three years (2005-2008), centered on the theme of the tensile membrane structures using in the building field.

If about the structural function of the tensile membrane is by now all known, accurately and plausibly, thanks to the continuous progress of the knowledge in structural field and to the development of the material production technologies, instead, with regard to the envelope function (use as building envelope), the field of study seems to be not yet a lot investigated, especially with relation to the indoor environmental performance.

According to this consideration, the aim of this paper, that we present here, is the in-depth examination and the systematization of the all information relating to the tensile membrane features. The objective is to check the environmental performance that the spaces delimited from these technical fabrics are able to guarantee to the end-users.

The requirements take into consideration concern to:

1. thermo-hygrometric comfort;
2. visual comfort;
3. acoustic comfort;
4. indoor air quality.

For each point, we have singled out the positive and the negative aspects able to influence the end-users wellbeing and the indoor environmental quality.

The paper ends with some observations that could orientate the designer to make a choice of the tensile membrane with function of building envelope.

INTRODUCTION

Fabric structures provide wide span enclosures of great spatial interest and variety, require minimal supporting elements of hard structure and provide very good overall levels of natural daylight.

From an engineering point of view fabric structures are thin membranes of constant thickness which by virtue of their surface shape and inherent large deflection behaviour are able to support the imposed loads required by Building Codes. They are modestly prestressed to enhance their stiffness.

In general, the materials used for architectural membranes consist of a woven fabric coated with a polymeric resin. Weft inserted fabrics, laminated fabrics and foils are variants of the general concept.

Precisely a membrane consists of different layers combined with the fabric; a prime coat, a top coat and a surface treatment for sealing or printing.

The principal used materials are: PVC coated polyester fabrics and PTFE coated glass fabrics; other materials in use are silicone coated glass fabrics, PTFE coated PTFE fabrics and ETFE foils.

METHOD

In order to check the environmental performance that the spaces, delimited from these technical fabrics, are able to guarantee to the end-users, we take into consideration the requirements concern to: thermo-hygrometric comfort; visual comfort; acoustic comfort and indoor air quality.

For each requirement, we have singled out the most important aspects.

- Thermo-hygrometric comfort

Due to their lightness and translucency, membrane enclosures should be considered as filters rather than as barriers to external weather conditions. Even though the environmental conditions within a space enclosed by a millimetre thick skin are bound to be different to those within heavier forms of construction. A value over all to demonstrate the low performance of the textile membranes: the core thermal resistance of coated membrane PTFE/glass is 0.0042 mKW^{-1} against 0,15 of concrete and 0,01 of glass.

Any temperature change on the external surface of the membrane, either due to convective or radiant heat exchanges, is matched almost instantaneously on the internal surface: measurements have shown that the difference of temperature between the two opposite surfaces of a single membrane skin is always less that 0,5 °C. Furthermore, the spanning of large spaces, as well the presence of high points to achieve the desired double-curvature of the membrane skin, almost inevitably leads to very large undivided volumes of air. Substantial internal ceiling heights favour the accumulation of floating warm air at the high points of the structure resulting in the formation of cooler layers of air in the lower occupied zones. This phenomenon is amplified during daytime when the lightweight membrane roof is heated up by solar radiation. The resultant vertical temperature stratification can be strong, with differences between high point and floor air temperature of up to 14 °C. The temperature gradient tends to invert at night as the membrane roof surface cools more quickly than the thermally heavier floor.

The very low thermal mass and the poor insulation properties of the building skin together with the hydrophobic nature of coated membrane materials are responsible of the vulnerability of membrane structures to condensation problems.

The presence of condensed water on internal surfaces of the building may have adverse effects on the building fabric, such as the promotion of mould growth on surfaces, leading to staining and discoloration and the corrosion of internal metal components in contact with condensed water and can significantly reduce the useful life of construction materials and interior finishes.

- Visual comfort

When the theme of light is treated combined with the membrane enclosures, it assumes a particular connotation due to a quality, that is often seen as the most valuable of tensile membrane architecture: the translucency.

Membrane structures present two aspects that create interior lighting conditions, unusual in the traditional buildings, which affect the design of their visual environment: on the one hand, being essentially a single storey high, the space is lit by a uniformly bright ceiling; on the other hand, most coated woven membranes have a high light scattering effect. Thus the daylight transmitted through them and reflected off their internal surface is highly diffused.

The daylight flowed into a membrane structures contributes to emphasize the lightness. High daylighting factors, defined as the ratio of the daylight levels between inside and outside, in excess of 10% can in general be achieved in spaces enclosed by a tensile fabric skin, as compared to less than 3% in most traditional buildings where daylight is only admitted through a limited set of fixed glazed openings. Even during a dull cloudy day, it is possible to achieve daylighting levels well above the minimum required illuminance for most activities. The amount of daylight admitted through the fabric skin is mainly a function of its light transmittance, which according to material type and grade ranges from 10% to 95%.

Very high are the visual performances of the ETFE film (95% of light transmittance), undoubtedly lower those of the membranes made of PVC coated polyester fabrics (12% of light transmittance).

Other qualitative aspects include the three dimensional vision: the perception of objects in three dimensions is strongly influenced by the modelling effect of a light flux. This directionality can be expressed by the vector-scalar ratio, which represents the ratio of the strength and direction of the flow of light to the total quantity of light reaching a point. A high vector-scalar ratio is achieved when objects are lit directly or through clear glass by a directional light source such as the sun. Inside a tensile enclosure the diffusing properties of the translucent skin can produce an excessively uniform lighting field and so the eye receives a uniform image and there is little differentiation between objects and planes.

Another aspect is referred to the perceived light levels: highly diffused lighting penetrating the space, such as fabric structures, can result in poor contrast and the absence of marked shadows; the user may confuse this with insufficient light levels.

Also important is the distribution of light: inside the fabric structures, there is a strong difference in brightness between the translucent ceiling and the other internal surfaces. Despite the great adaptability of the human eye to brightness level, there is a maximum acceptable ratio of brightest to dimmest light for good vision (about 1:10).

To assure visual comfort, is important the colour perception: white or off-white membrane skins give good colour perception inside the enclosed space as they demonstrate a relatively linear spectral transmission of visible light.

- Acoustic comfort

The particular nature of the membrane materials doubtless creates problems to the acoustical designers; it isn’t possible to use the mass for blocking the sound, because it is in contrast with the philosophy of the membrane constructions. Actually, limited success has been had with single skin membrane as far as preventing noise infiltration or leakage is concerned. More limited is the research about the multi-layer structures.

Very important is the notion of skin drumming, whereby the patterns and intensity of rain and hail may have serious effects on the noise levels experienced within the space.

It should be considered carefully the integration of services to structure; it is essential that the services must not engage any local excitation that can spread throughout the structure.

- Indoor air quality

A large number of pollution sources are present indoors. Some compounds are identical to those found outdoors; other contaminants are more specific to the indoor air such as volatile organic compounds (VOC) and semi-volatile organic compounds (SVOC) whose concentration and chemical nature are mainly different from the outdoor air. Indeed most studies reports indoors concentrations to be 2-20 times higher than outdoors. Having low-molecular weight and volatility at room temperature, 30 to 300 of those compounds, mainly belonging to alcanes, aliphatic and aromatic hydrocarbons, aldehydes, ketones, alcohols and esters, are released from a number sources: the most important concerns the building materials and furnishings.

The tensile membrane, considered that are constituted by polymeric resin coated a polyester fabric, belong to the polymeric products; consequently, the potential sources of chemical pollutants, mainly organic compounds, could be monomers, plasticizers, stabilizers, solvents, antibacterial, impurities, reaction products.

Some clarification are important. Not all the polymeric materials have the same danger level; its depends on the different raw materials that are in the finished products, but in part is due to the studies, overall about the innovative plastics, that are not so deep and can't outline the complete toxicological situation. Moreover, in order to evaluate the possible emissions from membranes, it could be expedient consider the all materials that constitute the membrane, but the available data are lacking.

RESULTS

In this section, we systematize of the all information relating to the techniques applicable to increase the performance of the membranes, referred to the four requirements.

- Thermo-hygrometric comfort

To improve the thermal behaviour of the membrane enclosure the number of layers constituting the building skin can be increased.

A large number of different constructions are possible and different membrane types and materials can be used together to take advantage of their particular properties. The strategy common to most multi-skin membrane constructions is to entrap air either between the different layers of membrane material, or within the material itself (fibre insulating materials, air cell fillings, lightweight foam,…), or as a combination of these principles.

The most common type of multi layer constructions is the double layer membrane. The inner side of the external structural membrane is lined with an additional layer of membrane and the two membranes are separated by an air space of variable thickness, from 100 to 500 mm. This air space reduces heat transfer by convection occurring between the outer membrane and the enclosed space.

Near the multi layer membranes, there are the insulated membranes too, consist of a layer of low-density insulating material sandwiched between the external structural membrane skin and internal liner membrane layers; the insulation material can be attached directly to the structural membrane skin, suspended from the main supporting structure or laid on an inner liner.

Usually are preferred the latter two solutions, as they keep the insulating layer independent of the structural membrane skin, which simplifies its handling during the phases of assembling and prestressing. On the market are available insulating materials range from simple foam coating to fibre mats and self-contained air cell films; these offer various levels of translucency and thermal insulation. The insulating layer can reduce the heat transfer across the thickness of the membrane construction by entrapping air inside a layer of porous, low density material, thus allowing a tighter control of the thermal conditions inside the enclosure.

Relating to the condensation problems, is possible to reduce the risks. In the case of a single layer membrane structure, by raising the temperatures of the surfaces inside the enclosure to increase their dew point or reducing the air moisture content.

In the uninsulated multi layer membranes is possible to reduce the problems by sheltering the inner membrane from direct exposure to the clear night sky, thus limiting its cooling by radiation losses, or providing a means of escape for condensed water by creating air spaces between layers that can be ventilated.

Moisture control in insulated membranes remains a problem. To date designers have mostly had to resort to opaque metallised vapour checks to control condensation effectively, thus eliminating the translucency of the membrane construction.

- Visual comfort

Particular attention should be given to assure the visual comfort, specially if the sheltered space is to host activities requiring good spatial vision, such as a sport hall.

Some solutions could improve the daylighting performance; for example, the problem of the distribution of light can be addressed by applying light reflective finish to the external surfaces and by allowing penetration of direct daylight through glazed openings into the lower parts of the enclosures. The provision of direct lighting inside the building through glazed surfaces can greatly improve contrast while restoring the balance between the brightness of the ceiling and the other internal surfaces. The total area of glazed areas should be skilfully distributed over the building skin.

- Acoustical comfort

Thoughtful the insufficient knowledge in the field of acoustical transmission within membranes, the following considerations are important.

The orientation and exposure of the membrane must be considered so as to reduce infiltration or leakage. Consideration should be given to the siting of the structure as well as to the design of the external barrier so as to compensate for more common ground-based noise problem, as well as acting as an insulator between noise source and structure. Generally, doubling the distance between source and structure allows a 6 dB reduction, while shrubbery 0,4 dB reduction.

Some experimental work hypothesised that the attachment of small weights onto the membrane skin may improve the low frequency insulation aspects of the material (from 5 to 11 dB increase in low frequency transmission loss, in general lower than 300 Hz) with a very low impact on the light transmissivity of the material itself.

- Indoor air quality

The first strategy to improve the indoor air quality is to ensure adequate ventilation into the membrane structures to control pollutants (by reducing and removing them through dilution, filtration and air cleaning).

DISCUSSION

The way to obtain a high environmental quality into the spaces created from the membrane enclosures is still long. If hardly is possible to equal the performance of the conventional building, nevertheless the design approach must be the same: to design for the whole person.

Full integration of environmental considerations in design will include indoor air quality, thermal comfort, lighting, acoustics, and spatial relationships. A building that meets the needs of its users (occupants, operators, others) will endure longer and more satisfied building users are, the longer the building will remain in service.

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LIFE CYCLE AND GLOBAL COMFORT AT SCHOOLS ON A 2050 PERSPECTIVE

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ABSTRACT

As a public facility, schools are one of the most frequent competition's programme in Swiss context, indeed they represent the 4% of the total constructed volume of the country [1]. The consequence is that with relatively few buildings education could sensitize the whole next generation about the challenge of sustainability and climate change. This paper analyses the reality of four recent low energy consumption school buildings to the light of users acceptance and external global targets as defined at the 'Efficiency Path for Energy', created by the Swiss Society of Engineers and Architects (SIA) [2]. After user's survey we confirm that all schools achieve positive global comfort albeit some summer discomfort and inefficient solar control. As climate is getting warmer [3], summer comfort and adaptability must be integrated at the project state to prevent future uncomfortable situations. Another interesting result: one example of natural ventilation performs equally well as mechanical ventilation examples in terms of comfort satisfaction and energy consumption. The conclusion of the natural ventilation air quality test was that user must be instructed to guarantee hygienic qualities [4]. As no directives existed at national level, Canton services had created them [5]. Life cycle analysis over 30 years [6] shows that only one of the examples achieves the B target of the SIA D 0216(2006) [2]. As a tendency, the schools with a Minergie standard energy consumption [7] consume as primary energy in operation as in the whole material life-cycle (manufacture, transport, replacement and elimination), validating the principle that only after reducing operating consumption below Minergie values material life-cycle becomes relevant [8]. Average whole cycle embodied energy comes first (50%), followed by thermal production (30%) and electricity consumption (17%). Over an 80 years life cycle the order is inverted with less variation: first thermal production (43%), then material life-cycle (33%) and last electricity (24%) according to average values. Main reduction potential is the structure as responsible of 50% of material cycle, and the energy vector, as renewable energy sensibly diminishes the weight of primary thermal operation energy.

INTRODUCTION

After the federal law of public contracts [9] large public commissions are adjudged in open competitions by procedures defined on SIA 142(1998). As schools are one of the most frequent competition's programme, they have been placed at the centre of professional discussion with a tendency on aesthetic overweight. This research aims to question school buildings with a large integrated vision, including project quality. Besides, schools are a living experience for future generations, potentially a learning tool for the actors of tomorrow complex scenarios. Primary schools were chosen since they are the main part of educational buildings (47%) [10] and have a basic programme, mostly classrooms and often an indoor sport facility. Despite the rather simple use, comfort requirements are elevated due to high density of occupation; and users experience with the classrooms is bigger, as they use intensively it during the whole year (superior levels of education stay less time in their own classroom, important for the survey).

In Swiss context primary school's construction and maintenance is within the responsibilities of the municipal government as a part of local public equipment. If decisions are on a municipal level, targets are defined by the canton authorities (federal autonomy) according to national norms established by the SIA.

Therefore, this paper focuses on users' global comfort and life cycle analysis of presumed exemplary energy building schools of different cantons (different strategies) to evaluate if they will achieve the targets of the 2000 watts society by 2050 [2]. Global comfort was included in order to qualify building systems used and their acceptance, while low energy consumption was a priority to compare material life-cycle and operation primary energy use on the whole cycle, otherwise heating consumption largely dominates de comparison [11].

The purpose of this article is to identify priorities to achieve global comfort and life cycle targets by 2050 in low-energy school buildings.

METHOD

The study was made during 2007 on four school buildings, each one in a different canton for strategy diversity. Only French-spoken Cantons were pertinent to facilitate contact and information exchange. For what is relevant in this paper, Table 1, Table 2 and Table 3 give a comprehensive overview of the main characteristics of the cases chosen.

Figure 1: Top left the extension of the Ecole Villa Thèrese at the Schoenberg neighborhood in Fribourg, top right Collège de La Croix-sur-Lutry in Lutry, below left the Groupe Scolaire quartier des Ouches in Geneva, below right Ecole de la Maladière in Neuchâtel.

School building	City_Canton	Execution	In use	Hall of sport	Context
Villa Thèrese	Fribourg_Fribourg	2001-2003	2004	yes	urban
La Croix-sur-Lutry	Lutry_Vaud	2002-2004	2004	yes	countryside
des Ouches	Genève_Genève	2002-2005	2005	yes	urban
Maladière	Neuchâtel_Neuchâtel	2003-2005	2005	yes	urban

Table 1: general data.

School building	Altitude ground-floor [m]	Degree-days winter*	Degree-days winter°	Degree-days summer°	SREo [m2]/ SREc [m2]	Compacity
Villa Thèrese_Fr	609.5	3’777	2’915	52	2'070 *(school)*	1.00
La Croix_Vd	589	*3’322**	2’344	126	3’154	1.70
des Ouches_Ge	425	3’061	2’351	142	6’922	1.36
Maladière_Ne	462	3’371	2’644	145	2’824	1.41

Table 2: energy data.

* SIA 381/3(1982): Winter degree-days 20°/12°, data from 1961-70. *Data from Lausanne*.
° Data from Metheonorm processed with Climpro: software copyright Darren Robinson, winter degree-days 15.5°C, summer degree-days 18° C

<table>
<tr><th>School building</th><th>Uwall/ Uwindow (g) [W/m2 K]</th><th>Heating production</th><th>Energy vector</th><th>Ventilation</th><th>Heating recovery</th><th>Sun protection</th></tr>
<tr><td>Villa Thèrese_Fr</td><td>0.19/1.3 (0.65)</td><td>Boiler</td><td>Gas</td><td>mechanical</td><td>50%</td><td rowspan="4">Fabric solar protection (all similar)</td></tr>
<tr><td>La Croix_Vd</td><td>0.32/1.4</td><td>Boiler</td><td>Wood</td><td>natural</td><td>-</td></tr>
<tr><td>des Ouches_Ge</td><td>0.14/1.3 (0.41)</td><td>Boiler</td><td>Gas</td><td>natural</td><td>-</td></tr>
<tr><td>Maladière_Ne</td><td>0.23/1.5 (0.41)</td><td>Boiler + HP</td><td>Gas + Elec</td><td>mechanical</td><td>50%</td></tr>
</table>

Table 3: building fabric and energy system data.

For each building the following analysis was performed:

Post occupancy evaluation (POE) [12]: a user satisfaction survey with questionnaires specially conceived for students and for teachers. The answer average was about 50% and 65%, respectively.

Life cycle analysis (LCA) with Eco-BAT [13]: the data for building operation was obtained from real consumption, then normalized by degree-days data; while the amount of building materials from construction details was quantified according to CFE classification [14]. System limits: earthwork at building site and infrastructure materials were not taken into account, in order to simplify data collection.

Functional unit and life cycle are defined in accordance to LCA building experience [8] [11]: as functional unit the heating surface corrected according to room's height (SREc) as indicated by SIA 380/1(2001); and a life cycle of 30 years as explained on SNARC [6]. The comparison will be expressed in [MJ / m2 x an].

After building’s data input with Eco-BAT [13], the software calculates amounts of primary non-renewable energy and other environmental impacts. To facilitate communication the paper only studies NRE values. As part of the study, the selected buildings allow comparison between mechanical and natural ventilation: user’s satisfaction and energy consumption.

RESULTS

From the above analyses the following was concluded:
Post occupancy evaluation (POE): all schools achieve positive global comfort albeit some summer discomfort and inefficient solar control. A sample of survey results follows:

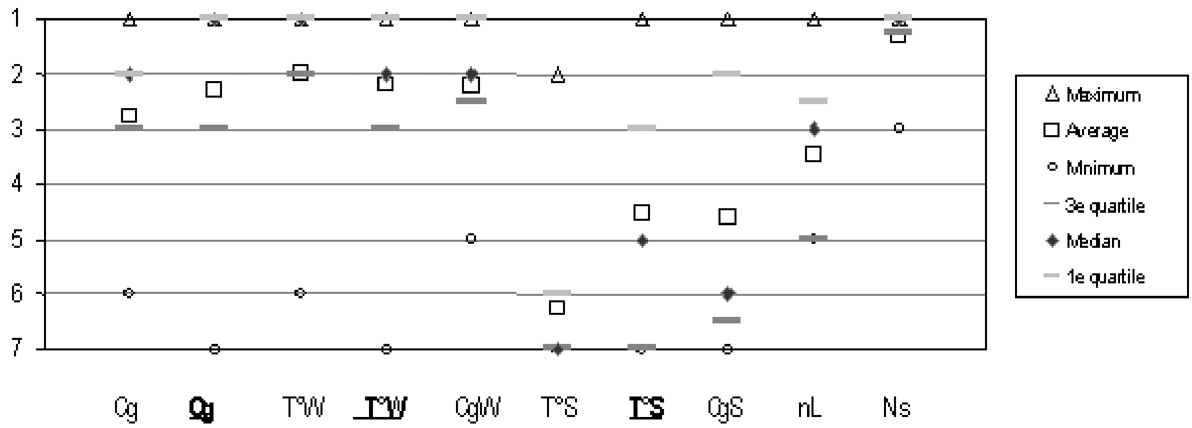

Figure 2: Users comfort satisfaction at Villa Thèrese school building and in classrooms, Fribourg. Evaluation values between one (satisfactory) and seven (unsatisfactory), number four means balance. [15]

Cg Comfort in general: All considered, how do you evaluate comfort in the building ?
Cg *idem* ***asked to pupils:*** *Is your school comfortable ?*
Winter (same with Summer)
CgW: How do you describe typical conditions in your work space during winter ?
T°W Winter temperatures: one (satisfactory) and seven (unsatisfactory)
nL natural Light: How do you describe the quality of natural light in your work space ?
Ns Noise: How do you describe your comfort level in relation with noise ?

The example illustrated (Villa Thèrese_Fr) has a high degree of insatisfaction in summer, the highest of all the examples. The building accumulates disadvantages: classrooms have a SE orientation and exterior black color with inefficient fabric sun protection; no natural ventilation can be created (as a Minergie [7] building equipped with mechanical ventilation it has no operable windows in the hall, opposite side of classrooms). The whole situation makes people feel uncomfortable with no possibility of adaptation, so the acceptance level is further reduced. A solution must be found.

Life cycle analysis (LCA) with Eco-BAT software: only one school, the reference building (La Croix_Vd), achieves the B target of the SIA D0216(2008) (adaptable building for the 2000 Watt society by 2050) [2]. Paradoxical as it has the highest thermal consumption, balanced by the wood energy vector in primary consumption.

School building	Thermal target useful	IDEth/ SREc useful		NRE thermal heat + hot water primary		NRE elec primary	NRE mobility primary	NRE mat primary	total
Villa Thèrese_Fr	144*	171.7		**218**		**102**	**-**	**277**	**493**
La Croix_Vd	264°	259.6		**93**		**23**	**52**	**193**	**362**
des Ouches_Ge	144**	119.4		**152**		**120**	**-**	**239**	**511**
Maladière_Ne	144*	86.4		**135**		**93**	**-**	**275**	**503**
Cible B SIA D0216	-	-		110	40	90	100	100	**440**

Table 3: energy consumption vs SIA D0216(2006) targets, expressed in MJ/m2 an

**IDE thermal target according to Minergie(2000) without electricity consumption for mechanical ventilation. / **High Energy Performance (HPE_Genève), without Minergie certification (no mechanical ventilation).*

°Sorane SA: Report, consumption in real conditions calculated 380/1(2000), pp 13, 2000.

CONCLUSIONS

Comfort: as climate is getting hotter [3], the summer alibi of empty schools during summer holidays is no longer acceptable, even more with scenarios where schools become an open structure for external users during the whole year. So summer comfort and adaptability must be integrated at the project state to prevent future uncomfortable situations (Minergie adapted their assessment in 2008, including a summer verification).

Air quality: natural ventilation performs equally well as mechanical ventilation in terms of comfort satisfaction and energy consumption in the Geneva example. At a practical level, the test of the natural ventilation air quality demonstrated that users must be instructed to guarantee hygienic qualities [4]. Directives concerning natural ventilation do not exist at a national level, so Cantonal services have created it [5]. This strategy is compatible with refurbishment cases and on a larger scope, with global warming, as winters will get less cold and mid-season get warmer. Consumption according to the directive's application has to be verified.

Material life-cycle: as the SIA 380/1(2009) requires energy consumption near to Minergie levels, this demand rises comparative weight of material cycle. The Minergie examples studied uses more primary energy in material cycle than in operation, validating the principle that only after reducing operating consumption below Minergie levels the values of material life-cycle becomes relevant [8]. Fixing targets for primary energy consumption on materials life-cycle will help to clearly incorporate this question at a professional level, as part of the big picture materialized by the LCA. The proper moment to ask for LCA results would be at competition stage, in this way an LCA can help informing the main decisions from competition definition till operation monitoring.

Energy consumption: as thermal consumption tends to be under control (recent projects do it better), the energy vector has a high influence and renewable energies should be promoted. The CEB [16] generalization will undercover primary consumptions. Electricity consumption values present variations that do not always have an explanation. Overconsumption in the Geneva example may be related to the restaurant's electrical kitchen, results suggests to prioritize gas kitchens, further more with the perspective of the continuous school day under discussion in some Cantons [17] (many new dining services should be opened).

Energy management: an element to incorporate in the energy strategy is intelligent meter zoning for annual monitoring allowing accurate reaction (most of the examples had difficulties in isolating school or services consumption). Management and exchange of experiences at this level (p.ex. Canton monitoring) could make a sensible difference.

Mobility: in urban context, school related displacements are not a problem. In this way the value defined at SIA D0216(2008) appears quite high, as the countryside example studied consumes half of the target value (table 3). Lutry achieves low consumption due to a shared transport service offered by the school, a priority in cases were the school is not at walking distance from pupils' homes.

Economy: in order to add transparency and clarify comprehension a Life Cycle Costing (LCC) would be a good complement, but fluctuation in energy costs introduce uncertainty on future projections. On the study Lutry's example was followed on economic aspects, the results showed that operation costs represented 0.44% of building cost, and annual salary of caretaker represents the double. Even if its energy consumption is quite particular (highest thermal index with lowest electricity consumption) it shows that energy cost is not high enough to financially justify energy economies. The caretaker's role as building maintenance and cleaning reesponsable has to be complemented with energy survey, aided by monitoring.

Discussion

Life cycle duration is a major question for material life-cycle. The method expressed in the SIA D0216(2008) is a good compromise, where each construction element is balanced in relation to their real life cycle. In this way, structure will became less predominant. On the other side, schools as part of neighborhood identity should be built for long lasting.

Education on sustainable development: the buildings analyzed are not used as learning tools, and educational concerns on sustainability and climate change were a personal choice of the teachers. The Education on sustainable development - Plan 2007-2014 [18] shows that education authorities are becoming conscious of the importance of these issues.

Users integration in the project process and their involvement in the building's operation should be improved, thus contributing to their engagement with sensitive climatic issues. In this way the building as a learning tool becomes real and needs teacher formation. Manual and direct control should be promoted when reasonable, together with systems to evaluate results and manage the moments when the building is empty (energy management).

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HUMAN BEHAVIOR AND THE OFFICE ARCHITECTURAL FORM:

ATTRIBUTES TO SYNTHESIZE IMPROVED OCCUPANT PHYSICAL ACTIVITY, ENERGY EXPENDITURE AND HEALTH

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ABSTRACT

This study explores the relationship between the indoor architectural design and physical activity and sets out to illustrate the dynamics of indoor office user behavior. Our paper builds on a five month data collection carried out on three floors of the cellular workplace of the AT&T laboratories in Cambridge. Based on our existing knowledge, on the health benefits of physical activity, as well as on our current research outcomes, illustrating how precisely we can estimate human energy expenditure within buildings, this work has set out to objectively measure occupant daily movement patterns and identify those most energy demanding. In the belief that physical activity could be prescribed by architectural design this study points out how spatial attributes could have a positive effect on office users' overall daily physical activity levels and subsequently health.

Keywords: office architectural design, occupant, physical activity, health.

INTRODUCTION

Physical activity is part of our daily routine. Growing medical evidence shows that physical activity of a moderate intensity (equivalent to brisk walking) can help reduce the incidence of obesity related illnesses and long term ailments. Although brisk walking is a readily available activity (i.e. requires no special equipment or training) (6), 60% to 70% of office users worldwide report spending increasing amounts of time over the day within an indoor working environment (4). Recent UK data confirm trends towards sedentary lifestyle in offices as an effect of both organizational and individual preference. According to the 1996 *Surgeon General's Report on Physical Activity and Health*, individuals of all ages should obtain "a minimum of 30 minutes of physical activity of moderate intensity on most, if not all days of the week" (12). It has been medically estimated that if this inactive lifestyle continues by 2010, over 25% of the adults will face a number of chronic health problems such as coronary heart disease, type II diabetes, osteoporosis and colon cancer.

This study suggests that physical activity is a function of the architecture of the space. Based on recent theories for the design of the workplace, the aim of this work is to further promote public health by staving off the tendency for sedentariness through architectural design.

METHOD

This study measures 340 individuals' daily movement patterns over a five month period (November to March). This population has been predominantly male aged from 25 to 65 years old. In addition, their height and weight ranged from 1.67m to 1.96m and 54kg to 94kg respectively. The data collection took place on all three floors of the AT&T computer laboratory building (Keynes House) that were conventionally designed to comprise rows of detached cellular rooms that were physically linked by a central corridor.

The choice of this workplace has not only been due to its conventional layout design but also based of its unique infrastructure and office culture for productive meetings and the avoidance of unsuccessful trips for job interaction. The building was hard wired with the Active Badge location mapping ultrasonic system which relies on sensors that were installed throughout the ceiling and the walls of the office space and were worn by the office users. This system registers the position of individual wearers' badges that emit bursts of ultrasound to the ceiling receivers. The estimation of the Badges spatial location is with an error of less than 3 cm 95% of the time (1, 5). Provided that all individuals would constantly wear the Badges, this system has been set to provide a minute by minute account to individuals of their colleagues' location within the office workplace.

Our previous studies (7) have empirically shown (by developing two theoretical models and by synchronising objectively measured position and activity intensity readings within a sample office space) that there is a strong association between physical activity levels and occupants' behavior in space. With the office users' consent for this study to gain access in the Active Badge system readings, we have been able to more specifically identify reasons for movement and we have monitored levels of space frequency to a certain length. Based on the wider medical strategy for small changes in physical activity that can lead to big differences in health, this study hereby builds on its data and presents evidence on how the office space could be designed to influence activity.

RESULTS

By formerly studying 18 Active Badge users at the Computer Laboratories at Cambridge we have identified a strong relationship between objectively measured individuals' energy expenditure (by the use of the GTIM Actigraph accelerometer), and occupants' behavior (7). In doing so, we have found that 90% of the energy expenditure estimated from our Active Badge model differed from the medical physical activity intensity monitoring by less than 340 J per minute accumulated over 24 hours, which is equivalent to approximately 100 kcal (the energy found in an average-sized banana). As the medical equipment measures activity intensity on the horizontal axis only and does not capture the Basal Metabolic Rate (BMR), the above result has been validated by the use of Newton's equations to capture occupants' kinetic (1) and gravitational energy (2) as well as by the use of Ralston's (1958) equation to determine energy expenditure from stationary power consumption to movement (giving a figure of approximately 2.02*m* (where *m* is mass in kg)) (3). These equations are shown below.

$$E_k = \frac{1}{2} \cdot m \cdot (\Delta v)^2 \qquad (1)$$

where E_k , energy expenditure in Joules

m , body mass in kilograms

Δv , the change in velocity in m/s

$$E_g = m \cdot g \cdot \Delta h \qquad (2)$$

where E_g , energy expenditure in Joules

m , body mass in kilograms

g , acceleration due to gravity (9.81 m/s^2)

Δh , change in height in meters

$$E_w = 29 + 0.0053v^2 \qquad (3)$$

where E_w , energy expenditure in cal/min/kg

v , velocity in m/min

As the UK National Health Service recommends a 2500 kcal intake for a man and 2000 kcal for a woman per day, the estimated error of our movement model (as compared to the Actigraph medical calculations) is less than 5% of the daily energy expenditure of a human being; we believe this is an acceptable error rate for estimating the health of office workers.

Based on the above this work has focused to more specifically capture reasons for occupant's movement and levels of space frequency. It has been reported (by informal discussion with the office users) and shown (by the location tracking device) that occupants' move for voluntary, imperative or a combination of both reasons. The imperative movements are normally directed by physical or managerial needs (i.e. visiting the toilet or the manager's office) and the voluntary are usually much more complex and can be heavily dependent on individuals' choice (i.e. visiting the coffee station or another individual's desk).

This study has identified that any voluntary trips would be a combination of stimuli that the Active Badge location mapping device would not be able to clearly state. It has shown however (through Active Badge readings) that the most popular office activities are those which involve personal initiative and provide opportunities for informal interaction. In monitoring the frequency and destination of occupants' movements, we found that the average probability of making a voluntary journey to a specific distance over a day at work is overall higher.

Most preferred spaces for movement are individuals' desks as well as the stair landings which as a whole attracted 2 to 3 times more movement than to the rest of the office spaces (Figure 1). Office users would walk up to an average of 7m. to meet a colleague. Occupants from different floors were recorded to walk an average of 10m. to a stair landing, carry out an informal discussion with a colleague from another floor and then normally proceed to the final destination of their trip. Voluntary journeys, mostly to the coffee station, the reception desk and to the main laboratory attracted approximately 1 trip a day with the maximum average recorded walking distance being 10 m. Note that the coffee station, that in other settings has been shown to attract up to 5 trips a day, was later informally reported as a relatively unpopular destination in this layout for the reason that it was windowless and perceived as dark and visually obstructed from the rest of the office site (Figure 2).

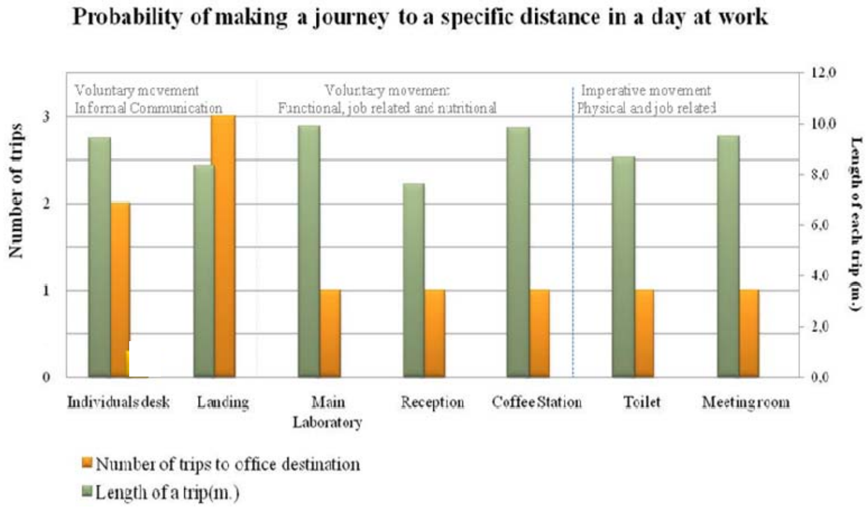

Figure 1 Probability of making a trip to an office destination and the average distance walked to this space over a normal day at the AT&T laboratories, Cambridge.

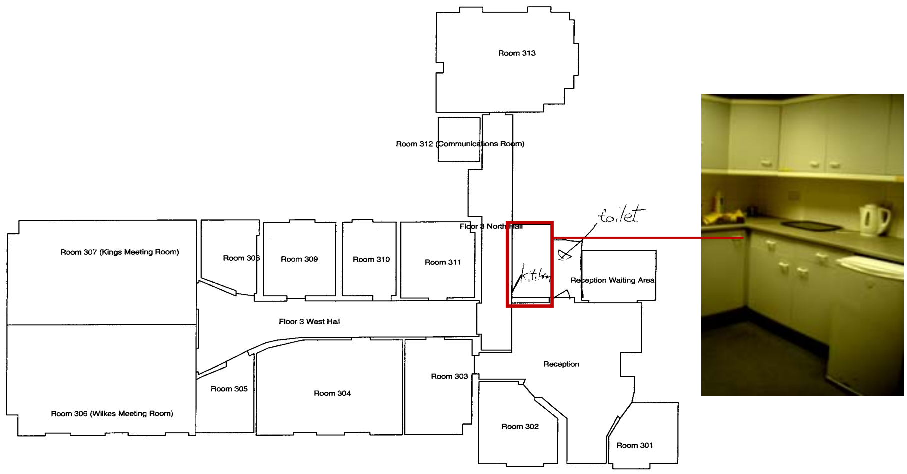

Figure 2 The coffee station was reported to be dark and windowless as well as visually cut off the rest of the office space.

Occupants visited the rest rooms, designed at an average distance of 9m. from their desk spaces, approximately once a day. Another imperative trip would be to the meeting rooms attracting a majority of the office population once a day. Both building meeting rooms were on the third floor located at the far end of the central corridor (Figure 3). Most of the first and second floor users would take the stairs to the meeting rooms. Stair use is of utmost importance in increasing physical activity levels. Medical studies have shown that the energy expended in walking up and down stairs is approximately three times that required to walk slowly on a level plane (Rowett Institute 1992).

Figure 3 illustrates Active Badge readings extracted for the third floor occupants' daily office activities. This shows that movement was normally fanned throw the corridors and directed towards the formal meeting rooms and voluntary spaces such as other individuals' desks, the kitchen and the toilet (denoted on the sketch below). It should be hereby mentioned that most trips to office destinations involved on route stops on the stair landings and floor corridors for informal discussions.

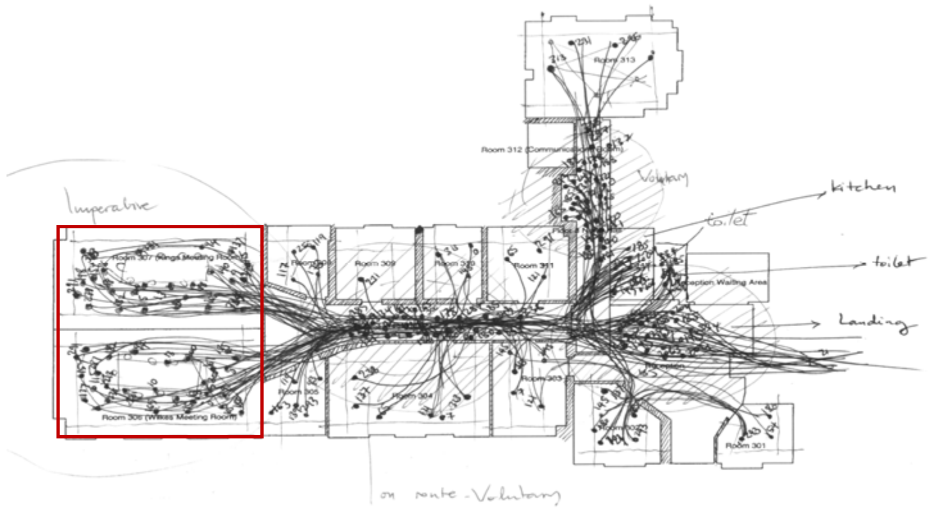

Figure 3 AT&T third floor (data extracted from the Active Badge objective location mapping system). The square denotes the location of the two meeting rooms of the AT&T Laboratories.

Based on the above, this study suggests that due to the imperativeness of specific trips designers can calculate and prescribe health promoting routes and their lengths from the design stage. In this way it is possible to design a number of layout scenarios that could incorporate stair use to the meeting rooms and the toilets that would lead to a daily accumulated higher intensity physical activity in the office. Thomas Allen's work (Allen, 1984), suggests that no voluntary trip is likely to take place further than 50 meters from occupants initial location. In combining the latter with the current study identification for the imperative nature of certain trips, we suggest that the meeting and rest room locations could be designed anywhere within this distance.

DISCUSSION AND CONCLUSION

Medical research suggests that no specific thresholds currently exist to define an increase in physical activity as clinically significant. As the public health recommendation for 30 minutes of physical activity is considered as a guideline, medical scientists emphasize the importance of shifting the distribution of energy expenditure, by being physically active, over a larger population size. In this case, it is estimated that less people will remain sedentary (as their overall everyday energy expenditure would increase) and these higher population levels of physical activity will help prevent heart attacks and will reduce the incidence of diabetes (National Service Framework for Coronary Heart Disease, 2000, 2003, 2004, NHS Department of Health, 2008).

Our current research suggests that there are numerous interrelated attributes that may affect physical activity, space choice, indoor behavior and health. We believe that designing for occupant imperative movement to specific lengths and through certain routes is possible and can be calculated from the design stage to influence higher levels of human energy expenditure (by i.e. involving stair use). Achieving this could lead architects to design spaces that would help increase population levels of daily activity and subsequently improve public health.

ACKNOWLEDGEMENTS

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NIGHT FLUSHING AND CEILING ACOUSTIC SOLUTIONS: THE EFFECT ON SUMMER THERMAL COMFORT AND ENERGY DEMAND

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ABSTRACT

The case analysed represents a standard size landscape office room in Oslo climate. The office envelope and system properties are in compliance with the TEK (2007). The study concentrates on the thermal comfort conditions in summer and two cooling systems are considered, one representing an idealised room cooling system and one representing a typical ventilation cooling system. Three acoustic solutions are considered: conventional horizontal panels, micro perforated resonant box, and vertical baffles. With the idealised room cooling system, micro perforated resonant absorbers covering the entire ceiling requires the same room cooling energy as the conventional insulating panels covering 30% of the ceiling. Vertical baffles with a sound absorbing area equivalent to fully covering the ceiling area are expected to have the same effect on room cooling energy as horizontally mounted panels covering 40% of the ceiling area. However, when accounting for room cooling energy and fans operation at day and night the differences between the acoustic solutions are levelled off, and the overall effect is small compared to the effect of using or not using the night flushing.

With the ventilation cooling system, night flushing proved sufficient to fulfil the legal comfort requirements on operative temperature, without use of direct room cooling. Concerning both the energy demand and the thermal comfort conditions, there is no significant difference in the performance of the various acoustic solutions. A critical look at the results lead to the conclusion that the framework for calculations (NS3031, 2007) was suboptimal for stimating the effect of concrete’s thermal mass. A more appropriate approach would require a finer description of the ventilation system and its control strategy both at day and night, as well as of the internal load and solar shading profiles.

INTRODUCTION

There was a quest to understand if and how the use of concrete, hence of thermal mass, could help satisfying the temperature requirements in new office buildings without using local room cooling (requirement from TEK, 2007 [1]) and at the same time help reducing energy demand, as it is indicated by the literature on the subject (see state of the art report from Haase and Andresen, 2007 [2]). There are contrasting needs for acoustic and thermal comfort on covering the ceiling surface. On one hand, the concrete ceiling should be exposed to the room air to allow the thermal mass absorbing excess heat at daytime and reduce temperature swing and cooling demand. On the other hand, there is the need to install sound absorbing elements on the ceiling to satisfy acoustic comfort requirements. The case analysed represents a standard size landscape office room. The office category was chosen because of its high internal gains that may give rise to overheating problems in summer time. The landscape typology was chosen because in such spaces there is the need to cover, all or in part, the ceiling with sound absorbing elements so diminishing the amount of directly exposed thermal mass.

METHOD

The calculations are performed using "EnergyPlus", a software tool for dynamic analysis of whole building energy and indoor climate performance. The landscape office room has standard dimensions that can be considered representative of a typical case in Norway; it is rectangular of size 25x12 m with a floor to floor height of 3 m. The room is in an intermediate storey and so it has little dispersions toward above or below; walls facing South and West are exposed to the exterior while the other two walls face internal zones with the same temperature regime and so are approximated as adiabatic. Each of the external walls has a window, and the orientation is with the long side exposed to South and the short side to West. A variable area of the ceiling, from 0-100%, is covered by acoustic elements. Parameters like walls and windows U-value, glazed area, air tightness, internal loads, ventilation system are set according to TEK (2007) [1]. All relevant parameters are reported in Table 1. The simulation period goes from the 1st of May to the 30th of September, and so the heating demand is not considered and the heating system is normally supposed to be off. Two cooling systems are considered, one representing an idealised room cooling system and one representing a typical ventilation cooling system. In a first step it is estimated the effect of night flushing the thermal mass. In a second step it is estimated the effect of partially or totally covering the ceiling's thermal mass with three different acoustic elements. According to KLIMA (2006) [5] the operative temperature in a working place should not exceed 26ºC for more than 50 hours of occupation time during summer. The simulations are performed with three different temperature set-points: 26, 24 and 22°C.

Parameter	Value	Notes
Envelope		
Floor area	300 m^2	
External walls	U-value = 0.18 W/m^2K	20cm concrete on the outside, inside 20cm insulation and gypsum board
Ceiling/floor	Concrete slab 20cm with linoleum	
Windows area	20% of floor area	
Windows	U-value = 1.2 W/m^2K g-value = 0.58	Overall, frame included
Solar shading	Automatic when solar radiation on window is > 200 W/m^2	
Thermal bridges	neglected	
Air tightness	n_{50} = 1.5 ach	Corresponds to an average infiltration rate of 0.1 ach
Internal Loads		
Occupancy	Mon-Fri 07:00-19:00	
People	10 m^2/pers, 40 W/pers	sensible heat only, NS3031 (2007)
Lighting	8 W/m^2	NS3031 (2007)
Electrical equipment	11 W/m^2	NS3031 (2007)
HVAC		
Cooling operating hours	Mon-Fri 07:00-19:00	Only for ideal room cooling system
Ventilation operating hours	Mon-Fri 07:00-19:00	
Ventilation supply air temperature	18°C May and September 17°C June to August	
SFP	Day: 2.0 $kW/(m^3/s)$ Night: 1.0 $kW/(m^3/s)$	Calculated at nominal flow = 70% of maximum flow

Table 1: Main parameters used in the simulation

The acoustic solutions considered are taken from the report by Hveem (2009) [3], and are they are: horizontal panels, micro perforated resonant box and vertical baffles. The horizontal panels are conventional sound absorbing elements made of porous materials that are both acoustically and thermally insulating, mounted horizontally on the ceiling surface. The micro perforated resonant box is a special type of resonator sound absorber with extreme small hole or slot dimensions (some μm). A good absorption characteristic is depending of interaction with a cavity behind and often two panels and two cavities are used to get good properties in a broad frequency range. Resonant absorbers can achieve good results even though they behave poorly than porous absorbers at high frequencies. Sound absorbers with a good metallic contact with the concrete will transmit heat to the concrete, and so the thermal mass is not strongly de-coupled from the room air. Two versions of this acoustic element are considered, and they are simulated using their equivalent thermal resistance, as estimated by Wachenfeldt and Zhang (2007) [4] with a FEM method: a profile with partial metallic contact with the concrete (extra resistance: 0.054 m^2K/W) and a box with full metallic contact with the concrete (extra resistance: 0.031 m^2K/W). The vertical baffles are essentially the same conventional panels that can be mounted also horizontally. A vertical baffle absorbs sound on both surfaces; so, in order to obtain a sound absorbing area equivalent to covering the entire ceiling, the baffles should be mounted at a distance of about 2xH (neglecting their thickness), given that H is the height of the baffle. Considering that the baffle’s height may be in the range 30-50 cm, this means that the baffles should be mounted with an average step of 60-100 cm, which allows enough room for lighting ballasts and ventilation ducts. In addition, the baffles should be mounted at a certain distance from the ceiling for not affecting significantly the free motion of air.

The analysis with the room cooling has the main purpose to estimate the effect of the different acoustic solutions on both thermal comfort and energy demand, when all other parameters are treated as optimal. The analysis with the ventilation cooling system has the main purpose to estimate the thermal comfort and energy demand achievable with a realistic system that has certain limitations, as on the maximum air flow available. In both cases the landscape office is supplied of a minimal amount of fresh air that is calculated as follows. the minimum requirements for supply of fresh air according to KLIMA (2006) [5] are on one part due to occupancy and one part due to material emissions. The TEK-VEIL (2007) [6] states that concrete can be considered as a normal-emitting material, and so the resulting airflow would be 6.1 $m^3/h/m^2$ with the given occupation density. This value could eventually reduce to 5.1 $m^3/h/m^2$ if an average occupancy rate of 60% is assumed. Nevertheless, in order to comply with the standard on energy calculations NS3031 (2007) [7], the minimum value is 7 $m^3/h/m^2$ is used. With ideal local room cooling ventilation is assumed to be constant at the minimum and provided without any temperature increase due to the fans, and the control is done directly on the operative temperature. Therefore, the value calculated represents the minimum requirement on cooling energy. Night flushing is also considered in an idealised way, and is active when indoor temperature is both higher than 19°C and higher than outdoor temperature. Airflow rate for night flushing is 12 $m^3/h/m^2$, which is the maximum airflow that can be supplied through the ventilation system. With ventilation system the supply air temperature is 18°C in May and September and 17°C in June-August. There is Variable Air Volume ventilation system, VAV, that supplies the minimum flow rate required for fresh air, but it is also controlled by room air temperature. When the room air temperature tends to go above a given threshold – 22, 24 and 26 °C in the cases analysed – the flow rate is increased in order to provide more cooling effect. The maximum flow allowed is 12 $m^3/h/m^2$, which represents a typical practice in Norway and a safe value in order to avoid possible uncomfortable draughts. The temperature rise due to the fan, however, is considered in this case; temperature rise is about 0.6°c and 1.6°C when flow rate is at minimum and maximum, respectively. The ventilation is equipped with a heat recovery unit that is by-passed when outdoor temperature is above 15°C (free cooling mode). The cooling battery is supposed to have infinite capacity, and so is always able to guarantee the delivery of supply air at the desired temperature. Nevertheless, it shall be noticed that the cooling capacity of the ventilation system is limited because of its limited flow rate. Night flushing is provided through the ventilation system with flow rate of 12 $m^3/h/m^2$, and with respect to the previous case has the following restrictions: outdoor temperature must be both above 12°C (to prevent condensation) and at least 4°C lower than indoor temperature (to operate the fans only when cooling can actually be effective). The relation between fan power and flow rate is assumed cubic, assuming that flow is fully turbulent. VAV ventilation systems are usually dimensioned for an air flow rate of about 70% than the maximum allowed; in this case it means that Q_{nom} = 8.4 $m^3/h/m^2$. This means that when airflow is at maximum, i.e. with night flushing, the fan power consumption increase significantly. However, the Specific Fan Power, SFP, is reduced at night (see Table 1) for example assuming that night flushing is done bypassing the air handling equipment and operated in combination with a partial opening of the windows, and therefore using only the return air path and so reducing the pressure drop.

RESULTS

The results from Figure 2and Figure 1 refer to the case with local room cooling.

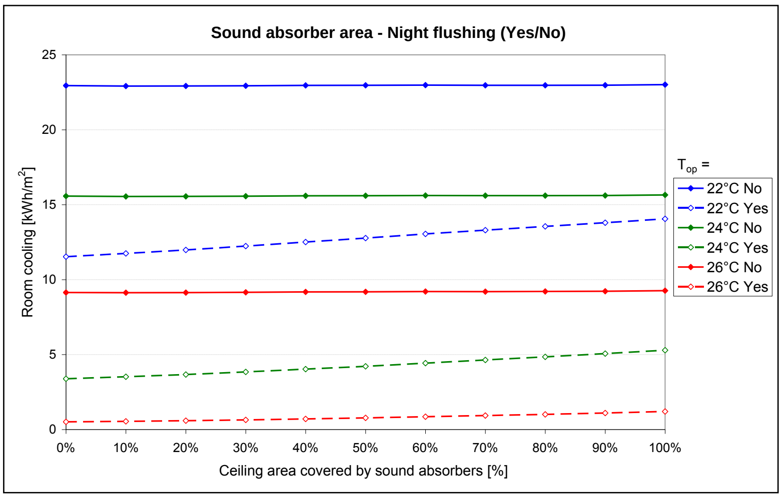

Figure 2: Cooling energy demand for various temperature set-points and with or without night flushing, as function of the ceiling area covered by sound absorbers

Figure 2 shows that cooling energy is significantly dependent on the temperature set-point, obviously; but it can be drastically reduced by using night flushing, at least in a thermally massive building like this one. Covering the ceiling with sound absorbers, partially or fully, does reduce the effect of night flushing because it somewhat decouples the ceiling thermal mass form the room air. However, the overall effect is small compared to the effect of using or not using the night flushing

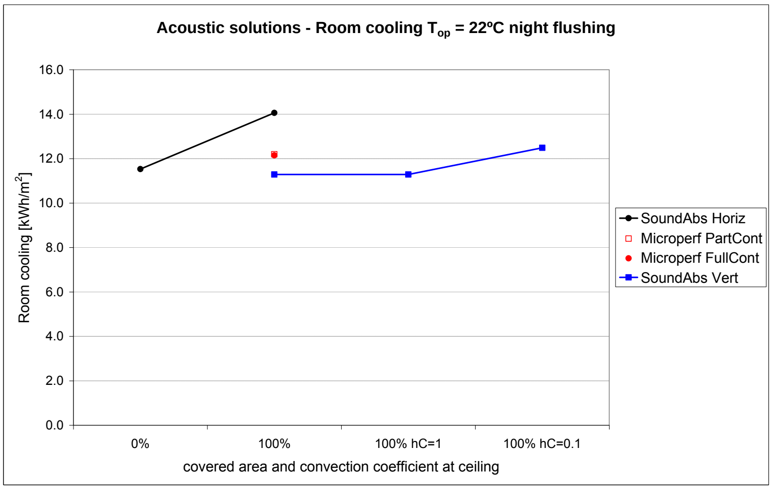

Figure 1: Cooling energy demand for various acoustic solutions, with set-point of 22°C and night flushing

Figure 1 shows the room cooling demand for the different acoustic solutions and set-point of 22°C. When used to cover the entire ceiling the energy performance of the micro perforated absorbers is approximately the same as that of the conventional insulating panels covering 30% of the ceiling; with the full contact box performing slightly better than the partial contact profile. Vertical baffles have the same performance as the fully exposed ceiling when accounting only for the modified pattern of radiation heat exchange between the room surfaces; that gives only negligible differences in the room cooling demand. However, air motion may be hampered if a bad layout is chosen, i.e. baffles mounted too close to the ceiling surface. The convection heat transfer coefficient (h_C) is calculated automatically by the software and its value varies at each time step, but is in average ≈ 1 W/m^{2}K. Figure 1 shows the effect of user-imposed h_C values of 1 and 0.1 W/m^{2}K – meaning 10 times lower than with exposed ceiling. The resulting room cooling demand increases, like if the ceiling was covered by 40% with horizontally mounted panels.

The results from Table 2 and Table 3 refer to the case with VAV ventilation and set-point on air temperature of 26°C. When no conditioning is provided and natural ventilation is used the operative temperature would not satisfy the requirement of Top > 26°C for less than 50 occupancy hours. Introducing a VAV system that supply air at 17°C improves the situation but do not allow meeting the requirements; this because the control is on the air temperature, and operative temperature results higher because of the warm surfaces. Introducing night flushing the thermal mass is cooled and the surface temperature decreased, therefore achieving the requirement as shown in Table 2.

Ventilation	**Night Flushing**	**Operative Temperature [°C]**		**Temperature Swing [°C]**		**Occupation hours T_{op} > 26°C**
		T_{op}_avg	T_{op}_max	ΔT_{op}_avg	ΔT_{op}_max	
Natural Ventilation, free floating	No	27.2	34.1	1.2	2.7	878
Natural Ventilation, free floating	Yes	23.1	28.9	2.3	3.7	75
Mechanical VAV, T_{air} = 26°C	No	25.9	27.0	0.4	1.6	866
Mechanical VAV, T_{air} = 26°C	Yes	24.0	25.8	1.5	2.2	0

Table 2: Summary of thermal comfort results for the case with natural ventilation and mechanical VAV, with and without night flushing

When looking at the overall energy demand – cooling battery in the ventilation system and the operation of the fans at day and night – introducing night flushing has an overall marginal effect, while allowing achieving the comfort requirements. The results show no significant difference in energy demand for the different acoustic solutions, the horizontal panels always performing somehow the worst.

Acoustic solution	**Energy demand [kW/m^2]**			
	cooling battery	fan day	fan night	Total
Exposed ceiling (no night flushing)	4.4	5.0	0.0	9.4
Exposed ceiling	4.4	3.5	2.4	10.2
Horizontal 100%	4.4	3.5	1.8	9.8
Microperforated box 100%	4.3	3.5	2.2	10.1
Vertical baffles 100% (h_C=0.1)	4.4	3.5	2.3	10.2

Table 3: Energy emand for the different acoustic solutions whit set-point of 26°C

DISCUSSION

The analysis with the idealised room cooling system showed that with the given dimensioning of the ventilation system, night flushing proved able to reduce overall energy demand, when accounting for cooling energy and fans operation at day and night. Covering the ceiling with sound absorbers, partially or fully, does reduce the effect of night flushing because it somewhat decouples the ceiling thermal mass form the room air. However, the overall effect is small compared to the effect of using or not using the night flushing. For all temperature set-points considered, the results show no significant difference in energy demand for the different acoustic solutions; the horizontal panels performing worst. Micro perforated resonant absorbers covering the entire ceiling induce approximately the same energy demand as the conventional insulating panels covering 30% of the ceiling. Vertical baffles with a sound absorbing area equivalent to fully covering the ceiling area may have – at worst – the same effect on cooling energy demand as horizontally mounted panels that cover only 40% of the ceiling area.

The analysis with the VAV ventilation system showed that night flushing proved sufficient to fulfil the legal requirements on operative temperature, without use of direct room cooling. Night flushing has an overall marginal effect on the energy demand, when accounting for cooling battery energy and fans operation at day and night. It is possible to further reduce the energy used by the fans dimensioning the ventilation system for the maximum flow; this, however, implies the use of larger ducts that is not always possible because of the extra space they would require. Concerning both the energy demand and the thermal comfort conditions, with all temperature set-points there is no significant difference in the performance of the various acoustic solutions. However, as the daytime set-point is reduced the effect of night flushing is reduced.

However, one main conclusion is also that the boundary conditions are not appropriate for studying the thermal mass effect. The input values were chosen in compliance with the NS3031 (2007) [7] because that is the reference norm for energy calculations and is commonly used by building industry practitioners to certify the energy performance of buildings. However, this does not mean that it can be used as a basis for answering questions of design and dimensioning nature. The NS3031 (2007) [7] method, simply, is meant to be used for estimating annual energy demand and so is based on average values and approximated values that fall in the safe side, but are not suitable for more detailed analysis, i.e. of a VAV ventilation system. In addition, minimal contribution of solar gains was assumed in order to “isolate” the effect of the different acoustic solutions. In other words, with low solar gains, low internal gains and high airflow the result is that surely it is possible to satisfy the temperature requirements, no matter whether the ceiling is covered or not. However, this does not mean that thermal mass has no effect. The most appropriate conclusion is rather that the method chosen for calculation is suboptimal. An adequate approach that aims at maximizing thermal comfort while minimizing energy demand would require a finer description of the ventilation system and its control strategy both at day and night, as well as of the internal load and solar shading profiles. Only in this way it is possible to appreciate the real effect of thermal mass.

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DISPLACEMENT VENTILATION FOR SCHOOLS: THE EFFECT ON PERSONAL INDOOR AIR QUALITY

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ABSTRACT

A new Integral Design approach was developed to design adequate solutions for ventilation of school buildings. The design procedure and a first design result are described. The design is implemented in an existing school and measurements were done in this school. During several weeks all the relevant parameters to calculate the PMV values were determined. In the same period questionnaires were held.

INTRODUCTION

Studies have been made over the last 300 years or so to establish recommended minimum ventilation rates and there has been specific interest for schools since about 1900 [1]. In the last 20 years an emphasis has been on the improvement of the energy efficiency of buildings. This has also had is effects on the design and construction of Dutch schools and has led beside better insulation and glazing, to a more compact way of building and the introduction of new components for heating and ventilation. Nowadays the indoor climate of primary schools is a hot item in the Netherlands. Despite the fact that this situation has been going on for years, there is a strong increase in scientific research and more focus on this problem. Indoor Air Quality at schools is of special concern since children are extremely sensitive to results of poor air quality. IAQ in schools must reach the basic requirements and should be considered as a high priority because [2]:

1) Children are more sensitive as they are still developing physically and are more likely to suffer from indoor pollutants; these growth processes are delicate and vulnerable to disruption,

2) Children are less well able than adults to metabolise and excrete most environmental toxins,

3) Children are relatively more heavily exposed to environmental toxins as they breathe higher volumes of air relative to their body weights.

Besides this important aspect of health, parents and health specialists become aware of the negative influence of a bad indoor climate on the learning performance. The pressure on the public institutions to undertake some action is rising. The GGD (Local Council Health organizations), TNO (Dutch institute for applied research) [3] among others the Technical University of Eindhoven [4,5] already conducted research (including field studies) to the indoor climate in Dutch primary schools. Problems like draught and poor air quality are very common in primary schools [4]. Beside the fact that pupils feel uncomfortable, poor indoor climate also influences performance, work productivity and sick leave [6, 87].

To obtain a good indoor climate, a large airflow is needed in the highly occupied classrooms without negatively influencing thermal comfort. In the Netherlands, most existing (and even newly constructed!) schools are provided with windows which can be opened to stimulate natural ventilation in the classroom. These measures are easy to implement at low costs. Several studies [4, 5] indicate that this ventilation method is not sufficient to achieve a good indoor air quality without causing draught problems. Besides poor fresh air distribution these solutions are strongly user- and weather dependent. The teacher can only consider a good indoor air quality at the expense of poor thermal comfort or vice versa.

METHOD

Different aspects of the problems were studied to find new solutions. In [4], 5 schools with exhaust only ventilation were studied in detail and extensive measurements were made. The aim of the study was to find means to improve the air quality without causing thermal discomfort for the student. Based on the gained insight of the measurements a simulation model was built and different configurations were evaluated. The main conclusion was that regarding the design of natural supply vents it is difficult to supply sufficient air without causing thermal discomfort. A draught prevention system is necessary and should be carefully designed.

In a next study schools with different ventilation systems were studied to have a good overall idea of the range of existing solutions for school ventilation [5]. It was found that while some systems performed better than others, no systems functioned adequately during the whole year with its changing outdoor conditions. Therefore a first start was made with a design approach to come up with better solutions [5]. After this primary design study a more extensive design study was made [8]. The design of a new and better functioning ventilation system for schools is a complex process. Design methodology helps the designer to give structure to the design tasks and solutions. The design process should not only lead to a solution, but also give insight in the reasoning about the design problems and the solutions itself. The decisions made during the design process should become clear and reproducible for other designers and disciplines. This simulates the multidisciplinary exchange of ideas and concepts. Using the Integral Design approach helped to design possible adequate solutions for ventilation of school buildings. Most promising solution was a concept using displacement ventilation. Dutch primary schools need a ventilation system which is able to supply and guarantee a large amount of air in a comfortable and efficient way throughout the year. Earlier research conducted [5] concluded that a displacement ventilation system could be able of supplying a large amount of air with a low velocity (no draught problems). Although this system seems to have a high potential as ventilation system in primary schools, more research is needed to obtain a better understanding of the critical factors of applying such system in a typical Dutch (primary) school environment. According to [9] a displacement ventilation (DV) is in first place meant to obtain a good air quality into the occupied zone. DV is suitable in rooms where the main heat sources are also the contaminant sources (like pupils); a classroom is a good example. A displacement ventilated classroom needs less fresh air (when compared to often applied mixing ventilation) to gain the same indoor air quality. This involves an energy reduction. Mattsson [10] conducted research on the performance of DV systems in classrooms under laboratory conditions. It seems that for example people movement demolishes the displacement effect, but the displacement flow pattern was re-established fairly quickly after ceasing the activity. The objective of our research is to obtain a good indoor air quality in primary schools by developing, constructing and validating a “standard” ventilation solution that can be generally applied in these schools. In spite of the fact that a laboratory environment is commonly used for measurements to validate ventilation systems (because of the controlled steady state conditions that can be achieved) we think it is more important to prove the efficiency of the ventilation system solution in an existing classroom environment. Several depending and dynamic physical variables need to be examined and monitored to obtain a reliable judgment of the DV system.

Field test with displacement ventilation

The measurements are carried out in a full-scale classroom (in use) approximately the size of a typical classroom in the Netherlands (see Figure1). To establish the conditions of the mean air quality of the classroom several CO2 sensors are placed on strategic locations. Also the level of comfort is measured which consists of air temperature, relative humidity, local air velocity and radiant temperature (black bulb). During the measurement period the ventilation behavior of the teacher and pupils is examined with a logbook to clarify the variations of the measured parameters. The tripod for comfort measurements provided with air temperature, relative humidity, radiant temperature, local air velocity, CO2 sensor and temperature gradient between 0,1 and 1,1 meter. There was an extra CO2, temperature and relative humidity sensor at 1,1 meter at the wall. Also the outdoor climate conditions were measured, air temperature, CO2 and relative humidity at the shade side of the façade. The floor area of the classroom is 7,72 x 7,3= 56,4m2 with a ceiling height of 3,13 m and a total space volume of 176 m3. The classroom is used by 26 pupils from group 7/8 (age 10-12 years) in standard school conditions. The façade has eight windows of which four can be opened by the teacher. The reference conditions were measured during Monday 3rd of May 2008 and showed that throughout the week the average indoor room temperature is reasonably constant, approximately 20ºC. Also the relative humidity is reasonably well with an average value between 40-50%. The indoor air quality, which is measured by the CO2 concentration, exceeds the limit of 1200 ppm by 55% and the desired value of 1000 ppm by 86%. This is unacceptable but unfortunately a recognizable situation within Dutch primary schools [4, 5].

New ventilation system

An air handling unit is mounted on the outer wall next to the classroom, see Figure 1. The air handling unit is provided with a plate heat exchange system to recover sensible heat from the exhaust air. The air is transported by a duct system which is mounted above the lowered ceiling in the classroom. The air is reheated (if necessary) by an electric heater connected with a temperature sensor nearby the supply diffusers, to obtain a minimal supply temperature of 18ºC in winter. The ventilation flow can be adjusted by a control panel which communicates with electronically commutated ventilators in the air handling unit and is fine-tuned with control valves. The air flow can be measured by prefabricated measuring instruments in the supply and the extract duct system. The air supply temperature is regulated by an electrical heating battery which is connected with a temperature sensor in the supply duct system. Two semicircular textile air diffusers (also called air socks) for displacement ventilation are mounted on the wall at floor level at the backend of the classroom. The main supply duct is vertically placed in the middle of the wall at the backend of the room. An air distribution box is placed at the end of the duct at floor level to divide the air flow over the textile air diffusers. The textile air diffusers have a length of 1,7 meters with a zipper at 0,5 meter to shorten the length (to 1,2 meter) and increase the supply velocity, see figure 1. Two exhaust grilles are mounted in the lowered ceiling on the opposite side of the classroom.

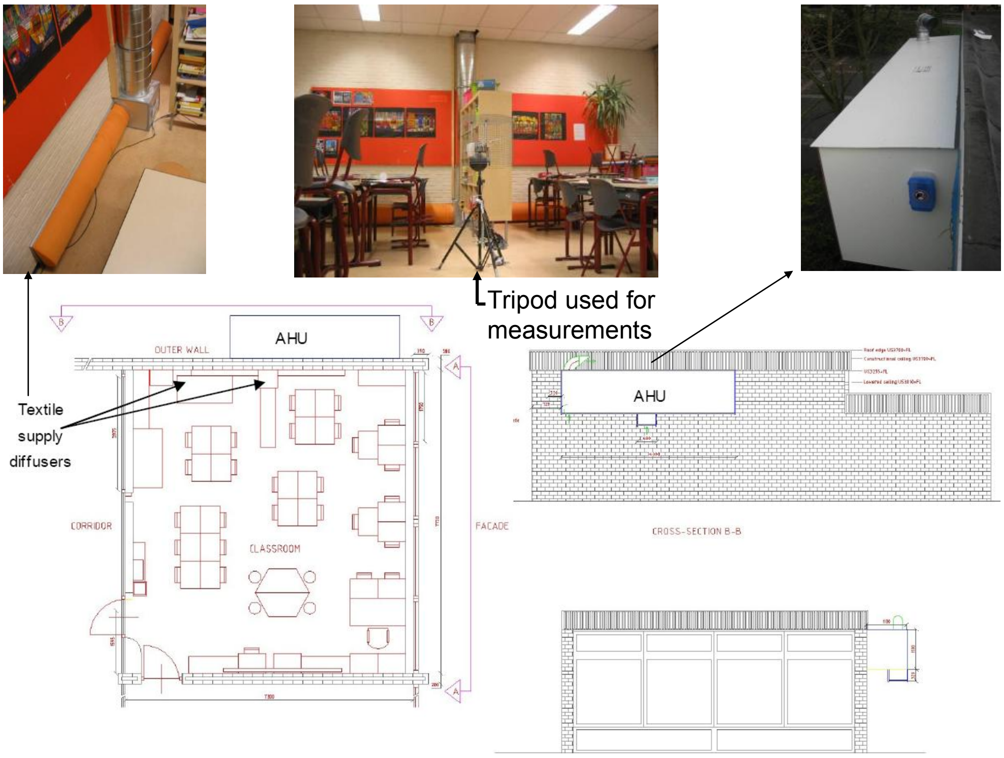

Figure 1: Experimental set-up ventilation system [11]

Person simulator

The air quality near the body of a human in a displacement ventilated room is verifiable better due to thermal buoyancy which stimulates fresh air supply from beneath. The buoyancy forces near the person simulator (PS) are used to validate (better) air quality in the breathing zone. Mattsson [10] already used a person simulator to measure the displacement effect near the body. The PS in this research is made of round 250mm duct material (see Figure 3).

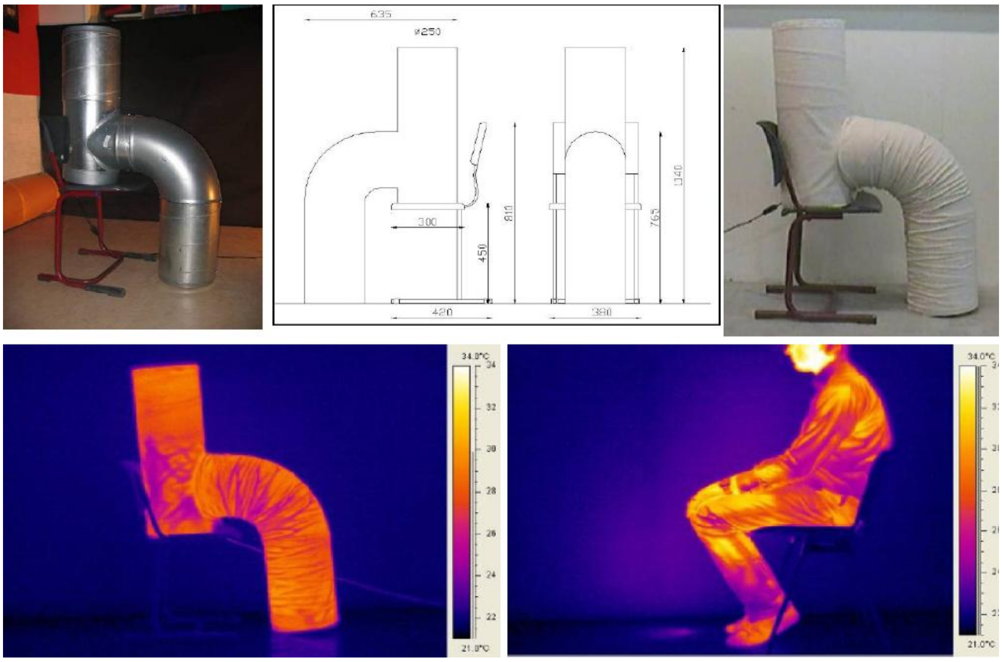

Figure 2: Undressed person simulator, its dimensions, the dressed version and the thermo graphical check by comparing the person simulator with a person [11]

The dimensions of the PS are determined by the furniture of the classroom and the average body surface of the pupils. The PS is used to mount on resistance thermometers and CO2 sensors. Thermo graphical pictures were made to compare the surface temperature of the PS with a real human. A comparison is made between the surface temperature of the PS and a real human being. The surface temperature of the PS (25-29oC) is, in contrast to the human being (22-33,6oC), equally spread from toe to head. The exposed skin of the human head was relatively high (32-34oC). The extra heat loss (per unit area) of the head, caused by high temperature, was to some extent compensated on the PS by its larger head area.

RESULTS IAQ

The ventilation measurements took place on a normal school day with a morning and an afternoon session. The occupation was constant with 23 persons and when the ventilation system turned on the air flow per person was 22 m3/h (6,1 l/s). As an illustration one of the measurements sessions will be presented. Before the start of the school day (first period) the ventilation system was turned off. After one hour the CO2 concentration was between 1700 and 1900 ppm just before the ventilation system was turned on. Within the first three minutes the CO2 concentration at the PS sensor was decreasing. After twelve minutes the CO2 concentration at the wall- and the tripod sensor were decreasing. It is plausible that the displacement effect at the PS causes the extract sensor to decrease earlier than the wall- and tripod sensors (after six minutes, see figure 3.

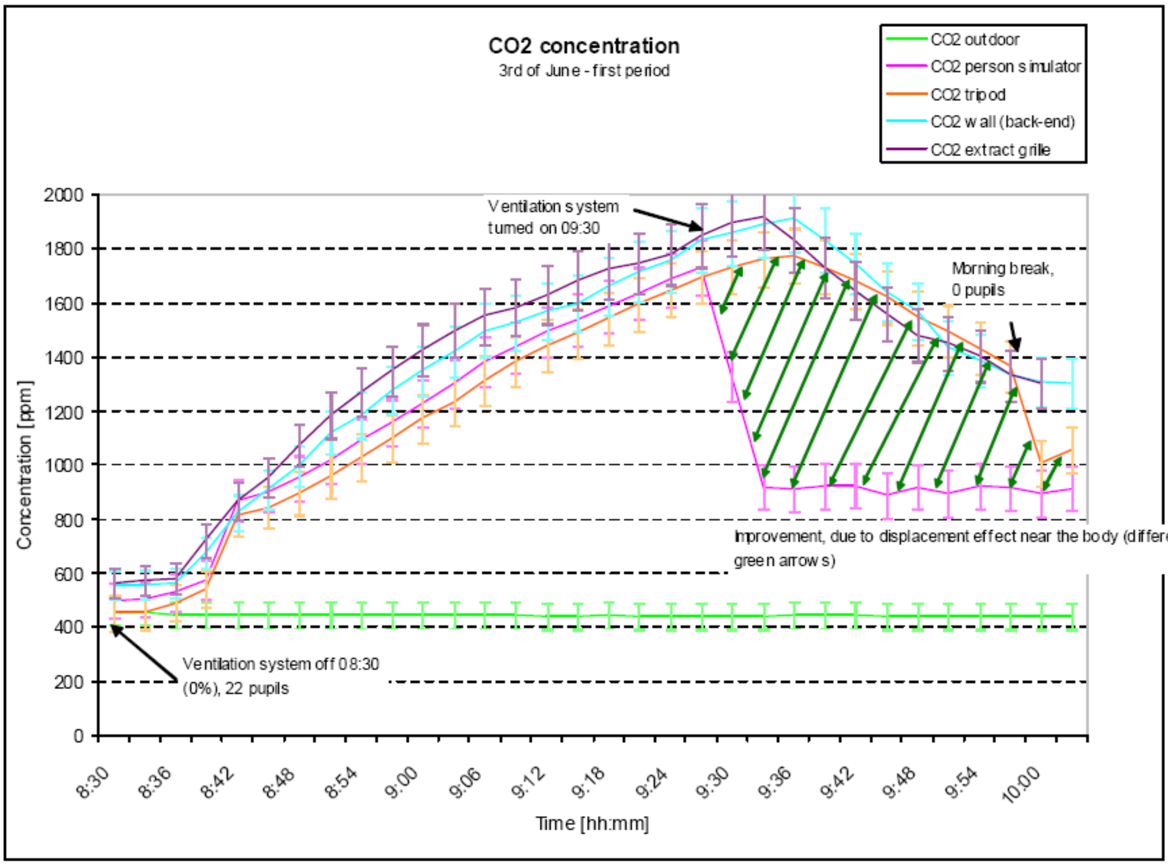

Figure 3: Measurement result of the CO2 concentration curves of the efficiency measurement in the new situation July 3rd CO2 concentration curves of the first period, displacement effect is marked with an angle. The improvement (difference between PS and other locations) is significant [11].

The displacement effect is the difference between the concentration at the tripod and the PS is marked with green arrows in figure 3. In the first hour the error bars of the tripod and PS curves cross each other. However, after turning on the ventilation system the error bars do not longer cross and a significant improvement is clearly seen.

CONCLUSIONS

The Integral Design method leads to new solutions for ventilation of class rooms. The displacement ventilation solution is applied in a class room to investigate the outcome. Measurements provide an insight in that displacement ventilation is a promising solution for primary school ventilation.

ACKNOWLEDGEMENTS

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PASSIVE THERMAL PROTECTION FOR ATTIC DWELLINGS

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ABSTRACT

Many buildings in Romania have attics and their number is growing, in order to increase the dwelling surface and as a substitute of the unsatisfactory old flat roof coverings. Now it is important to satisfy the summer comfort requirements, without using electrical air conditioning devices. A reasonable way is to achieve the thermal protection using a naturally ventilated air layer, situated between the airtight roof covering and the thermal insulation covered by a thermoreflecting sandwich of metallic thin sheets. In order to establish the minimal temperature difference able to determine the air ventilation and the best configuration of the air channel, a model scale experiment was organized using the similitude Grashof criterion.

INTRODUCTION

There is a real trend in Romania to build attics on the new buildings and also when old blocks of flats are rehabilitated, in order to improve the thermal efficiency and to increase the dwelling surfaces, the flat roof coverings being considered unsatisfactorily. A good thermal insulation of the inclined roof, i.e. about 20 cm of mineral wool, is needed. However the request for thermal comfort in summer remains often unsatisfied. A way to improve the attic inside temperature, without using electrical air conditioning devices, should be obtained with a natural ventilation process. Near the Black Sea, where the atmospheric humidity is high, the contribution of the night ventilation through windows cannot be satisfactory. Therefore it is more efficient to resort to a ventilated air layer situated between the roof covering and the thermal insulation, Figure 1. It can evacuate most of the solar heat, but only if the air can flow from the eave to the top of the roof, due to the thermal and wind draught. A thin metallic thermoreflectant layer (ALFOL), covering the thermal insulation, should also be used, in order to contribute to this favourable effect.

In order to investigate the minimal temperature difference (between the inner surface temperature of the roof covering and the temperature over the thermal insulation) able to set the air layer in motion, a convenient laboratory model scale experiment, based on the similitude criterion Grashof has been organized.

THEORETICAL BASIS OF THE EXPERIMENT

Considering a prototype (N) and a physical model (M), the thermal convective motion of a fluid is ensured if the Grashof criterion is observed:

$$\mathrm{Gr} = \frac{g \cdot \beta \cdot \Delta T \cdot L^3}{\nu^2}$$

with:

g - gravity acceleration (m/s^2); β - volumetric expansion (1/˚C); ΔT - temperature difference (˚C); L – length (m).

It is obvious that if we want to reproduce the natural convection with a physical model using the same fluid, the Grashof condition can be fulfilled if the scale model temperature difference is:

$$\left(\Delta T \cdot L^3\right)_N = \left(\Delta T \cdot L^3\right)_M$$

Then the model should catch fire.

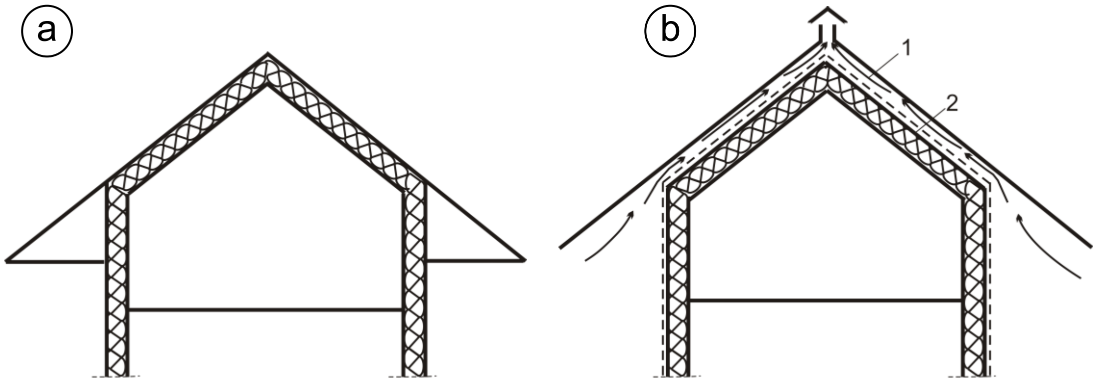

Figure 1: Building attic: a- traditional structure; b- ventilated air layer (1), and thermoreflectant thin metallic sheet (2)

But we can use conveniently the model scale physical model in order to establish the effect of very small temperature differences on the air motion (Figure 2).

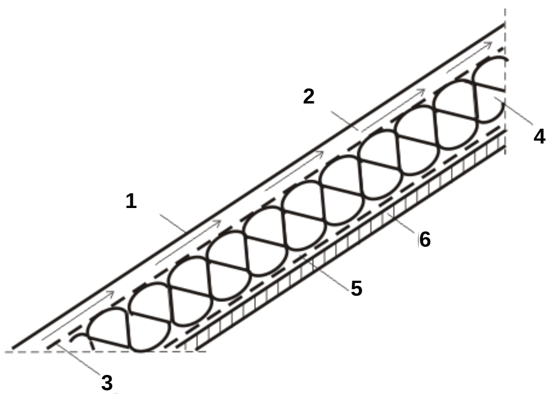

Figure 2: Roof covering structure: 1- air tight covering; 2- ventilated air layer; 3- thermoreflectant metallic sandwich sheet; 4- mineral wool; 5- vapour barrier; 6- support

LABORATORY APPARATUS

The laboratory physical model is representing a vertical section of the attic roof (Figure 3), the lengths scale was 1/10. The warming effect of the sun radiation is simulated by an electrical heating wire. The movement of the air inside the air layer can be seen through the glass wall with a smoke tracer. More then that, with an infrared camera very good images of the warm air flow has been obtained. The air temperature has been measured with thermocouples.

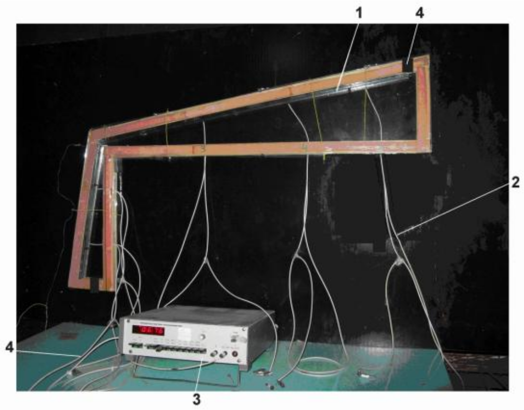

Figure 3: Physical model for a half attic: 1-heating wire; 2-thermocouples; 3-microvoltmeter; 4- air admission; 5- air exit Physical model for a half attic: 1-heating wire; 2-thermocouples; 3-microvoltmeter; 4- air admission; 5- air exit

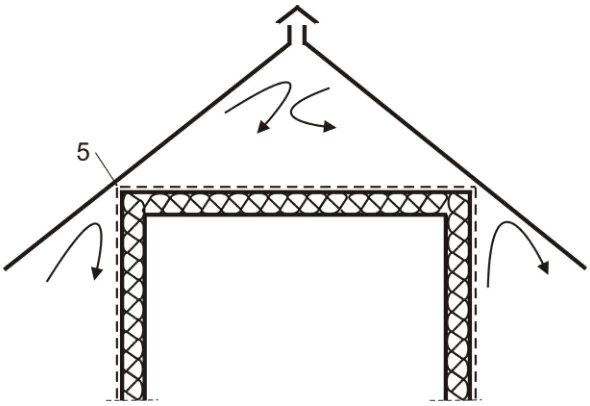

Figure 4: Air flow pattern when the air layer is strangulated in point 5

EXPERIMENTAL RESULTS

The air flow is presented in Figures 4 and 5. It was established that the air flow inside the air channel is beginning at very small temperature differences, i.e. only 2 or 3°C at the natural scale.

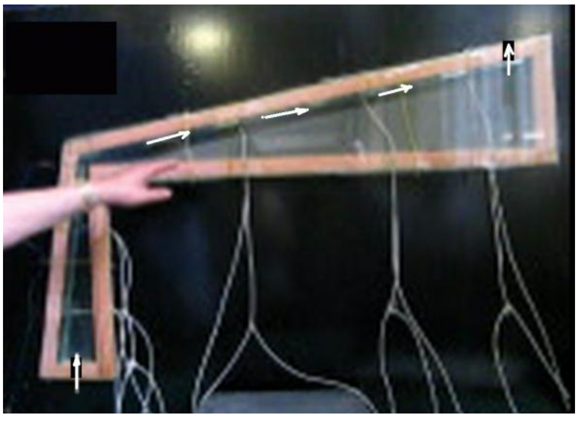

Figure 5: Air flow image with tracer gas (grey smoke)

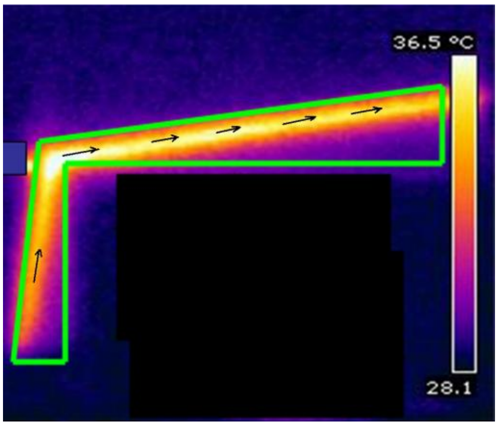

Figure 6: Air flow image with an infrared camera

CONCLUSIONS

A simplified scale model simulation for the convective air flow through the attic roofs was established and the efficiency of a ventilated air layer has been made evident.

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Advanced Building Control Systems

DESIGN OF AN AGENT ARCHITECTURE BASED ON THE POWERMATCHER APPROACH FOR COORDINATION OF HEATING AND COOLING IN BUILDINGS AND DOMESTIC DWELLINGS

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ABSTRACT

A lot of simultaneous processes do occur in a building. With the increase of the number of devices for heating and cooling of the building, there is a higher risk of one device counteracting the other. This leads to unnecessary loss of energy. It is becoming harder for conventional comfort control systems to satisfy the objective: 'provide thermal comfort at the lowest energy use'. Multi Agent systems for climate control can offer a number of advantages in this field because of their bottom-up modelling principle starting from the low-level primary process, in this case comfort control.

The aim of our research in the Flexergy project is to design a Multi agent climate control system for buildings and domestic dwellings as well. In the process of obtaining this, an intermediate goal as an objective for a study was spontaneously formulated.

During the operation of a central control system for a representative office building in the Netherlands, it was observed that, due to high insulation, solar irradiance and internal heat sources, the net demand for cooling over a year is higher than for heating. As a heat pump connected to an aquifer was responsible for delivering the cooling power it was also observed that the temperature of the aquifer increased. This decreases the availability of cooling power for the building in near future.

The question was raised how a multi agent could help to retain the energy balance of the aquifer over a year. It was suggested that two technical possibilities to retain this balance could be exploited: first to cool the building by outdoor air during the morning hours by an air conditioning unit and second to load cold during the night with a bypass preventing warm air from entering the building.

This study describes the details of a design of a simplified Multi agent climate control aimed at retaining the energy balance of the heat pump connected to an aquifer, exploiting the ability of the PowerMatcher to trade two or more commodities through the use of the above mentioned methods [2].

INTRODUCTION

In order to achieve an acceptable indoor climate in an office or conference room, different resources are available: mechanical ventilation, heating or air conditioning unit. In the design of these systems the capacity of the resources is calculated according to a standard reference situation. This means that not all of the time the designed capacity is totally used. This leaves room for optimization of the utilisation of the capacity in place and time. A multi-agent market approach can be able to coordinate these energy flows to achieve global optimization and obtain decentralized control.

Other benefits of a multi-agent approach are 1) the generic description of installations 2) plug and play behaviour of appliances 3) adaptation to the circumstances in stead of predefined behaviour and 4) no need for flow diagrams. For coordination of electricity there has already been developed and tested a successful concept ‘the PowerMatcher’.

The PowerMatcher is designed as a market-based control concept for supply and demand matching (SDM) in electricity network [2]. It is concerned with optimally use of the possibilities of power producing and consuming devices to alter their operation in order to increase the over-all match between power production and consumption. Each device is represented by a software agent that tries to operate the process associated with the device in an economically optimal way, so no central algorithm is needed. Furthermore the communication overhead between software agents and an auctioneer, which performs the price-forming process, is very limited. The only information that is exchanged between the agents and the agent platform are bids. These bids express to what degree an agent is willing to pay for or receive a certain amount of power. Since bids are constructed in a process of weighing the profits versus the costs, bids are a projection of the utility function of the agent. As a response the market clearing price is returned, so the agent knows how to act, start producing (resp. consuming), or wait for the next event to happen and adjust its bid. The auctioneer searches for the equilibrium price and communicates a price back whenever the price changes significantly. It has been shown that the PowerMatcher agent concept works very well for virtual power plant control [4].

The same concept can also be used for coordination of heat flows. Huberman & Clearwater [5] have claimed success with a multi-agent system for the climate control of large buildings with many office rooms. Based on their work Ygge & Akkermans [6] proposed an alternative market design which was formulated as a quasi equation: “local information + market communication = global control”.

Before describing our test case some general remarks must be mentioned. A major difference between the electricity market and heat market is the need of scheduling. Whereas electricity is almost immediately available, with heat there is time delay. Although this is not discussed in this study, one of our goals is to find a design that incorporates a solution to this problem.

Apart from controlling the thermostat or complaining about comfort, until now the user has not been part of the building comfort system control strategy in offices, the energy consequences of the user behaviour are not accounted for. In this study the user is not part of the model. However, in the building management systems the user will be the central point as not the temperature in a room but the perception of temperature by the user will be input to construct the bid that expresses the demand of the system.

Also, Multi Agent systems as a technological solution for making renewable energy solutions should be natural, easy and intuitively understandable for architects and consultants. The challenge is to design agents in such a way, that they can be implemented straightforwardly with only little configuration and always be able to work together with other agents without knowing the others technical details and intelligence.

This study is not limited to control the comfort in buildings. The PowerMatcher can also be used for domestic dwellings. It is possible to use it straightforwardly for situations where in case of a black start the demand of heat pumps of the dwellings might exceed the maximum load of the local substation.

In this paper the PowerMatcher approach is applied to the regeneration of a seasonal heat/cold reservoir (aquifer).

THE NEED FOR AN AQUIFER BALANCE

Within the Flexergy project context it was observed that the demand for cold of a building representative for the Netherlands exceeds the demand for heat. As the cold is supplied by a heat pump connected to an aquifer, this results in a temperature raise of the aquifer, which deteriorates the reliability of future cold demand and has environmental consequences. The need for control of the aquifer energy balance was suggested, using Multi Agent climate control.

Table 1 contains the suppliers for heat and cold for an actual building at Utrecht. The heat pump is designed as the main supplier. District heating should only be used as a backup for days when the power needed (heat demand) is larger than the heat supplied by the heat pump. The air conditioning unit is located on the roof and offers the opportunity to load cold at hours where the outdoor temperature is still low, whereas there is also a cooling demand of the building. Such conditions generally occur during the morning and the late afternoon in autumn and spring.

	Main supplier	Backup	Flexible
Heat	Heat pump	District heating	
Cold	Heat pump		Air conditioning unit

Table 1: Suppliers for the energy of the building.

The technical design of the building will in near future incorporate a bypass from the air-conditioning unit to the heat pump, enabling the possibility of loading cool outdoor air without warm air entering the building. This offers the opportunity to load cold during the night when the outdoor temperature is low. Such operation is of course at the expense of the energy efficiency of the building, as electricity is consumed by the pumping devices. So the price of electricity, which is generally low during the night, plays an important role here.

DESIGN OF AQUIFER BALANCE STUDY

The design for an energy balance study is shown in figure 1. Note that there are two agents controlling the same device, the heat pump.

Two commodities

In this design discrimination can be made between the left part in figure 1 where the trading for the heat demand of the building occurs and the right part in figure 1 where the trading of the cold demand occurs. So, there are two markets and hence two separate PowerMatcher networks for two commodities: heat and cold, which are simultaneously trading. As can be seen the “District heating agent”, the “Heatpump Heat agent”, the “Heat auctioneer” and the “Hourly Heat demand agent” balance their supply and demand by trading heat.

Aquifer

Two types of building blocks are visible in figure 1, the rectangular one representing an agent, the parallelogram representing input data. Only the “Dynamic Aquifer state” is also output, here the heat pump agents can write the amount of energy they have consumed (heat) or have loaded (cold). The data in the “Building Data demand” is able to secure whether there is only heat or cold demanded, thus preventing the conflicting state where both the “Heatpump Cold agent” and the “Heatpump Heat agent” offer energy. However, the design offers the possibility to have a heat and cold demand as well. This is due to the possibility for the agents to write to the dynamic aquifer state whether the heat pump is already employed for either state. The agent's intelligence will guard that only supply will be offered when it is permitted by the value of this state (see below the explanation at figure 2).

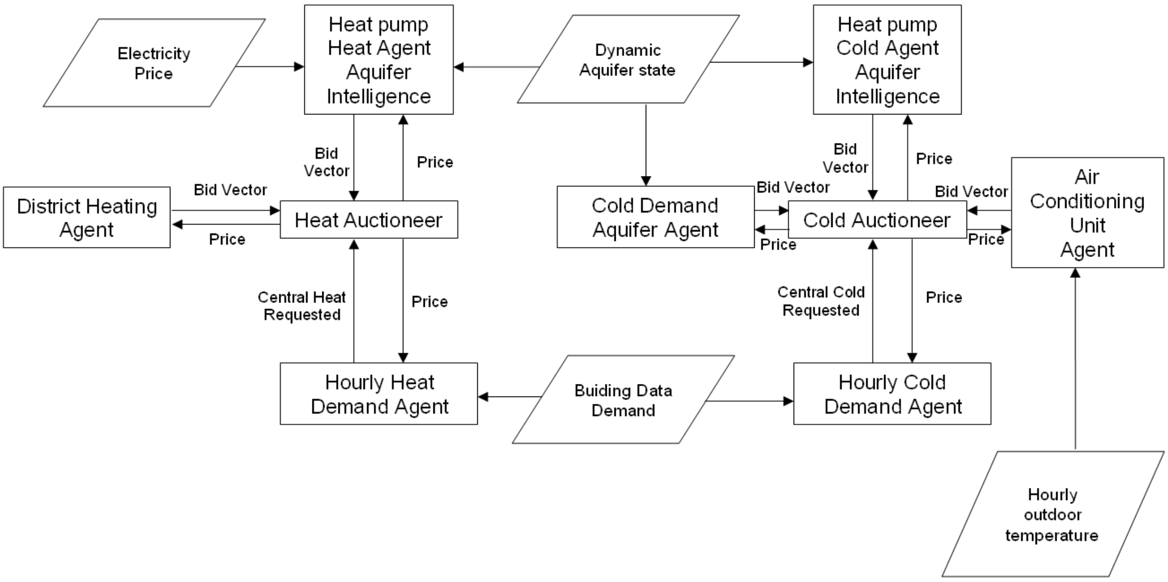

Figure 1: Design of a energy balance study for an aquifer using two commodities. The building data demand may secure whether only heat is demanded or cold and resp. in the left part allocation for heat takes place or in the right part allocation for cold takes place.

Demand Agents

The "Hourly Cold demand agent" for the cold commodity and the "Hourly Heat demand agent" for the heat commodity are agents which accept any price for their consumption, though still preferring the supplier offering power at the lowest price. So for heat, either the "Distict Heating agent" or the "Heatpump Heat agent" will supply. When the aquifer needs cold, the "Heatpump Heat agent" wants to deliver and the agent simply has to adjust its bid resulting in a price that is just below the price of the "District Heating agent".

Supply of cold to the building and the aquifer

The most interesting part of the design is in the network for the cold commodity. The heat pump can offer cold depending on the state of the aquifer. With the knowledge of historic data in the "Dynamic Aquifer state" it can calculate how much energy it still can offer, depending on the season and the expected price developments. The price is high when it concludes there is a small amount of energy left in the aquifer in view of the expected period to the maximum exhaust level. The "Air conditioning Unit Agent" can offer cold only at times when the outdoor temperature is low; at low price. This occurs mainly in the spring and autumn during early morning hours. The aim of course is to cool the building with outdoor air, avoiding further heating of the aquifer.

To elucidate the generation of bid curves figure 2 explains some situations. It shows the expected state of the aquifer during a year as a dashed line. In situation 1 and 2 the cold well of the aquifer contains too less energy related to the expected state of energy, so it is not willing to pay for production of cold. In situation 3 there is an excess of cold, so it is willing to offer cold at even a very low price.

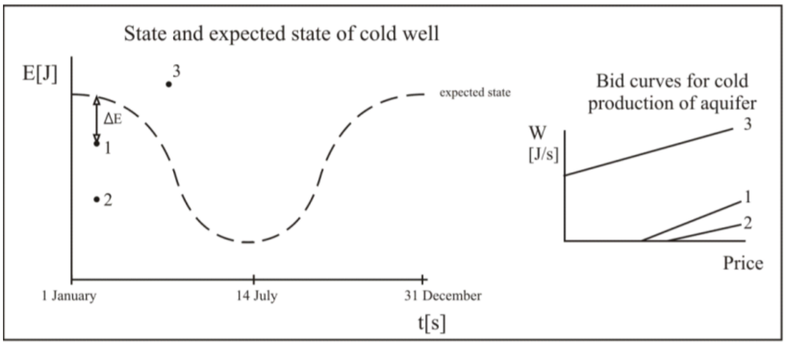

Figure 2: Generation of bid curves for discharge of the "Heat Pump Cold agent" dependent on the state and expected state of charged energy in the well.

Another way for the aquifer to retain its heat balance is introduced by an extra agent called "Cold Demand Aquifer Agent". Outside working hours, depending on the state of the aquifer the agent may demand cold. Especially during the night when outdoor temperatures are low it will demand cold, which is physically merely transferred to the aquifer. The price for such a demand will be low. Of course only the air conditioning unit should supply this cold. The intelligence of both the "Heatpump Cold Agent" and "Cold Demand Aquifer Agent" must be tuned to prevent the system from wasting energy with the heat pump pumping cold just to bring it back to the aquifer.

Some final remarks

For this simulation purpose it will be sufficient for the network to operate at a time schedule of one hour intervals, since the energy balance covers a year.

The "Building Data demand", which is just a static input file, is retrieved by processing the data from the building at Utrecht. From the original data of the building, containing the original actual energy production of the heat pump and the loaded as well as the unloaded energies at the aquifer, the actual heat or cold demand of the building during one year is calculated.

The prices at which the heat pump Agents and the air conditioning unit offer their energy depend also on the price of electricity. These prices can be read from a text file "Electricity Price", which can be generated from Dutch day-ahead electricity prices "APX prices".

DISCUSSION OF DESIGN OF AQUIFER BALANCE STUDY

The above design exemplifies the capability of the PowerMatcher to use two commodities in a simplified climate building control system. Two methods are possible in this design to load cold to the aquifer in order to retain the heat balance. One is possible when outdoor temperatures are low and the building has cooling demand. The other is possible at night when the outdoor temperature is low and the price of electricity is low as well.

This study might as well be extended using more commodities than just heat and cold. The heat pump e.g. buys electricity on an electricity market. So a heat pump agent trading merely on the heat market but also on the electricity market is more realistic if there are more electricity providers e.q. from renewable energy resources. This is technically possible with the PowerMatcher and where future research is further aimed at.

There is some limitation in the design of the aquifer balance study with respect to building climate control. This becomes most visible when the "Air Conditioning Unit Agent" is discussed. The building demand for cold is the highest during the summer in the afternoon. Then supply of cold by the “Air Conditioning Unit Agent” is not possible, as the outdoor temperature is generally high. When the PowerMatcher system is used without any forecasting or scheduling mechanism it represents a real-time market. The control is based on the current state of the process. One solution to solve this may be the introduction of an extra Option based market, where heat or cold can be bought in advance, likewise the way it is handled in the real world electricity market system. Options, then, provide the long term modelling view and the bids the real-time adjustment view. Another possibility is the use of an external computational program estimating the heat or cold demand for the next 24 hours and use combinatorial optimization [7] to get the optimal installation components production profile. This will be the input for agent based architecture for coordination of heating and cooling in buildings.

The purpose of the project is to prove the validity of the design must be proved through simulations. The intelligence of the agents will be useful in further developments of the heat matcher, based on the PowerMatcher.

ACKNOWLEDGEMENTS

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Coupling Thermal Simulation and Multi-Objective Optimization for Blind Controller Design

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Abstract

In this paper we present results of computational experiments where multi-objective algorithms were used to tune a controller for blind movements in a room of the LESO experimental building. The blind controller which is based on fuzzy logic was optimized not only in terms of energy consumption but also in terms of thermal comfort. The goal is to show saving potential for intelligent blind controller on a real world example rather than on tailored idealized *test rooms*. Therefore we combined a state of the art simulation program with a multi-objective evolutionary algorithms. It was found that with elementary control systems, like schedules for the lighting in a building, almost 40% of the energy could be saved. With the help of more advanced controllers the savings can be further increased.

1 Introduction

Energy-efficiency for buildings has always been a topic of interest, but with increasing energy costs the interest in this field is even growing. The main proportion of energy in the housing sector is used for space heating and cooling. Therefore, a good control of the blinds is important because they influence significantly the thermal profile of a building via heat gains, which are welcome during winter, and should be avoided during summer time. Since the control of these and other complex systems in a building are not trivial, automatic controllers for technical equipment are more and more used. On the other hand design tools and simulation software nowadays has reached a level of accuracy which allows proper analysis of the performance of such a controller. For assessing the saving potential we use one room of the LESO experimental building which we model in the IDA ICE building simulation software. This allows us to test different types of blind controller in a fast and exact manner. To point out the influence of blinds we compared the average transmitted power with closed and with open blinds and measured that at the south oriented LESO room average power amounts to *529 W* with opened blinds, and only to *49 W* with closed blinds.

In most of the publications it has been shown that their proposed controller in terms of energy consumption is superior to an on-off controlled counterpart [1, 2]. Unfortunately the complete saving potential has as far as we know not be evaluated. Our goal is on the one hand to optimize the energy efficiency of our controller and on the other hand introduce as a second objective a measurement for thermal comfort. This gives us the possibility to identify the complete saving potential and furthermore establish a trade-off between user-comfort and energy-efficiency. For a more realistic simulation we introduce stochastic models to handle occupancy, internal loads and artificial lighting which influences the energy consumption directly.

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Table 1: Specifications of the LESO building

Blind	External blind, total shading coefficient: 0.14, short wave shading coefficient 0.2, no influence on the U-Value
Room	Floor area of a room: $15.7m^2$, Room height: $2.8m$
External Wall	Facade wall (to South): $5.4m^2$, light wall ($1cm$ plaster panel + $12cm$ thermal insulation + $1cm$ wood)
Internal Wall	light partition wall ($1cm$ plaster panel + $4cm$ thermal insulation +$1cm$ plaster panel)
Floor	$15.7m^2$ ($1cm$ rubber coating + $6cm$ screed + $6cm$ thermal insulation + $25cm$ concrete slab)
Window	$3.8m^2$ net area (double glazing with IR coating, U-value: $1.4W/m^2K$)

2 Experimental setting

One room of the LESO building was modeled with IDA ICE according to its real dimensions. For the window we did not model the daylighting system of LESO [3] with an anidolic[2] and a normal window, instead we used just one window with the combined size of these two windows. As a simplifying assumption we consider that the building is not surrounded by other buildings that essentially block the sunlight. It is located in Lausanne, Switzerland at a latitude of 46.53°, longitude of 6.67° and altitude of $380m$.

2.1 Heating system

The room is equipped with one electric radiator which is positioned below the window and has a setpoint of 21 $°C$[3]. The LESO building is not equipped with an air conditioning unit but we introduced one in the simulation to measure the unpleasant heat gains in terms of energy.

2.2 Occupation

As each human being emits heat and pollutants, her/his presence directly changes the indoor environment. In addition to that, the interaction with electrical appliances as well as the use of artificial lighting increases the internal heat gains and the consumption of electricity. We use the stochastic models developed at LESO by Jessen Page [4] since they include the latest development in this field of study and are adaptable to our requirements. The Occupancy density in our flat is $10m^2$ net area/person with a metabolic rate of $1.2met$ and heat emissions of 70 W/person.

2.3 Artificial Lighting

How artificial lighting is used depends mostly on the occupant and whether there are automated schedules already installed in the building. To simulate the attitude towards the usage of artificial lighting we implemented the Lightswitch 2002 algorithm [5] which simulates the switching behavior of occupants. This gives us a realistic feeling of the periods where artificial lighting is most probable used and the blind settings can adapt according to this. The installed nominal power in the LESO room is 4.5 W/m^2 with an efficiency of 55.2 lm/W

3 Framework of the optimizer

When optimizing a system with many parameters where the relation between them may not simply be understood, conventional optimization techniques proved to be not always the best

[2] The upper window in each LESO room has an anidolic mirror to provide sufficient illumination during overcast skies as well as illuminate the back of each room.

[3] The temperature is kept via a closed loop control of the internal temperature.

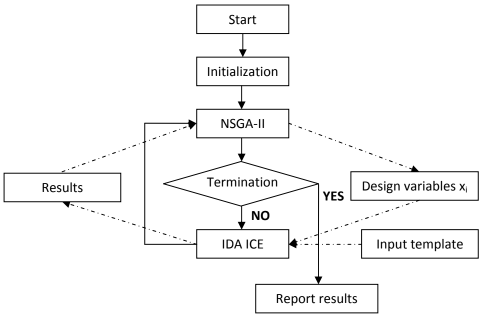


Figure 1: Operation diagram.

If *Season is winter* and	I_{glob} *is night* then $\alpha = x_1$
If *Season is winter* and	I_{glob} *is high* then $\alpha = x_2$
If *Season is winter* and	I_{glob} *is mid* then $\alpha = x_3$
If *Season is winter* and	I_{glob} *is low* then $\alpha = x_4$
If *Season is summer* and	I_{glob} *is night* then $\alpha = x_5$
If *Season is summer* and	I_{glob} *is high* then $\alpha = x_6$
If *Season is summer* and	I_{glob} *is mid* then $\alpha = x_7$
If *Season is summer* and	I_{glob} *is low* then $\alpha = x_8$

Figure 2: The fuzzy rules for the controller with the parameter vector $\mathbf{x}$ $(x_1, ...x_8)$.

choice. Since in this case the results for the fitness function are provided by an external simulation program which acts like a black box, genetic algorithms seemed well suited. Given that we will cope with two objectives, the energy consumption and the thermal comfort, a multi-objective evolutionary algorithms (MOEA) will be used for the optimization of the blind controller.

3.1 Multi-objective optimization

Like in many real world problems we deal with two objectives which contradict each other and therefore we cannot identify 'one' optimal solution. Hence for the decision making it is important to know the trade-off between the solutions by computing the pareto-optimal frontier. For that task in recent years a variety of genetic strategies have been proposed (for an overview see for instance [6, 7]). Let us consider a typical multi-objective optimization problem:

$$\begin{array}{lll} \underset{(\mathbf{x})}{\text{Minimize}} & (f_1(\mathbf{x}), \ldots, (f_M(\mathbf{x})), & \\ \text{Subject to} & g_k(\mathbf{x}) \geq 0, & k = 1, 2, \ldots, K, \\ & \mathbf{X}^{(L)} \leq \mathbf{x} \leq \mathbf{X}^{(U)} & \end{array} \tag{1}$$

Here f_m are the objective functions, g_k the constraints and $\mathbf{X}^{(L)}$,$\mathbf{X}^{(U)}$ the bounds for the parameter vector $\mathbf{x}$. For finding the reliable frontier NSGA-II has been applied.

3.2 Layout of the optimization

To perform the optimization we combined two independent programs. The NSGA-II [8] optimization algorithm and the IDA ICE 3.0 (IDA Indoor Climate and Energy) program [9, 10]. IDA ICE is a dynamic building simulation program that makes simultaneous performance assessments of all parts of the building: energy consumption, light, shape, envelop glazing, HVAC, systems, controls, indoor air quality, etc. The IDA ICE simulation tool is iteratively called by the NSGA-II via batch mode whenever there is a evaluation of the fitness function needed. The results from the optimization are given back to NSGA-II which is evaluating the fitness functions and changing the design variables according to its crossover and mutation operators. With the new design parameters the IDA ICE is called again until termination criteria is fulfilled. The operation diagram is given in Fig. 1.

According to [11] there are two main ways of adapting fuzzy systems with GA's. First by generating rule sets and second by changing parameters in the membership functions. Because the fuzzy rules are based on a real world tested controller [12] we apply the second possibility. Generally the parameters of the membership functions are used for modification. But since we use a Sugeno[13] type fuzzy inference and the outputs (x_i) are crisply defined, only these are considered for the adaption. Within these controller attention is mostly given to thermal aspects, the rules are shown in Figure 2.

I_{glob} is the Global vertical illuminance in [lux] on the window plane and *Season* the current outside temperature in [$°C$]. The output values α correlate directly with the blind setting, where $\alpha = 0$ means blind is closed and $\alpha = 1$ stands for blind is open. Since we measure the illuminance at different positions we get different blind movements for every window.

4 Objectives of the optimization

The fuzzy-logic controller is responsible for attempting optimal use of the blinds during occupancy and without occupancy. During that time we want to optimize the energy consumption and the thermal comfort in the rooms. Of course blinds are also affecting heavily the visual comfort. To optimize a shading algorithm it is substantial to quantify objectively the visual discomfort. The two main cause of visual discomfort are glare and insufficient illuminance where glare is, by far, the more difficult problem of these two. To evaluate every blind position for glare is not in the scope of this work and is especially for residential buildings difficult. The level of illuminance is included indirectly in the optimization: If the illuminance falls below 300 lux the electric lighting is switched on and we consume energy which will negatively influence the first objective.

4.1 Energy efficiency

Objective one is the cumulated energy which has been used for the HVAC and the artificial lighting:

$$f_1(\mathbf{x}) = \int_T (P_H + P_L)\ dt \tag{2}$$

Where P_H is the Power for heating and cooling, P_L the power of artificial lighting, and T the duration.

4.2 Thermal comfort

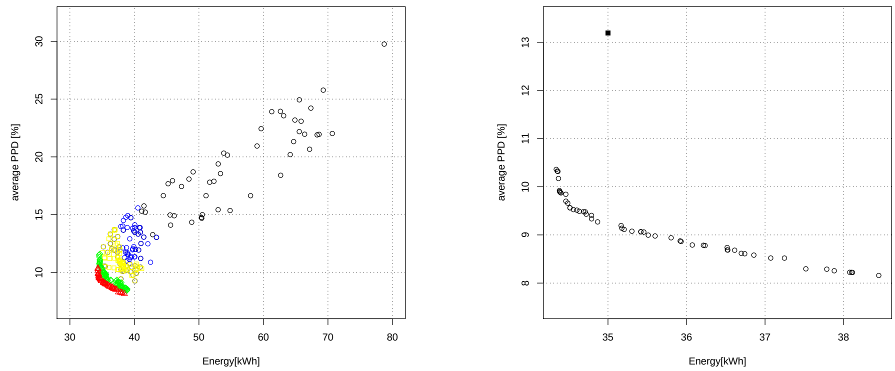
The main purpose of installed heating and air-conditioning systems is to provide an environment that does not impair performance and health of the occupants. In our study we concentrate on satisfying the general thermal comfort so as an objective for quantifying that the PPD [14] is in our eyes a suitable measure. The occupants do not change their clothing (0.5 CLO) during the optimization. Although this may not reflect real behavior, it makes the results of the simulation comparable and does not influence the procedure we present for optimizing a blind controller.

$$f_2(\mathbf{x}) = \frac{\int_T PPD dt}{T} \tag{3}$$

5 Results

We run the NSGA-II for 80 generations with a population size of 80. One evaluation of the fitness function in IDA ICE takes about 15 s on a 3.00 GHz Pentium PC which caused an execution time of about 27h. The SBX recombination probability is set to 0.9 and distribution index of 15, the mutation probability is 0.1 with a distribution index of 20 [6]. The simulation covers seven cold days 14 intermediate and five warm days. These synthetic periods are chosen to cover all kind of climate conditions and keeping the simulation time manageable. To take into account the internal heat reservoir the dynamic simulation repeats the first 24h until all conditions have balanced out and only after that starts the main simulation. Although this takes computational time it increases accuracy significantly.

To get comparable results first we analyze the parameters which have been originally proposed and also the two extreme cases: blinds are always lowered, blinds are always open. The



(a) Developing of the solutions during the optimization. The initial population is shown in black, the second in blue, the third in yellow, the 10^{th} in green and the final population in red which is also shown in Figure 3(b).

(b) Pareto front of the LESO optimization with a population of 80 and 80 iterations. The case L_{ref} is shown as a filled quadrat, L_{open} and L_{closed} are not shown because of scale.

Figure 3: Pareto-fronts

Table 2: Results separated by periods.

Setting	$f_1^{winter}[kWh]$	$f_1^{intermediate}[kWh]$	$f_1^{summer}[kWh]$	$f_2^{winter}[\%]$	$f_2^{intermediate}[\%]$	$f_2^{summer}[\%]$
L_{open}	31.15	36.20	16.11	11.60	8.27	5.98
L_{closed}	39.86	17.12	0.59	8.30	43.78	13.14
L_{ref}	33.02	1.57	0.40	13.47	15.09	9.11
L_{best}^{f1}	33.30	0.96	0.09	9.97	12.38	6.71
L_{best}^{f2}	31.16	7.14	0.00	7.84	9.33	6.09

pareto-front of the best population is shown in Figure 3(b) together with L_{ref} the solution with the reference setting, L_{open} and L_{closed} are not shown because of the scale.

In Table 3(a) we show how the optimization is advancing from population to population and converging towards the pareto-front. In the first generations the population is moving fast towards the optimal pareto-front whereas at the end the movement is slowing down heavily. With this knowledge the number of generations for fututre optimizations can be estimated to avoid useless iterations.

The best setting in terms of energy consumption is L_{best}^{f1} which consumed 34.34 $[kWh]$ and has an average PPD of 10.36%. One can see that L_{ref} is relatively close to the ideal energy consumption but is lacking average PPD. On the other hand L_{best}^{f2} which is the best setting for objective f_2 (average PPD) does not improve average PPD thus much, creating a flat trade-off between the two objectives.

In Table 2 we show how energy consumption (objective f_1) is distributed over the periods. One can see that the minimum energy consumption for the winter can be reached with leaving the blinds open all the time. This makes sense, since the heat gains are maximized and the blinds have no influence on the insulation. The high energy consumption during the winter periods are due to low radiation in the winter period which can not be compensated by any blind controller. In the intermediate and summer case, one can better see the impact of a good controller. The energy consumption in L_{best}^{f1} is reduced by 98% in intermediate and by 99% in summer period compared to L_{open}. By comparing L_{best}^{f1} and L_{ref} there is still an improvement of 39% in intermediate and 77% in summer period. It should be mentioned again, that the occupant is not adapting himself in terms of clothing, for that reason the PPD reaches high values. With a temperature of 21 $°C$, a clothing of 0.5 CLO, and an activity of 1.2 MET the

PMV reaches around -1.5, which refers to a PPD of around 50%.

6 Conclusions and future work

In this paper we proposed a combination of a high level simulation program and an optimizer based on evolutionary algorithms. We showed that the combination is capable of finding solutions which are significantly better than our reference case. Due to detailed modeling the results can be transfered directly into real world application. The energy savings we found show the necessity of optimization in this field and the superior of the found solutions in terms of energy and thermal comfort to the *human made* counterpart. Also the results would only fit for that special setup, the approach is capable of really assessing the saving potential while keeping in mind the comfort of the occupants. This makes it possible to benchmark different systems and make a statement about the theoretical saving potential of them. One can also compare different types of controllers and may get a combined pareto-front consisting of the best results by different systems. Then, according to the preferences of the user, the most suitable controller can be chosen. For the design of a new controller, the data of the parameter, can be used to identify the critical factors more easily.

6.1 Future work

For future work we want to investigate adequate objective functions for visual and thermal comfort of human beings, since this is the most crucial point for the acceptance of controllers. Furthermore, criteria for blind controller can be investigated with this approach and help to develop an adaptable blind controller.

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INFORMATION MODELLING AND SOFTWARE TOOLS FOR ENERGY MANAGEMENT IN BUILDINGS

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ABSTRACT

Current information modelling and software tools in buildings are deficient in their ability to integrate and process building energy data to deliver actionable information to support decision making process at an Energy Management (EM) level. Therefore, this paper introduces two software tools for the creation of sophisticated energy consumption aggregation for the improvement of Energy Efficiency (EE) in buildings and the optimization of the Building Energy Management (BEM) process. These tools are: Data Warehouse (DW) technology and Data Mining (DM) techniques. Furthermore, this paper describes the strategy of their inclusion into the (BEM) field, followed by an explanation of how EM benefits from this usage. It also details energy data aggregations[1] and their application into the EM area.

INTRODUCTION

There is a great interest in improving energy consumption in buildings considering the increasing prices, and the global goal of reducing CO^2 output. Energy Management (EM) in buildings is one of the very actively growing sectors of services with a long-term demand for efficient tools and strategies directed onto the effective usage of energy. This is in order to maintain acceptable tenant comfort, reduced energy consumption and the cost of buildings maintenance. The focus of proficient Building Energy Management[2] (BEM) is concentrated on the important interaction between the building as a structure and the technical facilities, so as one of the main goals there would be achievements in the maximum possible building's efficiency with minimum costs. Furthermore, there is a need to find the optimal balance between building occupant's comfort and the cost of the energy bill.

The comfort of building users, from an energy management perspective, consists of several important components which affect the occupants comfort in a particular room. These components include levels of illumination, temperature, air-humidity, a consistently low level of CO2 and other pollutants and particles in the atmosphere within the buildings. The best possible integration of regenerative energies on the entire life cycle of a building should be also taken into consideration.

[1] Data aggregation is information is gathered and expressed in a summary form, for purposes such as statistical analysis (cf. [2])

[2] BEM is the effective and efficient usage of energy to achieve a higher level of energy-efficient building operation (cf. [1], p.1).

There are several National (e.g. Irish Building Standards) and International buildings occupants comfort standards (e.g. ASHRAE, CIBSE and ISO) at present. These could be taken as a background to obtain the optimal value of building occupant comfort components, so that the building manager cannot just reduce energy consumption by minimising the workload of Heating, Ventilation, Air Conditioning (HVAC) systems. Optimization of energy-efficient building management should be done through optimised monitoring and tracking of the energy consumption and/or production. This will help to perform on-time and predictive adjustment of building climate-control equipment in order to achieve comfort to the occupants internal environmental conditions.

Currently, the main problem in the “Energy and Facility Management” domain is the unavailability of consistent and complete building energy data. Traditional Database Management Systems (DBMS) are used to store building energy data. These DBMS lack the ability to create data aggregations and do not support the analysis of building energy data to deliver reports and actionable information (cf. [3], p.29). Actionable information here means information which leads to action or starts a chain of actions and reactions of people and equipment. This information is used for manager-decision support in energy-managing areas and optimisation of energy consumption while maintaining an acceptable user comfort.

Moreover, the energy data aggregations become very complex when several different organizations (e.g. groups, departments, different companies) occupy one building and each of these groups use different electrical equipment that vary in energy consumption and/or production. If there is a restriction on energy budgets for these groups, management needs to have energy data aggregation (i.e. per organization, or per rooms, or per groups in one room within defined time-scale) to split the bill proportionally to the usage of energy between these groups. This task seems to be difficult to perform because at the present most of the current monitoring tools do not provide sophisticated data aggregation and advanced analysis features, such as energy consumption aggregations per specific location in a given period or point of time.

To perform the procedures of efficient energy control and distribution, managers of the building should be able to apply modern ICT tools in order to aggregate the data of energy consumption for further analysis, evaluation and corrective measures in any time-frame they require.

Thus, this paper introduces two information tools. First, it provides EM with an easy overview of building energy consumption using DW technology. Second, it provides advance features, using DM, to evaluate the energy efficiency of building operation. It presents a DM model which automatically identifies comfort rooms with abnormal conditions in order to evaluate energy systems efficiency.

Therefore, Data Warehouse (DW) technology is introduced to manage and analyse building energy data in an integrated way (cf. [4]), to facilitate the use of modern analysis approaches such as Data Mining (DM) techniques (cf. [5], p.35), and to discover previously unknown energy efficiency characteristics, relationships, dependencies, or trends (cf. [6], p.744).

DEMONSTRATION OF USE CASE

This paper uses the Environmental Research Institute[3] (ERI) as an energy-efficient building demonstrator. The ERI building is used by multiple research groups as a “Living Laboratory” to demonstrate the smart building concepts. Several requirements are available for EM there to help optimising energy usage while maintaining the steady occupant comfort. These requirements include identification of locations with uncomfortable conditions (i.e. abnormal temperature, humidity, CO2), and the monitoring of HVAC system efficiency, but is not limited to simple overview of energy consumption.

An example of DW and DM usage would be a case when an energy manager needs to analyse the energy consumption of building. He needs to know when (time) the high energy usage is occurring, at which location within the building, and by whom (organisation).

DATA WAREHOUSE FOR HIGH BUILDING PERFORMANCE

A DW is designed to support data analysis. It contains historical data derived from transaction data. It separates the analysis workload from the transaction workload. This helps to maintain historical records and achieve better understanding of the business processes.

DW technology has been introduced to the construction management domain to improve the management of historical data (cf. [7, 8]). Publications report about the development of a module designed to help the construction manager during the construction process (cf. [9]) or to support the selection of the most appropriate site for development (cf. [10]). DW technology has been also been applied to support the exchange of documents amongst multiple parties in construction projects (cf. [11]).

DATA WAREHOUSE FOR ENERGY-EFFICIENT BUILDING OPERATION

DW designed to store large amounts of data to deliver data aggregations, reports, and actionable information. The multi-dimensional data analysis concept and DW techniques for building performance are further detailed in Ahmed et al. (2009, cf. [10]).

Figure 1 below shows the Graphical User Interface (GUI) implemented for the ERI DW. The three available energy consumption data categories are: (1) electricity (main power board meter), (2) natural gas (boiler + labs meters) and (3) water (mains water meter). They are selectable at the bottom of the screen. The operator can quickly get an overview of the building’s energy consumption from the top level (several year per building), down to detailed levels (hourly per room) by narrowing his query with the dimensions. The dimensions can be specified on the left of the panel with building and zone (rooms) options which belong to the location dimension. Organisation and equipment represent individual dimensions. The calendar allows specifying the time dimension from years, through month, to single days. If the operator modifies his query, the data warehouse responses fast with results.

[3] ERI, Cork, Ireland, built in 2002.

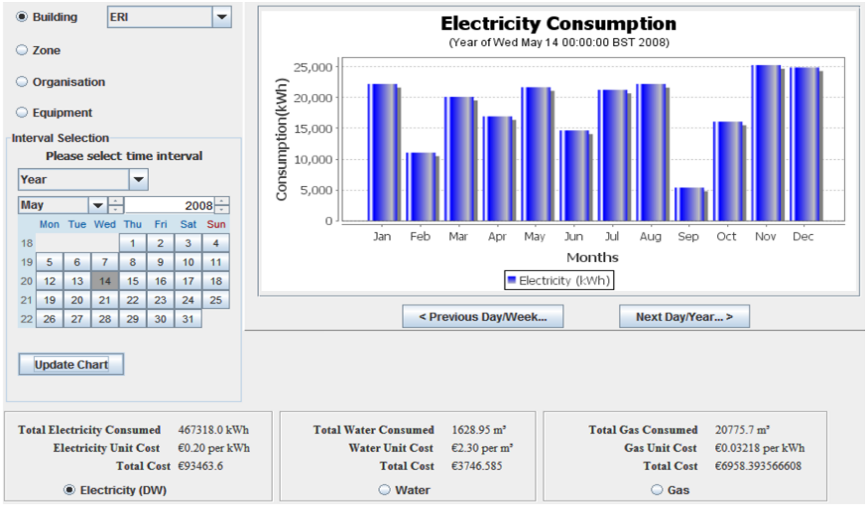


Figure 1. DW Graphical User Interface

DATA MINING FOR ENERGY MANAGEMENT

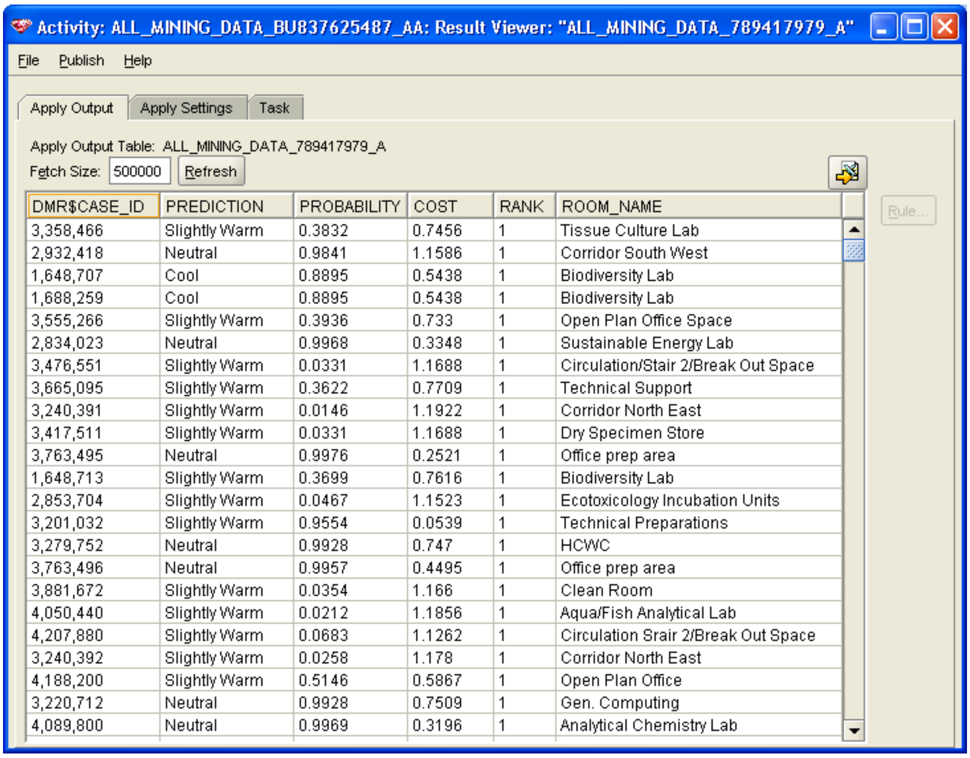
Knowledge Discovery and Data Mining (KDD) is extracting or mining knowledge from large amounts of data (cf. [5], p. 5). That is the implicit useful knowledge (cf. [12]) used to address specific business problem.

In buildings and energy fields, data mining is used in modern building automation (cf. [13]) to deal with different types of demands in buildings. It is also introduced to estimate energy consumption time series in residential buildings (cf. [14]), and to predict energy consumption in tropical regions (cf. [15]). Characterization of the electric energy consumer was acquired using data mining (cf. [16]). An approach to discover hidden patterns in a power company data base to solve power system operational problems was accomplished (cf. [17]) by utilizing data mining.

In energy management we introduce the DM tool to evaluate building energy efficiency. The approach was based on an analysis of room's thermal comfort by identifying awkward rooms. The model classifies rooms based on their thermal comfort into hot, warm, slightly warm, neutral, slightly cool, cool, and cold. These comfort values have been calculated depending on the Predicted Mean Vote[4] (PMV), which is based on the temperature, humidity, air velocity, occupants clothing, etc. Further details of the model design can be found at Ahmed et al. (cf. [18]).

At the present in the ERI, the DM model is designed to predict occupant thermal comfort levels using room temperature and outdoor weather conditions in order to evaluate the building energy efficiency. The model is feasible as it uses the minimal number of sensors (i.e. one temperature sensor per room) to evaluate system efficiency and predict room comfort in order to keep the evaluation and prediction process as low in cost as possible. A sample table output is shown below. The output can be formatted to meet specific EM requirements.

[4] PMV is a standard of ISO 7730 (2005)


Activity: ALL_MINING_DATA_BU837625487_AA: Result Viewer: "ALL_MINING_DATA_789417979_A"

File Publish Help

Apply Output | Apply Settings | Task

Apply Output Table: ALL_MINING_DATA_789417979_A

Fetch Size: 500000 Refresh

Rule...

DMR$CASE_ID	PREDICTION	PROBABILITY	COST	RANK	ROOM_NAME
3,358,466	Slightly Warm	0.3832	0.7456	1	Tissue Culture Lab
2,932,418	Neutral	0.9841	1.1586	1	Corridor South West
1,648,707	Cool	0.8895	0.5438	1	Biodiversity Lab
1,688,259	Cool	0.8895	0.5438	1	Biodiversity Lab
3,555,266	Slightly Warm	0.3936	0.733	1	Open Plan Office Space
2,834,023	Neutral	0.9968	0.3348	1	Sustainable Energy Lab
3,476,551	Slightly Warm	0.0331	1.1688	1	Circulation/Stair 2/Break Out Space
3,665,095	Slightly Warm	0.3622	0.7709	1	Technical Support
3,240,391	Slightly Warm	0.0146	1.1922	1	Corridor North East
3,417,511	Slightly Warm	0.0331	1.1688	1	Dry Specimen Store
3,763,495	Neutral	0.9976	0.2521	1	Office prep area
1,648,713	Slightly Warm	0.3699	0.7616	1	Biodiversity Lab
2,853,704	Slightly Warm	0.0467	1.1523	1	Ecotoxicology Incubation Units
3,201,032	Slightly Warm	0.9554	0.0539	1	Technical Preparations
3,279,752	Neutral	0.9928	0.747	1	HCWC
3,763,496	Neutral	0.9957	0.4495	1	Office prep area
3,881,672	Slightly Warm	0.0354	1.166	1	Clean Room
4,050,440	Slightly Warm	0.0212	1.1856	1	Aqua/Fish Analytical Lab
4,207,880	Slightly Warm	0.0683	1.1262	1	Circulation Srair 2/Break Out Space
3,240,392	Slightly Warm	0.0258	1.178	1	Corridor North East
4,188,200	Slightly Warm	0.5146	0.5867	1	Open Plan Office
3,220,712	Neutral	0.9928	0.7509	1	Gen. Computing
4,089,800	Neutral	0.9969	0.3196	1	Analytical Chemistry Lab

Figure 2. The results of Oracle DM model application

The sample table shows each row with the: (1) Identifier (CASE_ID), (2) PREDICTION of the most likely class, (3) the PROBABILITY of the right guess, (4) the COST of incorrect prediction, (4) the RANK to categorize predictions and (5) the ROOM_NAME to ease readability.

The model is able to make a correct prediction with average probabilities higher than 0.99 for the "Neutral" label when applied to the scoring data, see Figure 2. Such a prediction is an indication of high energy system efficiency. A high probability value of the "Cool" label such as 0.88 is an interesting case as it indicates a fault in the energy system. As the heating system is not heating this room to the occupants' preference specified settings, this case needs to be investigated. Another prediction of the "Slightly Warm" label with a probability of 0.03 is not an interesting case as the probability is too low, and it indicates that the energy system is efficient.

The created model can be applied to any data in the same structure and format to predict the comfort class.

CONCLUSION

The data warehouse approach and the data mining model introduced are required to achieve a higher level of energy management efficiency. The DW provides a single repository to integrate energy data, creates reports, actionable information, and facilitate the integration of DM to discover previously unknown energy efficiency characteristics, relationships, dependencies, or trends.

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IMPROVING THERMAL COMFORT IN OFFICE PRACTICE: BIOMIMETIC COMFORT PROFILES

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ABSTRACT

In the office building of Kropman in Utrecht a number of measurements were done, by means of NEN-EN-ISO 7726, to determine thermal comfort in the office building. Also two enquiries were held to determine the thermal comfort perception of the employees. The evaluation of the measurements and enquiries led to a number of adaptations that have been made to the parameter setting of the climate installation which resulted in a better thermal comfort against a lower energy usage. Instead of central power generation we looked into more decentralized system solutions. Also we took the individual preferences of the occupants, their biomimetic profiles as a starting point. The personal demand is leading in the process control of the indoor climate system.

INTRODUCTION

The productivity of an employee stands in direct relation with his or here comfort perception. Comfort depends on holistic and deterministic factors. The holistic factors, such as mental state, surroundings and colleagues can't be influenced. The deterministic factors however, such as air temperature, air speed and relative humidity, can be influenced. The desired indoor climate depends on the outdoor climate. Users adapt their clothing to the outdoor situation which leads to a different desired indoor climate because of the adaptation of clothing. This adaptation has a positive impact on the energy usage of the HVAC installation. In the summer period you can offer a higher and in the winter a lower indoor temperature while the comfort level remains preserved. Besides these aspects it is good to look into biomimicry or imitation of nature as a basis for new process control strategies. Normally we presume a constant thermal comfort profile. But humans like all living things in nature have a day rhythm which changes during the day, however normally this biomimicritical aspect is not considered.

METHOD

The comfort control is based on the PMV-index. The most important research on thermal comfort is done by P. Fanger in the early nineteen-seventies [1]. The Predicted Mean Vote model (PMV) is the basis of the most important indoor climate standards in Europe, ISO 7730-2005 [2] and America, ANSI/ ASHRAE Standard 55-2004 [3, 4]. This model includes thermo physiological properties of the human, such as sweat production and heat resistance of the skin. So individual characteristics and clothing are important aspects [5]. The thermal environment in an office is not always optimal from an energy saving and occupant satisfaction perspective [6]. For example some occupants feel cold in an office while an air temperature is controlled based on thermal standards such as PMV and ISO 7730 [6]. The main reason of this issue is that air-conditioning systems are controlled without taking the occupants' needs into account. This was so pointed out by field surveys such as Bordas and Leaman [7, 8]. With measurements and calculations, the PMV (Predicted Mean Vote) of Fanger can be determined. This stands in direct relation with the number of dissatisfied people in an office building because of the indoor climate. The requirement of the user concerning the indoor climate depends on the expectation on the thermal comfort in the office building. The expectations of a building with a complete manageable indoor climate, a HVAC installation, are higher than in a building without a HVAC installation. Because of this an office building with HVAC installation has stricter requirements concerning the indoor climate. This results in a smaller band width of the indoor climate because of the thermal sensation of the employees. Further we look into the individual comfort preferences.

Human thermal comfort is affected by a number of parameters, according to Franger's comfort equation, and the respective standard EN ISO 7730 [2]. Underlying the resulting predicted mean vote (PMV) or the predicted percentage dissatisfied (PPD) as indices for thermal comfort quality a comfortable ranges of the six model parameters, air temperature, radiant temperature relative air velocity, humidity, clothing and activity, are calculated. Several measurements according to NEN-EN-ISO 7726 [9] were done in an office to determine the personal thermal comfort of occupants in relation to the six above mentioned parameters. Also twice a questionnaire was held to get a picture of the perceived thermal comfort of the occupants. The results of measurements and questionnaires were used to adjust some of the parameter settings. End-users are normally represented in the design of a HVAC system by Fanger's comfort model [1] which model predicts user's evaluations of the indoor climate in a building. A increasing volume of research shows that dynamic thermal perception and adaptive response is significant for occupants' comfort [10]. While Fanger is criticized for using the 'standard' occupant with defined clothing and activity level, most adaptive comfort research uses the 'statistical' occupant under static conditions with statistical clothing and activity levels derived from the statistical analysis in large databases. Neither of them are the 'individual' occupants were the specific environments is design for [10]. While clothing of men in office buildings during the year only slightly changes but depends on their own preference, the women dress more according to the outdoor climate. Experiments show that the clo-value can even be 0.3 for women in summer [11]. During our experiments we found out that in one office, the clo-value can vary between 0.3 and 0.8 clo for different people during the same day. In Figure 1 the influence is presented of the adjustment of clothing at constant indoor temperature and activity level. The clothing aspect is more elaborated in [14].

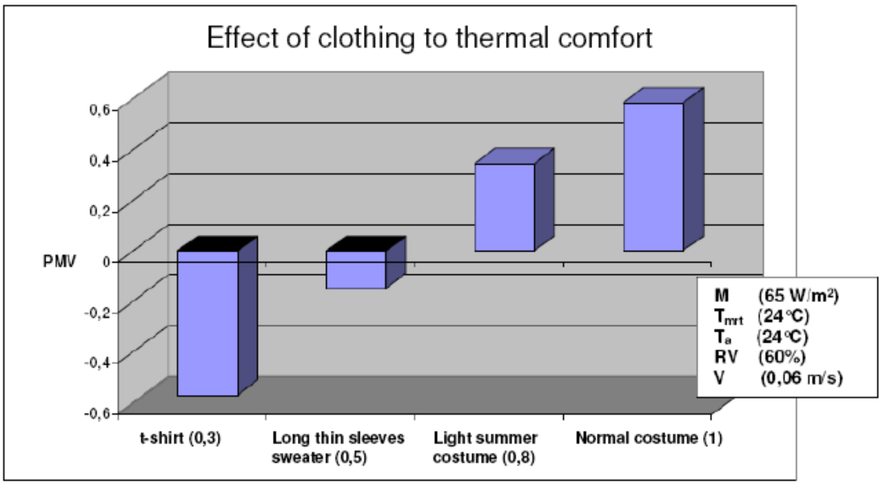

Figure 1: Effect of variations of clothing to thermal comfort in a constant situation [13]

Measurements

In order to obtain objective information about the performance of comfort systems with respect to thermal comfort measurements were conducted. The measurements were conducted during minimal 1 week. The measurements include measurements of air temperature, radiant temperature, relative humidity and air velocity and were logged every 6 minutes.

Questionnaire

Users opinion is of great importance. First of all, perception of indoor climate is important for determining whether users are comfortable. Secondly it is important how the interaction with the system is experienced. The users were asked to rate different aspects of the comfort. Distinction was made between summer and winter. The questionnaire used is based on the validated list which has been developed in the Health Optimisation Protocol for Energy-efficient Buildings research [14] and uses the 7 point thermal sensation scale of ASHRAE.

RESULTS

During the period of 29-06-2007 till 27-08-2007 the PMV was determined based on measurements of the different parameters in de office. Also in this period a first questionnaire was held. Figure 3 shows that all aspects are perceived on average from sufficient to good, which is of course a rather good result compared with the normal office situation in the Netherlands The calculated PMV of the office building over the period from 29-06-2007 till 20-07-2007 is given in figure 2. Here an Iclo of 0,4 is used, as it represent the actual clothing situation of the occupants. The thermal comfort according to the theory of Fanger, the PMV, is rather low. The HVAC system of the office building has a fixed set-point for the room temperatures. This setpoint is the same over the whole season, thus for summer and winter, and is given in the Dutch standard design brief value for the Iclo of 0,8 [clo]. In figure 2 is presented the effect of different clothing so different Iclo values have for individual adjustment of the PMV calculations. Here the actual value of a person with Iclo 0,4 is taken instead of the Dutch standard design brief value of Iclo 0,8. This leads to a recalculated PMV distribution around the ideal “zero”, see Figure 2.

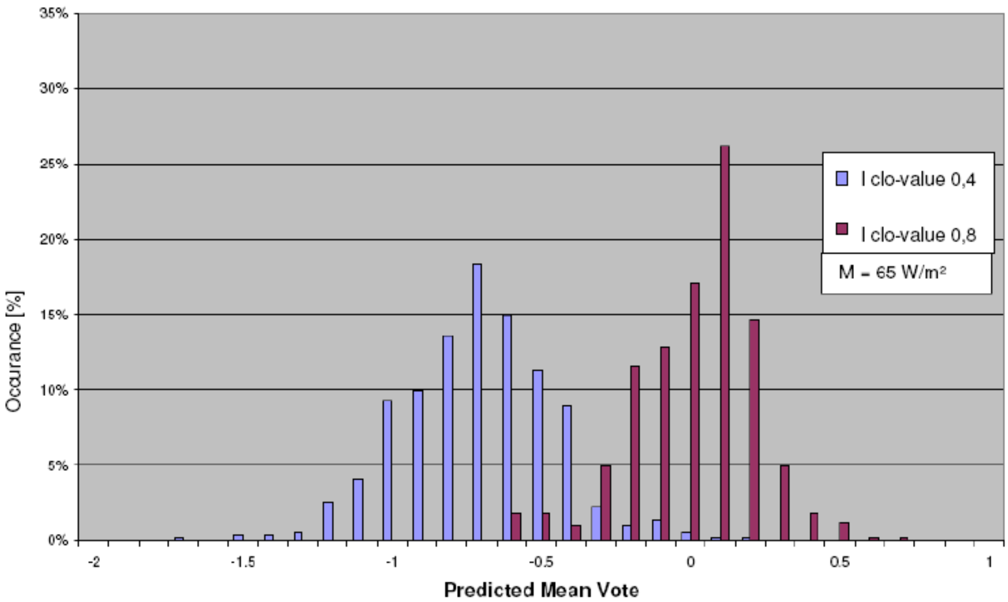

Figure 2: Calculated PMV based on the measurements for the actual Iclo of 0,4 and the recalculated PMV for the Iclo of 0,8 from the Dutch standard design brief specifications [13]

So here you see the influence of the clothing behaviour in relation to the thermal comfort. As we wanted to look into more detail to the individual perceived thermal comfort by occupants during the day, we first had to check whether the measured thermal comfort is in good correlation with the comfort perceived by the occupants. In this questionnaires 32 occupants participated and the results shows a good correlation between the measured and the perceived thermal comfort see, Figure 3.

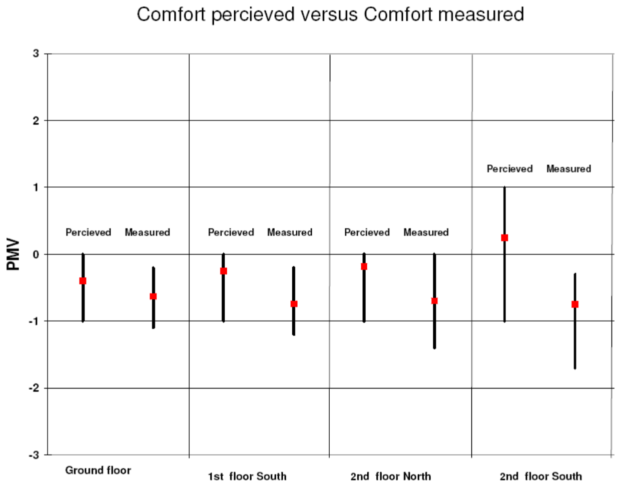

Figure 3: Comparison measured and perceived thermal comfort[13]

Now we knew that the perceived thermal comfort by the occupants is quite accurate, we looked in the individual comfort differences during the day. In July 2007 during each hour 18 different persons were asked about their perceived thermal comfort. We used the results of the questionnaires to look into the different individual thermal comfort preference during the day. As the thermal conditions were stable we could actual distinguish different preferred comfort profiles. In this stage of the research it is not our intention to have absolute comfort profiles, we were mainly interested in if differences occur during the day and if there were differences between individuals. The results show quite remarkable difference between people and also differences during the day, see Figure 4.

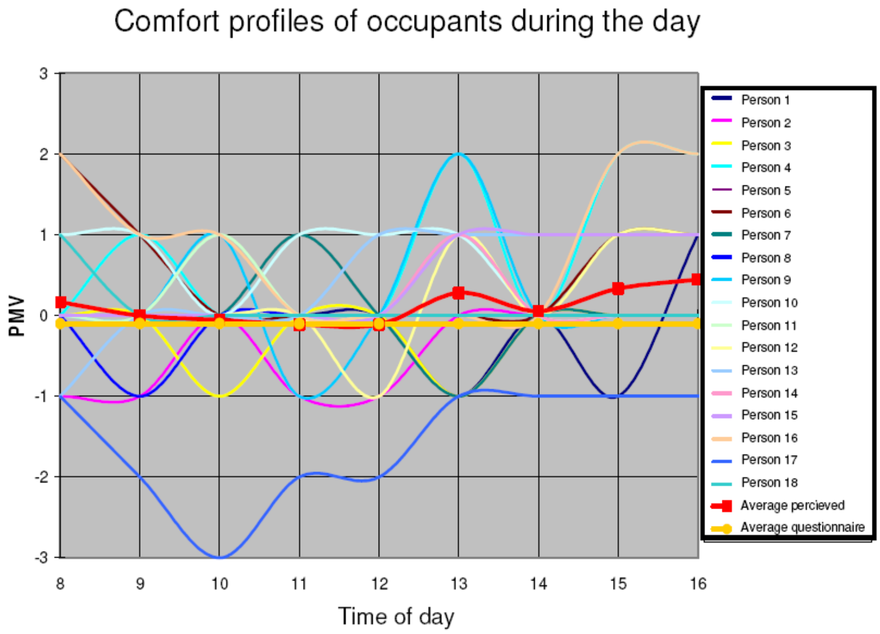

Figure 4: Different comfort profiles of 18 persons during the day[13]

DISCUSSION

It is well-known that there is a diurnal cycle of body temperature in man. Body temperature rises in the morning to reach the maximum level in the afternoon and falls in the evening. This circadian variation of body temperature is considered to be driven by the biological clock and circadian variation of thermos regulatory responses such as heat production, heat loss, heat and cold defences have been reported in relation to this variation [16]. Internal and external factors contribute to resting core temperature and affect thermoregulation. Still a robust circadian rhythm exists, implying that the body is in ‘‘heat-gain’’ or ‘‘heat-loss’’ modes at different times during the 24h.

Models of thermoregulation must take into account the influences of circadian rhythms, independent of environmental factors. The circadian variation in body temperature persists under conditions of light and moderate exercise [17]. However in the research of Fanger [18] it was concluded that although the rectal temperature and the mean skin temperature were slightly higher in the evening than in the morning the subjects did not prefer an ambient temperature which was different from that in the morning, indicating that the same thermal comfort conditions can be used from morning to evening [18].

Still in a longitudinal field study of thermal comfort in an office building in Sydney, Australia a total of 532 morning/afternoon data pairs were collected including details of metabolic activity over the preceding hour were obtained [19]. This revealed that for 78 percent of respondents the estimate for the afternoon different from that obtained in the morning. Mean values were, however, constant at 1.2 met during the whole period of the study [19]. ISO rules for estimation of comfort temperature indicate a change of 0.1 met will produce a change equivalent to a temperature change of 1°C and a change of 0.4 met will cause a sensation change of at least 2.5°C. It is concluded that the value of 1.2 met for a large group of office workers is robust; but that random individual variability caused by the changing demands of the job and possibly lunchtime recreation may be an unrecognised and difficult to diagnose cause of much of the complaint about thermal comfort in offices. The only corrective for this situation would be individual control of the personal thermal environment [19].

CONCLUSION

An important factor connected to the individual differences is the different clothing of persons. Correcting the preset temperature setting to the actual average clothing factor, leads to a much better perceived comfort and leads to an energy saving of around 5% because a slightly higher room temperature in summer is allowed which results in less cooling. Taking the individual preferences of the occupants in connection with their biomimetic profiles as starting point another improvement could be made. The personal demand must be leading in the process control of indoor climate systems.

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Urban Ecology and Metabolism

SUSTAINABLE MASTERPLANNING IN PRACTICE: EVALUATION AND SYNTHESIS

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ABSTRACT

During the summer of 2008 a selection of urban communities which have become renowned for their sustainability were visited. These case studies include Vesterbro in Copenhagen (DK), Bo01 in Malmö (S), Hammarby Sjöstad in Stockholm (S), Eco-Viikki in Helsinki (F), BedZed in London (UK) and Vauban in Freiburg (D). During each of these visits members of the urban planning team were interviewed as were residents of the communities in question, a photographic survey was conducted and documentation of the design and post-occupancy evaluation was collected.

The objective of these visits was to identify strengths in sustainable masterplanning which should be repeated in future projects and weaknesses which should be avoided; in particular with respect to the design process, the quality of the completed community projects as well as their ongoing management; considering social, economic and environmental perspectives.

In this paper we briefly describe the key characteristics of each of the projects evaluated. We then present a series of recommendations, based on our analyses of these projects, to support the future design and planning of sustainable communities.

INTRODUCTION

For the first time in history, half of the global population is now living within urban settlements which are responsible for the majority of greenhouse gas emissions. With increasingly stringent inter-governmental commitments to reduce these emissions it is becoming increasingly important to identify ways of improving the sustainability of new and existing urban developments. A number of communities have been developed or renovated in Europe in recent years to demonstrate how this might be achieved. The purpose of the present study was to evaluate the effectiveness of these demonstration projects with a view to identifying strengths which should be repeated and weaknesses that should be avoided in future projects. But the challenge is not to develop a small number of improved demonstration projects. No, the real challenge is to identify the potential for widespread replication of good ideas and of course avoidance of bad ones; to ensure that sustainability becomes the rule and not the exception. This is the real inspiration behind our work, which started in 2008 with the award of the CIBSE Ken Dale Travel Bursary to visit sustainable community demonstration projects throughout Europe.

These case studies (Figure 1), which include Vesterbro in Copenhagen (DK), Bo01 in Malmö (S), Hammarby Sjöstad in Stockholm (S), Eco-Viikki in Helsinki (F), BedZed in London (UK) and Vauban in Freiburg (D), were each visited during the summer of 2008. Each visit involved the following:

- Audio-recorded structured interviews with members of the design / planning team.
- Photographic survey.

- Questionnaire administered to a sample of residents.
- Acquisition of documentation describing the project, its background and measured performance.

The interviews addressed the background of the project; its timing, the project brief, its cost, the degree of public participation, novelty and perceived strengths and weaknesses. More specific questions were also asked in relation to the social, economic and environmental sustainability of the project. The residents' questionnaires addressed a range of issues including social integration, civic and transport amenities, the quality of outside space and their overall satisfaction with the development. We have since evaluated these data in an attempt to (at least partially) respond to the above objectives.

Figure 1: The five Case Studies: clockwise from upper left we have: BedZED, Vauban, Bo01, Hammarby, Eco-Viikki.

In the following we provide a cursory introduction (due to the restricted length of this paper) to the case studies evaluated before proceeding to present a tabulated synthesis of their key characteristics as well as indicators of their performance. In this we omit Vesterbro. This is partly because it was a renovation of an existing development whereas all others were new build projects and partly because of difficulties in obtaining supporting information.

We then conclude the paper with a comprehensive set of recommendations, to help improve the sustainability of future urban developments. In this we also take into account what was learnt from the visit to Vesterbro.

INTRODUCTION TO THE CASE STUDIES

<u>BedZed (London, UK)</u>: Located in the Borough of Sutton on the outskirts of London, BedZed (the **Bed**dington **Z**ero **E**mission **D**evelopment) was the first concerted attempt in the UK to develop a net zero energy consuming mixed-use community. Energy demand is minimised through a highly insulated envelope, the utilisation of passive solar gains and the use of efficient lights and appliances, whilst a combination of renewable energy conversion systems provide much of the remaining energy needs. The principle strength of BedZed is its holistic

treatment of community resource flows, such that careful attention has been paid to minimising mains water use, the use of high environmental impact materials and waste recycling. Other strengths include the high density of the community and its social diversity.

Vauban (Freiburg, D): Built around the renovation of a French army barracks, Vauban exemplifies the achievements that are possible though pro-active community participation. Considerably larger than BedZed, this project has also tackled the minimisation of resource flows whilst providing for pleasant, welcoming and biodiverse external spaces in a holistic way. Vauban also demonstrates both Passivhaus and Plusenergiehaus concepts as well as excellent integration of public transport and other strategies to minimise private automobile use and the integration of a sustainable urban draining strategy. Since its completion Vauban has inspired several bottom-up sustainable community participation initiatives throughout Europe.

Bo01 (Malmö, S): Constructed for the 2001 European Exposition under the theme "City of Tomorrow" the Bo01 project is a redevelopment of the degenerated port of Västra Hamnan on the outskirts of the City of Malmö. Particularly strong features of this project are the dominance of pedestrians over cars, the quality of landscaping and a real attempt to promote local biodiversity and the supply of energy from renewable resources. This project has proven to be very popular with its residence and attracts a large number of visitors, particularly during the summer months due to its bather-friendly landscaping and other local amenities. Such is the success of the project that a second phase is now under construction.

Hammarby Sjöstad (Stockholm, S): Constructed to accommodate increasing population pressures in Stockholm in a sustainable way, Hammarby is a triumph of public-private partnership to deliver high quality housing, whilst carefully integrating the necessary civic, transport, energy supply and waste treatment infrastructure from the outset. This 'Hammarby model' was in part facilitated by the Swedish financial model: land is state owned, but leased to developers. The revenue then finances the desired infrastructural investments; as was also the case in Malmö. Apart from the architectural continuity which is absent in some of the other examples, Hammarby has also benefited from a strong vision for the creation of high quality pedestrian-friendly space, but without being hostile to cars on its main roads which provide a source of vibrancy as well as clientele to the many local small businesses.

Eco-Viikki (Helsinki, F): Located on the outskirts of Helsinki, Eco-Viikki was intended as a national demonstration project of the principles of sustainable community planning and design. By purchasing the land for this project the City municipality was able to impose a relatively strict brief on competition entrants wishing to develop individual or groups of homes and, for the first time, to require competitors to rate their entries according to standard performance criteria. It was also a way of providing their desired mixture of social and private housing (as with BedZed). Particular strengths of the final solution at Eco-Viikki include the provision of a pedestrian friendly outdoor environment dominated by greenspace in which a real concerted effort has been made to improve biodiversity, the possibility for inhabitants to grow their own food and to benefit from associated social encounters. Commendable also are the municipalities efforts to evaluate, objectively and subjectively, the performance of the end result, to communicate the results from this exercise in a transparent way and to respond proactively by rectifying, where possible, problems that have been identified.

Table 1 below presents a summary of some of the key attributes of each of the projects as well as key indicators of their performance.

PARAMETER	**BedZED**	**Vauban**	**Bo01**	**Hammarby**	**Eco-Viikki**
Site area (ha)	1,7	38	22	200	40
“COS”	0,35	0,16	0,18	0,18	0,29
Number of homes	250	2000	1303	11000	600
Deliberate social mix	+	++	-	0	0
Community participation	+	++	0	0	+
Competition/Evaluation criteria	++	+	++	+	++
Site layout (solar irradiation)	++	++	0	+	++
Energy consumption ($kwh/m^2/year$) – Thermal	48	n/a	167	n/a	120
Energy consumption ($kwh/m^2/year$) – Electrical	34,4	n/a	118	n/a	45
Energy conversion systems installed Capacity (MW) or area (m^2)					
- Photovoltaic panels	772 m^2	2500 m^2	120 m^2	☑ *	200 m^2
- Solar thermal collectors	☒	☑	1400 m^2	390 m^2	1248 m^2
- Wind turbines	☒	☒	2 MW	☒	☒
- Ground heat pump	☒	☒	1,2 MW	☒	☒
- District heating	☑	☑	☑	☑	☑
- District cooling	☒	☑	☑	☑	☒
- Biomass	0,13 MW *	☑	☑	☑	☑
Annual energy supply	88 MWh	n/a	6305 MWh	n/a	n/a
Water saving devices	++	+	0	0	0
Water consumption (liters/person/day)	72	115	200	150	126
Rain water harvesting	+	+	+	++	++
Waste water treatment	++	0	++	++	0
Waste recycling	+	0	++	++	0
Recycled materials	++	+	+	+	0
Low embodied energy content materials	++	0	+	++	+
Car sharing	0	++	0	+	0
Priority to pedestrians	++	++	+	0	++
Public transport integration	+	+	0	++	-
Civic amenities	0	++	+	++	+
Green space/biodiversity	0	++	++	+	++
Performance monitoring	++	0	++	0	+

Legend ☑ Yes, ☒ No; (++) Excellent, (+) Good, (0) Average, (-) Poor, (- -) Very poor; * present, quantity unknown, *no longer operational

Table 1: Synthesis of the five projects

RECOMMENDATIONS

Based on analysis of our structure interviews, residents questionnaires and analysis of the documentation that we have obtained for each project we proposed the following recommendations; starting with the planning phase of future more sustainable urban settlements and concluding with specific design recommendations.

Planning

Community involvement: The success of Vauban (Germany) suggests that it is important to integrate the local community, in particular potential future residents, into the planning of a new project as soon as possible. This may help generate ideas, but particularly valuable is the acceptance of the project (and any unconventional ideas) as well as the likelihood that the community will invest time and effort in ensuring its long term success.

Social housing: It is important to ensure the creation of a socially inclusive community, balanced in terms of age, income and ethnic background. This can partly be ensured by providing accommodation of different sizes and of varying degrees of subsidy.

Transport: The size of a new development, or its integration within existing urban fabric, needs to be such that there are sufficient local residents / employees to justify the creation of new public transport routes or the deviation of existing ones. The appropriate organisations should then be consulted early to achieve the desired influence on local transport planning.

Amenities: It is also important to ensure that the local community has the carrying capacity to support key local amenities and that the conditions be provided to support their creation. Examples include healthcare, leisure and childcare facilities, restaurants and shops.

Competition criteria: Eco-Viikki (Finland) was unique in establishing clear criteria against which competition submissions were to be judged and in identifying quantitative ranges according to which points would be awarded. This was both to aid selection and to guide the proposals in the preferred direction.

Performance evaluation: An important complement to competition criteria is the ability to be able to predict the performance of planning and design proposals in a consistent way and thereby to predict the degree of success to which the criteria are satisfied. This helps not only in optimising the proposals by the respective teams, but also in selecting the strongest candidate(s).

Visitors: Visitor centres can be very useful in promoting a successful project (and a useful source of revenue), but they can also be very unwelcome amongst residents. This is a delicate balance, which may require the involvement of the local community if it is to succeed.

Specific recommendations

Green space: A sound landscaping strategy is important not only in providing safe and fun environments for children, their parents and for pets, but can also facilitate important social exchanges amongst residents. This can be reinforced through community involvement in the maintenance of green space. One productive way of achieving this is to provide places for residents to grow their own food, as at Eco-Viikki.

Biodiversity: One of the successes of Bo01 in Malmö (Sweden) was the preparation of a biodiversity checklist – a set of options for encouraging biodiversity which planners and designers could choose freely from and find ways to integrate into their proposals. Although not foolproof, this has clearly helped in establishing a rich diversity of environments suitable for a range of different species.

Site layout: Alongside basic requirements for the total floor area required for different uses to be accommodated on the site (however this be expressed), it is also useful to be able to give some guidelines (as distinct from rules) regarding the orientation of buildings (or perhaps a fraction of them) and the relative distance between them, to maintain solar access. Alternatively, some performance criterion might be specified, such as the total incident annual solar irradiation.

Buildings' thermal design: Performance standards (e.g. heating requirements, in kWh/m2), in excess (preferably significantly) of current norms, are a useful way of facilitating good overall standards. These standards may be specified without stipulating how they are to be achieved. This is a way of encouraging innovation. One such example is the innovative passive stack ventilator with integral heat exchanger at BedZed.

Overheating: In combination with energy-related thermal performance standards, it is important to define some criteria against which overheating risk should be judged, along with a methodology against which this risk should be evaluated.

Electrical energy use: Highly efficient lights and electrical appliances are an effective way of reducing electrical energy use; experience at BedZed suggests that the associated payback period can be within 10 years. Nevertheless, this overhead may be incompatible with the desire for low cost housing, unless effective subsidies are available.

Energy supply: Experiences in Scandinavia (particularly Malmö) have shown that it is possible to supply the energy needs of a community using 100% local renewable resources. However, to avoid passing the associated cost on to future residents some form of subsidy may be required. Alternatively agreement may be sought with en energy supply company. Promising technologies include co-generation, ground source heat pumps and solar cells (depending upon the feed-in tariff).

Materials: There is not necessarily an additional cost involved in sourcing materials of low embodied energy content. Achieving this could be much facilitated by advice on which materials to choose (or access can be given to a database such as EcoInvent) and where to source them from.

Waste treatment: Experiences in Scandinavia show that it is possible to effectively apply industrial ecology principles, to maximise the circularity of flows of resources within urban developments. In that context heavy use has been made of vacuum chutes, linking local collection points with centralised stores. There is some doubt however as to whether this is environmentally effective, given the energy costs involved. The alternative is more frequent local collection.

Water: It is straightforward and cost effective to specify appliances which minimise water consumption within the home. It is also worth considering the collection and storage of rainwater, supplying the needs for which potable water quality is not required. Consideration should certainly be given to effective surface water runoff (sustainable urban drainage).

New technologies: New untested technologies are best avoided, despite the temptation to demonstrate novelty in any ambitious project. This novelty may better come from achieving an integrated solution to sustainable urban design in a cost-effective way and which may be widely replicated.

Performance monitoring / ongoing management: Finally, it is important to be able to compare predicted against actual performance in order to be able to direct strategies for improving the ongoing management of resources as well as to provide feedback to planners and designers. The most effective way for achieving this is to install electronic measuring devices linked with a data acquisition system (preferably internet enabled). Interviews with residents can also be indispensable in identifying issues that need to be resolved in order to optimise their health and welfare.

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Energy Efficiency of Urban Buildings: Significance of Urban Geometry, Building Construction and Climate

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Abstract

Cities in general and the building sector in particular affect dramatically and durably the energy use worldwide and hence the global warming. Urban sustainability can only be reached if energy-efficient buildings in urban areas become standards. The energy consumption of an urban building is affected i) by the surrounding microclimate which differs from the standard weather data and ii) by the mutual obstructions between buildings, which decrease sunlight and wind flow potentials, i.e. internal solar gains and passive cooling. As well, the building construction itself affects both the outdoor and indoor microclimates through its envelope. This research addresses these interdependences, because the urban context has been mostly neglected in building energy analyses so far. Several urban structures are investigated with various geometries (H/W, solar orientation) and building properties (thermal insulation and inertia, window ratio, etc.) and three different climate regions are considered: one temperate mid-Europe location and two in the subtropics: hot-humid and hot-dry. The numerical method used combines the urban canyon model TEB, and the building energy model TRNSYS for simulating the building's energetic and thermal responses to external and internal settings. Target quantities are heating and cooling loads. The huge amount of outputs is analyzed statistically. This paper is an introduction to an extensive research underway, and some results are presented exemplarily to illustrate the high relevance of this issue, the method applied and the significance of all investigated factors.

Introduction

Urban designers and architects increasingly face up to produce energy-efficient urban buildings which effectively reduce the global energy demand and gas emissions. To achieve this goal, interdisciplinary work between urban microclimatology and urban design on one hand and building physics and architecture on the other is decisive [1]. The project introduced here aims at investigating the interdependences between urban and building scales in respect with energy performance, because the urban context and urban climate are often neglected in building energy analysis. The main objectives are to answer the following questions:

- How the urban structure modifies the microclimate: air temperature, wind flow and irradiation quantities?
- How this "new" urban microclimate affects the energy efficiency of an urban building?
- At urban level: What are the effects of the street vertical profile and plan density in combination with the solar orientation on the energy efficiency of an urban building?
- At building level: To which extent are building describers like thermal insulation and thermal inertia, window ratio, material properties, etc. decisive?
- How will the climate conditions influence the whole energy behaviour of the building?

Target quantities are: heating, cooling and total energy loads, as well as lighting and ventilation loads, and thermal Comfort. This paper reports on some preliminary results.

METHOD

The method relies on numerical modeling with combination of two calculation models: at i) urban level by means of the urban canyon model TEB [2] and ii) at building level with the TRNSYS model. TEB is used for simulating the urban heat or cool effects on one hand (i.e. new urban air temperatures adjusted from standard climate data), and TRNSYS [3] is used for simulating the energy demand indoors. The mask effects due to neighboring buildings, as shown in Fig. 1, have been included in TRNSYS. Solar radiation fluxes and day-lighting potential for each building thermal zone facing the in-canyon have also been adjusted in the building model according to the obstacles effects.

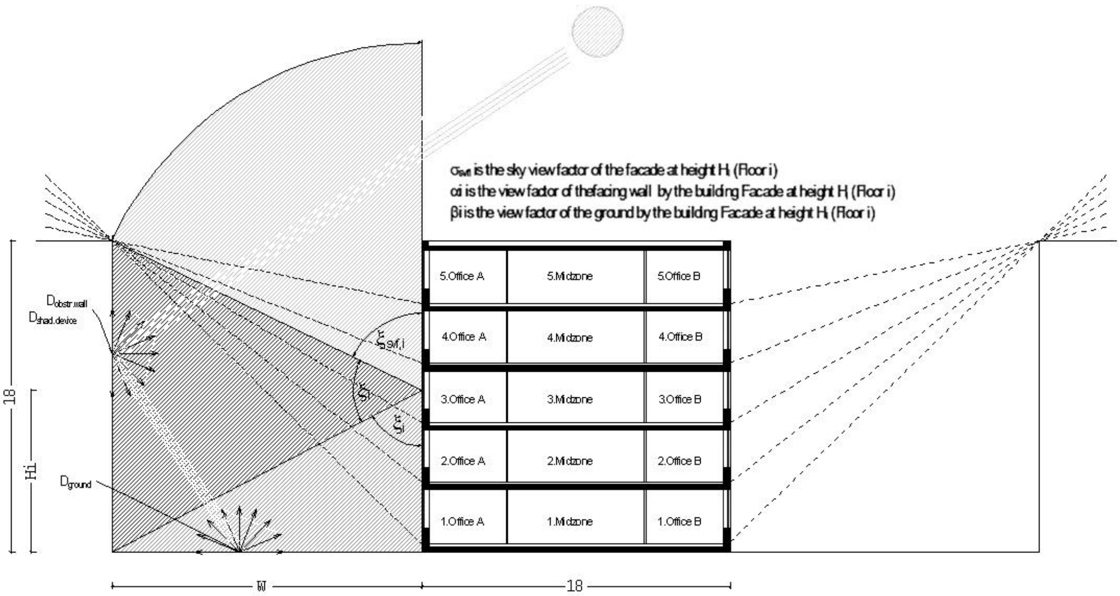


Figure 1: Office Building in a row-type urban structure as simulated with TEB and with TRNSYS 16, including 10 thermal zones with external exposure.

The investigation consists of a parametric study where urban describers, building describers, as well the climate are varied (Table 1). A number of urban structures are investigated with various urban canyon geometries and building properties (height-to-width ratio, solar orientation, building envelope, materials, etc.). First, the urban microclimate changes due to the urban structure itself are assessed including the thermal, irradiation components and wind flow, as these constitute the actual ambient climate under which the urban building performs.

	Coded form →		-1	0	1
Urban Context	A =	vertical profile*	H/W = 0.2	H/W = 1	H/W = 1.8
	B =	solar orientation*	NS	NESW	EW
Building	C =	window ratio*	30%: hole facade	60%: row facade	90%: glass facade
	D =	thermal insulation*	U_{wall} = 0.15 U_{window} = 0.7 U_{roof} = 0.10	U_{wall} = 0.40 U_{window} = 1.5 U_{roof} = 0.35	U_{wall} = 0.65 U_{window} = 2.3 U_{roof} = 0.60
	E =	thermal inertia	light construction	-	massive construction
Climate	F =	climate	Mannheim: 49.31°N	Algiers: 36.24°N	Ghardaia: 32.34°N
* Values are set equidistant to be appropriate for the statistical analysis. Climate data for Mannheim are provided by the test reference year TRY 12; for Algiers and Ghardaia by the software METEONORM 5.0. Total number of simulations runs with all possible variables combination (full factorial): 486.					

Table 1: Variables of the parametric study used for TEB and TRNSYS simulations

Secondly, the thermal conditions, passive solar gains, heating & cooling loads are quantitatively investigated for one office building in each urban context for the building describers given in Table 1. The main indoor settings are listed in Table 2.

The "Design of Experiments DoE" statistical method is used for analyzing the huge amount of outputs by highlighting within a hierarchy i) the individual effects of each investigated parameter on the resulting energy quantities, ii) the multiple interactions between the input parameters and their effects on the target outputs and finally iii) by providing an overall prognosis formulae which expresses the output Y in dependence with all relevant x_i inputs ($Y = f(x_1, x_2, x_3 \ldots x_n)$). The final goal of this investigation is to provide the urban designer and architect with useful guidelines at early design stages for optimized use of renewable energy. This research is a contribution to an integrated methodology which links between the urban scale (urban microclimatology) and the building scale (building physics).

Building description	Office building with 5 thermal zones arranged vertically on each orientation.
Occupation Period (OP)	8:00 - 18:00 on weekdays. No use on week-ends.
Heating	6:00 - 20:00 during OP. set temperature T_a = 20°C. 17°C outside OP (night-time sink).
Cooling	Set ON if operative temperature $T_{op} \geq 26°C$ during OP. No cooling outside OP.
Ventilation Rates*	In the daytime during OP: 4 vol./h if $20.5°C \leq T_{op} \leq 23°C$ and $T_{a,ext} < T_{op}$. 1.6 vol./h if $T_{op} > 26°C$ and $T_{a,ext} \geq T_{op}$. 1 vol./h as infiltration rate and used outside OP. In the night-time: 1vol./h. when $17.5°C \leq T_{op} \leq 23°C$
Internal Gains	Persons: 2 persons with 75W / person. Equipment: 230 W (PC's) Artificial Lighting: 10 W/m^2, fluorescent light. All internal gains during OP.
Shading Devices	Shading factor = 0.75 (75% of solar radiation reflected away)
* The simulations reported here are based on ventilation rates but more simulations are underway which consider the potential of urban natural ventilation assessed by means of TRNFlow.	

Table 2: General settings for the building operation for the TRNSYS simulations

RESULTS

Urban Air Temperatures

Figure 2 exemplarily shows urban air temperatures calculated with TEB on hourly basis for one case study (C = -1, D = -1, E = 1, A & F = all, B indifferent). It shows that urban air temperatures are effectively different from standard climate data with a clear trend of warming of the canyon up to 2 K as far as the geometry is concerned. Basically, both heating and cooling effects within the canyon are more significant for the subtropics than for a mid-Europe latitude due to more global radiation on one hand and to more shading on the other hand, alternatively. Extreme values of air temperature deviation ($T_{a,urban}$ - $T_{a,standard}$) in both positive and negative cases are attributable to the relative inertia of the urban structure which makes it react slowly to occasional abrupt fluctuations of the standard data used as inputs. Figure 2 also makes clear that standard climate data are not representative for building energy simulation in urban context since the thermal behaviour of the urban canyon varies throughout the year. Case to case adjustment of air temperature at hourly basis is necessary for including the impacts of urban geometry, building construction and geographic location. Systematic investigation of more combinations is underway with focus on a detailed analysis of how the urban canyon reacts thermally in dependence with the major TEB simulation settings.

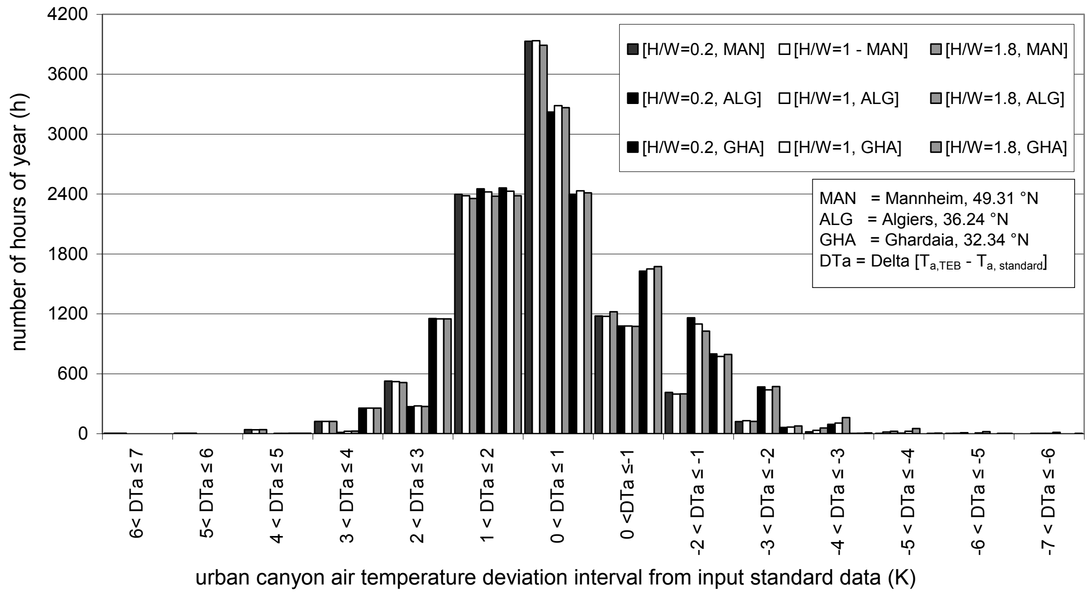
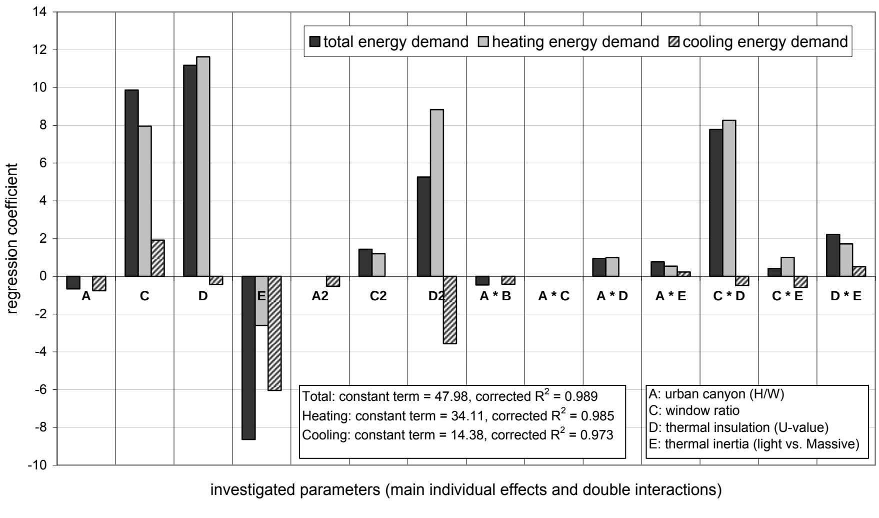


Figure 2: Example of TEB-simulated urban canyon air temperatures deviation from standard climatic data for various vertical profiles and for 3 climate locations. Here, the building is massive with a window ratio of 30% and a high thermal insulation (U_{wall} = 0.15).

Heating and Cooling Energy Demand

The energy demands shown in this paper are average values for the 10 thermal zones of the building with external façades. These values are surface-related and calculated over one year and expressed in kWh/m^{2}a. Figure 4 shows one example of energy demand calculations for the mid-Europe location Mannheim in case of adjusted urban air temperatures with TEB.

Figure 3 summarizes the corresponding statistical analysis with the regression coefficients showing the main effects of each individual variable as well as the double interactions between the variables in their impacts on the outputs. Positive values reveal a proportional effect whereas negative values mean inversely proportional effect according to the coding used in Table 1. The correlation R^2 is very high which confirms the reliability of these statistics.



Variable	Heating	Cooling	Total
Constant	34.110	14.383	47.985
A		-0.764	-0.667
C	7.953	1.917	9.863
D	11.624	-0.438	11.175
E	-2.600	-6.045	-8.640
A^2		-0.525	
C2	1.195		1.433
D^2	8.826	-3.569	5.258
A * B		-0.419	-0.458
A * D	0.989		0.947
A * E	0.540	0.231	0.769
C * D	8.264	-0.486	7.774
C * E	1.001	-0.593	0.409
D * E	1.719	0.508	2.221

Figure 3: Example of a statistical analysis for Mannheim (49.31°N, 8.33°E) i.e. TRY12 adjusted for urban context with TEB, showing the significance of all investigated parameter on the energy demand: heating, cooling and total.

For instance, here is resulting formulae (in coded form [-1, 0, 1]) which allows the calculation of the total energy demand:

$$Y = 47.98 - 0.67A + 9.86C + 11.17D - 8.64E + +1.43C^2 + 5.26D^2 - 0.46AB + 0.95AD + 0.77AE + 7.77CD + 0.41CE + 2.22DE$$

Heating demand decreases with better thermal insulation, less window area and massive opaque construction; whereas cooling demand decreases with massive construction, deeper streets, less window area and less thermal insulation. The window ratio C has the particular effect to raise both heating and cooling if increased.

Hierarchically, parameter D (thermal insulation) and then C (window ratio) are the most influencing the energy demand especially as this relationship is not linear as given by the squared terms C^2 and D^2. Increasing the vertical profile H/W (A) leads to a decrease of the total energy demand due to less cooling needs as a result of more shadowing of the canyon, however, the impact is the lowest as main individual effect.

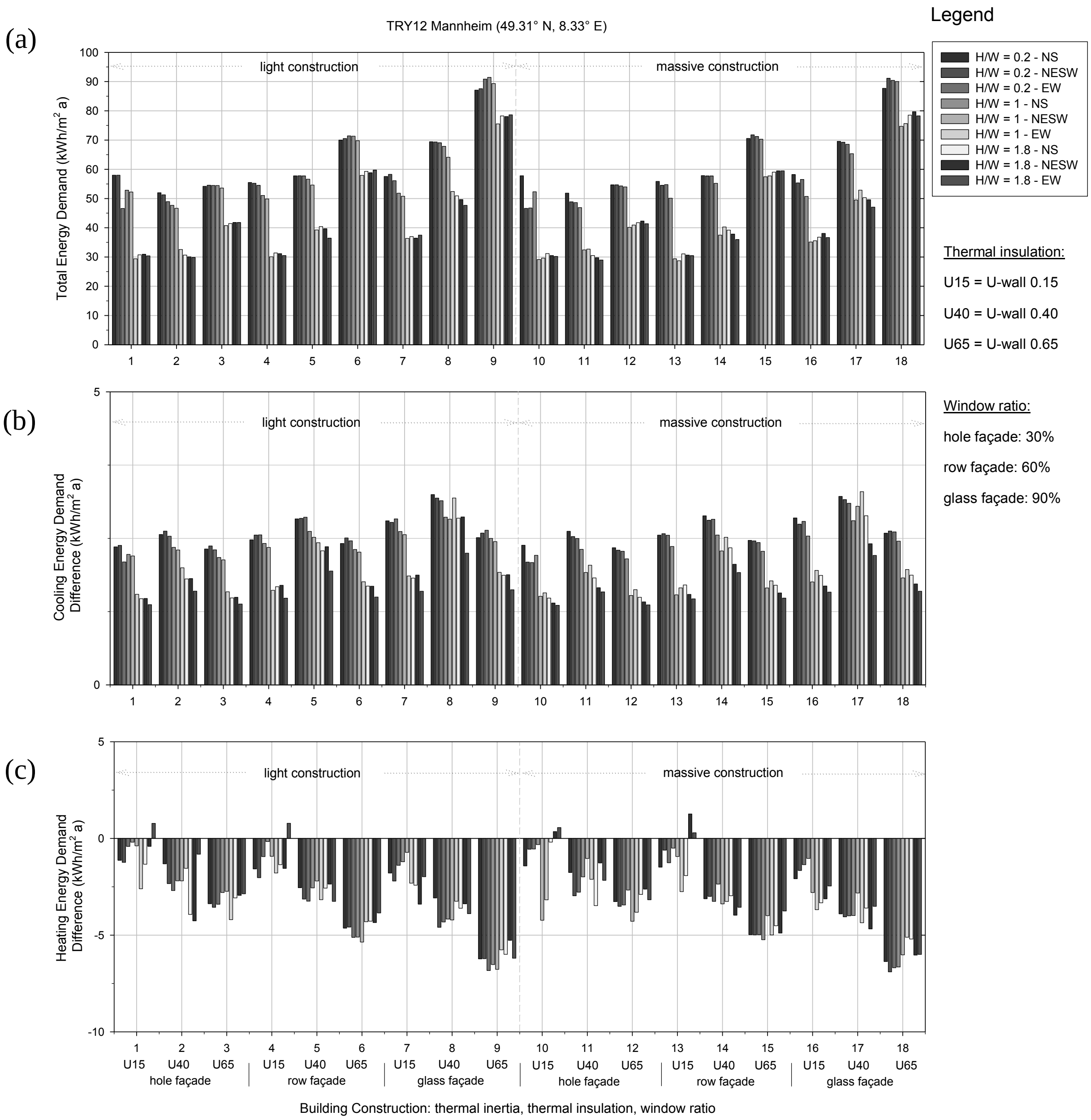


Fig. 3: (a) Total energy demand for Mannheim (49.31 °N) in dependence with urban and building describers and a comparison for (b) cooling and (c) heating between urban climate data versus standard data as inputs

The parameter B (solar orientation) shows no relevant effect because the energy demand values reported here are averaged for 2 orientations in each case (i.e. N & S, E & W, NE & SW); yet an evaluation for separate orientations would better reveal the specific impact of B, as well as its interaction with the vertical profile (A * B). In addition to these main effects of individual parameters, many double-interactions reveal to play a role in the energy demand: For example A is interactive with the solar orientation B for cooling, with the thermal insulation D for heating and thermal inertia E for both heating and cooling. Building describers C, D and E are all strongly interactive with a dominant effect of the pair window ratio – thermal insulation C * D, namely the building envelope.

Figure 3a shows the total energy demand at a glance. Figs. 3b and 3c show the difference in the energy demand if adjusted urban air temperatures versus standard data are used. The cooling demand increases when the urban heat island effects are included (T_a adjusted with TEB) and this is more evident for light construction (higher albedo and lower emissivity) and low density (more sun exposure). By contrast, heating demand is basically lower when the urban context is properly modelled because of higher outside air temperatures.

The hierarchical importance of all investigated variables as well as the urban context relevance briefly introduced here is specific to the location of Mannheim (49.31 °N). Very different energy patterns are found for Algiers and Ghardaia (not shown here) for which the subtropical location characterized by intense solar radiation, higher temperatures, clear sky, etc. are much strongly influenced by urban describers like the vertical profile or the solar orientation and where the building describers affect the energy demand in another way. For example, less thermal insulation is required in the subtropics than in Europe because the latter case is more concerned with heating than cooling. Extensive results for all cases with the corresponding analysis will be made available soon.

Conclusion

The present paper has shown exemplarily some preliminary results on an ongoing project which aims at exploring the interdependences between outdoor and indoor climates, and especially the effects of the urban context, building construction and climate on the internal energy demand. The relevance of adjusting air temperatures according to urban context including the vertical profile geometry, urban density and building materials has been shown. The importance of all building describers has also been addressed for the case study of TRY12 Mannheim. The research is gathering numerically more knowledge about these interdependences in a systematic way and further results will be reported soon, together with a discussion on the capabilities of the models TEB and TRNSYS used as method, as well as their extension.

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HABITABILITY, THE SCALE OF SUSTAINABILITY

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ABSTRACT

This paper will explore an alternative to so-called 'sustainable' models and strategies currently applied in the field of building, architecture and urbanism.

In front of irrational resource consumption and an ever-growing waste generation or other problems, seemingly inherent to the current industrial productive model and now transferred to the production of space, the most critical and concerned sectors within these disciplines keep on applying scale-segregated sustainable solutions, i.e. working and intervening at the scale of the single built unit, or at that of the urban model.

Instead, the paper will explain ongoing research related to the possibilities of generating another model based in the concept of "**global habitability**", that would allow the application of those and other new solutions and mechanisms at all scales in a much more holistic approach to the implementation of sustainability: working transversally and simultaneously, from the room to the city.

If current strategies aim at an increase in efficiency exclusively based in the reduction of resource consumption and waste generation, the new model would propose a redefinition of the other term intervening, namely utility. The very subject of sustainability is changed here through this redefinition; no more space but activity, no more the object but the process.

Utility and use within architecture can be identified with habitability, here understood as the achievement of adequate social and environmental conditions in order to satisfy the socially acknowledged basic needs of people.

Two different factors would determine such idea of utility: on the one hand the conditions of 'matter', as an expression of requirements related to space, resource flows and equipment needed to develop an activity; and on the other hand, the conditions of 'orgware' or 'privacy', another term that would include *synergy* – as the relation between the level of individuality and the level of collectivity - and *management*, as a combination of time, control and legislation.

The main aim of the paper will be thus to present this reformulation of the idea of 'habitability' as the only effective strategy towards an implementation of sustainability in the field of building. A systemic intervention, re-thinking the utility of architecture from the smallest spatial unit (the room) and extending its scale to that of the urban services (i.e. providers of any need that can't be fulfilled within the dwelling), allows achieving the maximum efficiency in terms of resource consumption; whereas social focus, incorporating individual, collective and organizational demands, allows the strategy to take roots in society expanding, thus, the likelihood of its success.

KEYWORDS

Habitability – Sustainability – Social Engagement – Sustainable Building – Matter – Orgware

INTRODUCTION

Irresponsible use and consumption of resources and an ever-growing generation of waste, typical of the industrial productive model, are now also characteristic of the ways in which architecture is produced. This has lead to the need of thorough analysis of the building sector in order to understand its situation in relationship to the social demand for sustainability. A demand that is already facing global issues (like the fight against global warming) that require specific and concrete strategies and answers for each productive sector.

In front of such an urgent demand, the first sustainable strategy consists of an increase in efficiency of the production processes of architecture as well as in its maintenance; efficiency is here understood as the optimal balance between the use or utility provided and the degree of entropic degradation produced through resource use and waste generation.

In relationship to this issue, the most critical and concerned institutions and professionals have dedicated themselves to the implementation of technological innovations capable of reducing the environmental impact of both the building itself and the urban model, through the use of renewable energies and less pollutant building processes and systems. This tendency has also lead during the last few years to the implementation of laws and regulations aiming at an increase in energy efficiency of every new building.

Nevertheless, the effectiveness of such strategies is seriously limited, since they are based in the application of scale-segregated and linear solutions, and the individual intervention in the various elements that form the system. It is necessary to note here that ‘life-models’ or ‘ways of life’ are always determined to a great extent by the availability of a certain amount of resources, and thus, a variation or a change in their availability will never cause evenly distributed change but will be rather assumed in a discreet way, altering internal relationships and generating occasional change. They are systemic.

In that sense, the improvement of building sector efficiency requires a new integral vision that is, first of all, capable of explaining the mechanisms for human-needs satisfaction in relation to a resource base, and, second of all, oriented to the development of effective sustainable strategies in a general framework of environmental-impact reduction.

NEEDS SATISFACTION AND RESOURCE BASE

Social organization provides satisfaction of basic needs of most of the individuals that form it, in a process, continuous in time, based in the ability to obtain resources from the environment. The approach to needs satisfaction that allows their linking to the availability of resources includes, as conceptualized by Max-Neef and its group CEPAUR, three different main terms: Needs, Satisfiers, and Material Conditions. [1]

Fundamental human needs can be defined as universal aims essential for the survival and physical integrity of human beings, so that when they are not met, individuals are objectively harmed (Doyal) [2]. Theses needs can be considered, according to Max-Neef, as “few, finite and classifiable” (as distinct from the conventional notion that “wants” are infinite and insatiable). They are also constant through all human cultures and across historical time periods. Examples of these needs could be eating (feed) or personal hygiene. [3] Satisfiers must be understood in turn as the ways in which each need is satisfied – in the case of the examples above by having breakfast or having a shower. They are, thus, culturally determined processes, specific to each individual or group, and they undergo constant transformation according to variations in culture, time, place, circumstances, or according to one’s limitations or aspirations. The relationship between satisfiers and needs would be, according to Riechmann, analogous to that of means and ends. [4] Finally, material conditions correspond to the physical conditions of culture and are thus the ones undergoing greater and faster transformation – going back to the example, fruits or vegetables and water or soap. [5] In front of a need such as *keeping personal homeostatic balance*, a cultural satisfier like *wrapping up warm* can be developed on the basis of some material goods as a *woolen coat and scarf*.

The availability of resources must be added as a shaping factor to the sequence of needs, satisfiers, and material conditions. It determines the material conditions themselves as well as the cultural strategies developed to generate satisfiers. For instance, the technological and productive possibilities of the industrial system have allowed the massive development of mobile phones, significantly altering the characteristics of the social satisfier that covered the need for communication.

Additionally, there is an ever more powerful mechanism for adjustment between needs and material goods, related to the conditions of privacy with regard to other people. Conditions of privacy are here understood as the control of the information (be it visual, acoustic, tactile or related to smell) that enters or exits the space where the activity is taking place. One could argue that individuals establish links and organize collectively in groups in order to maximize the possibilities for satisfaction of their needs within a specific social model that is, in turn, acknowledged and supported on the basis of an also specific resource framework. This situation implies the generation of diverse agreements among people with the aim of sharing and collectively using certain available resources or goods as efficiently as possible. In other words, it is a process towards a balance between the individual and the collective, i.e. a process of continuous adjustment of the conditions of privacy regarding the satisfaction of each and every need.

One can find a complete range of examples of diverse nature in everyday life, from the sharing of a space such as that of the house, the workshop, terrace roof or garden, to the shared use of a material flow such as the water from a rainwater tank or the hot water coming from cogeneration energy plants, or even the collective use of goods and equipment such as a boiler, telecommunication antenna or a car.

The types of links established today in order to solve these individual needs end up getting a name: flat mates, relatives, friends, neighbours, sport team, cooperative, association, co-citizens, and so on… Each of these groups or economic units *decides* which will be the needs to be satisfied collectively through the available resources, finally coming to specific conditions in each specific situation. It is nevertheless necessary to understand that these management units are not stable, but rather constantly evolving according to the availability of resources, modifying its own structure, the needs to be satisfied and the material conditions to do so.

In a situation of growth or increase in the economic capacity or availability of resources, thus, the limitations to material conditions decrease, a fact that reduces in turn the demand to establish or form resource-sharing groups. Individuals do not need to share anymore and are thus able to carry out their activities in ways more and more individual, increasing the conditions of privacy regarding the satisfaction of their needs. This would be the first hypothesis for a social model with an ever-growing resource base: the unstoppable tendency towards the private satisfaction of needs.

In that sense, throughout the period of great economic growth spanning from the second half of the 20th century until today, important changes can be detected in social organization and lifestyles, specially regarding the conditions of privacy of their members. On one hand, domestic space has evolved as a consequence of an increase in the material conditions related to a greater availability of space, material flows and equipment for each individual. Spaces in dwellings today have specialized according to use, resulting in play-rooms, storage-rooms, bath-rooms, office-rooms, study-rooms, corridors and halls, etc… and additionally, they have been individualized through the implementation of individual bed-rooms and as many bathrooms as possible. Simultaneously, the equipment installed or contained in the house has increased similarly, with a tendency towards a more and more private and individual use. The house incorporates now functions and uses that once took place collectively or in the public domain, such as cloth washing and drying (from the sink and roof terrace to the washing machine and tumble dryer), personal hygiene (from public bathing to the bathroom), evacuation (from latrine to water closet), or leisure and communication (from neighbourhood movie theatres to home-cinema), etc…

In the opposite situation, when available resources decrease, limitations to material conditions increase, forcing the establishment of new linkages and agreements in order to maximize the ability to satisfy needs. Such a mechanism affects the conditions of privacy given that individual must share a greater number of material goods, as well as carry out activities together or coordinate them.

Historical processes of growth of the family core, such as the one that took place during the European industrialization, can be understood from that point of view. Family homes were in that case forced to expand and hold parents in order to cope with the hard social and labour conditions of the time- such as a high price of housing rents and food, inexistent protection in the case of unemployment or illness, or the absence of social care to help families with kids [6].

Other processes taking place today can be also understood on the basis of the relationship of resources and conditions of privacy, when inequalities marginalize specific groups preventing their access to a growth in resources. The costs of accessing to or keeping a house today is preventing the emancipation of younger generations in some cases, and forcing the formation of groups to share it in other. One can understand then the persistence of large family units where several generations live together, and the emergence of new forms of residence and dwelling such as cohabitation groups – groups of people without kin relationships-, or reunified families, in the cases where for instance the parents of a recently divorced child return home.

Finally, this process of satisfaction of needs – articulated through satisfiers, material conditions and available resources, and structured through the demand for maximum privacy – has a very specific material translation, expressed in the organization of space, be it domestic or urban, since it determines built landscape, mobility systems and, ultimately, the use of space.

HABITABILITY

Architecture's first function is that of supplying adequate spatial conditions in order to shelter human activity, or in other words, the achievement of socially needed habitability. It is the discipline that arranges and organizes all these processes in space, and simultaneously and precisely for that reason, the reflection of growth and contraction phenomena in the ability to satisfy needs related to the availability of resources.

Current regulations in the field of habitability are conceived without a truly conscious distribution of basic human needs to be provided, but rather acting directly onto the material conditions, forgetting satisfiers and needs, and fixing a number of spatial and constructive solutions. The result of not working on the basis of needs often leads to a lack of adequate conditions for people's everyday life, and very significantly, to an excessive and inefficient consumption of resources.

Contrary to this approach, a new model of habitability, efficient in terms of the use of resources, should be referred to *needs* rather than to the material conditions that satisfy them - in a way similar to that of more recent regulations such as the Spanish 'Codigo Técnico de la Edificación' - and should be formulated from the acknowledgement of the wide range of basic needs related to dwelling, endorsing the corresponding satisfiers typical of today's society.

If habitability regulations today demand the implementation of specific goods within the space of the house, such as for instance a *kitchen* – through the specification of a number of square meters, a specific equipment and certain flows – a new model should guarantee the satisfaction of needs, in this case *eating* (feed), through the acknowledgement of a number of possible satisfiers such as the ability to eat, the ability to obtain food, the possibility of preparing meals or producing food… understanding that not all of them exist in all situations, and thus, accepting that they can not be all mandatory in all cases. A good example is the case of hotels or residences, where feeding needs can be satisfied without a specific space and equipment for it in one's room, since there is a collective food-related service in the same building.

Habitability understood as the ability to satisfy those needs depends thus on two facts: what is required to satisfy them and who to satisfy them with.

What does a person require to satisfy a need? **Material conditions** required to carry out a specific activity can be grouped in three types of requirements: those of space, those of equipment, and those of material flows. The first of them, requirements of space, have to do on one hand, with morphological conditions such as geometry, surface and dimensions, qualities, textures or colors of those surfaces… and on the other hand, with environmental conditions, such as light, air, temperature or humidity conditions. The second group of requirements associated to equipment has also into account the tools, belongings, furniture, appliances or machines that are needed in each situation. Finally, the requirements related to material flows include the whole of resources needed, the infrastructures required to supply them, the waste produced and the infrastructures needed to evacuate or take them out. The actual organization of all those requirements and thus, of the material conditions for the satisfaction of needs, is one of the functions of architecture.

It is necessary to note here that the set of material conditions includes those expressed in the same place where the need is satisfied – be it interior or exterior – as much as those implied in its achievement. In that sense, considering material conditions of the satisfaction of needs allows exceeding the domestic space extending out to the urban realm.

With whom is a need satisfied? The way in which a need is satisfied is determined by the group as well as by the political and social environment in which the activity is carried out, or in other words, by its **conditions of privacy**. These conditions are in turn determined by two factors: the set of individuals with whom a function is shared, and the ability to manage that function. The group of people with whom an activity is carried out is the group that shares certain resources in order to satisfy a specific demand, as for instance a couple sharing the same bathroom, neighbours sharing the staircase, or citizens moving around in the same bus or swimming in the same swimming pool. One can see that "sharing certain resources" refers to the already mentioned material conditions and can take place in many different ways: it could mean sharing just a space (staircase), or a space and some equipment (a library with books and tables), or even a space along with some equipment and some material flows (a bathroom with a shower and fresh water). The use of these resources can be organized in time differently, simultaneously, as in the case of a library, or taking turns, as in the case of a bathroom.

Besides the set of individuals, privacy conditions are also determined by management, an element that combines the degree of control over material conditions with the ability to regulate the inward and outward information-flows. The conditions of privacy will ultimately determine the degree of intimacy in the satisfaction of a need and, as shown above for the previous case, allow the expansion of the domestic realm into the more political city-space or urban space. A journey from the room to city-space that takes place as soon as the full range of needs is analyzed: those satisfied within the individual realm, those within the realm of the family, those within the neighbourhood, and ultimately, those satisfied within the public realm.

CONCLUSION: THE NEED FOR A NEW HABITABILITY

Habitability, understood in a wide sense, involves the organization, management and maintenance of socially established material conditions for the satisfaction of needs. Habitability is thus, the expression of a social organization derived from the availability of resources and its social distribution; an always-maximized distribution as a result of the tendency towards individualization in the satisfaction of needs.

As a consequence, in front of scenario of progressively growing restrictions in the emission of waste, an increase in efficiency in the production of socially needed habitability must necessarily include a redefinition of the function of the architectonic process itself. In other words, it must undertake the formulation of a model of habitability that allows an efficient use of resources and the reduction of emissions. The proposal is thus to define such a new habitability model as opposed to the current approach to habitability regulations, always defined from the point of view of specific material solutions and exclusively expressed within the realm of the house.

A new model that allowed considering the precise conditions for the satisfaction of socially acknowledged needs – from the domestic to urban – taking into account today's and future restrictions regarding the destruction of resources and the generation of emissions involving their fulfillment, and more specifically, the restrictions regarding green-house effect gases causing global warming.

A new model of habitability that understood the importance of its flexibility and adaptability regarding the restructuring of social organization and transformation of the conditions of privacy for the satisfaction of needs, not only to adapt to the new framework of restrictions, but most importantly as a primordial factor of its own definition, from the limitation of resource use itself.

In that sense, maximum resource-related efficiency must not be formulated today exclusively from the point of view of an increase in the efficiency related to the achievement of material conditions acknowledged to satisfy human needs (often achieved through technology). It must be rather conceived from another point of view that formulates the necessary tools for the evolution and transformation of those needs, one that would not only allow a much-wanted increased efficiency in the use of resources, but also prevent these efficiency-related achievements from being obsolete, once the inevitable change in material conditions arrives.

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ECODYNAMIC LAND REGISTER, CURRENT DEVELOPMENT LEVEL OF THE TOOL

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ABSTRACT

The paper describes current development of the ELaR methodology. ELar stands for Ecodynamic Land Register, it is a further innovative elaboration of a PhD thesis carried out at Politecnico di Milano developed to assess the “strong sustainability” of design choices (presented in its early development stage during the last edition of Cisbat 2007). The main goal is to provide a design oriented methodology and assessments tools to spread the principles of “strong sustainability” [1] to multi-scale design applications. Such a paradigm implies the analysis of energy and material flows and global and local ecosystem regeneration capacity for the different human activities.

The specific information system developed is based on the geometric structure of the land cadastre and allows evaluating different design options in terms of amount of input and output flows activated in a single land parcel to sustain the activities carried out there. Geo-referenced input and output flows are related with the bio-capacity of the local context. The same option allows evaluating the quantity of flows generated by the number of persons using the services provided by the single particle, and therefore the per-capita sustainability level. The per capita flows estimation is a basic condition to verify the right of the Earth’s inhabitants to have equal access to renewable resources.

The activities taken into consideration at the present stage of development are related to the consumption categories “housing” and “food”. From the practical point of view the methodology is based on two specific synergetic tools:

- A Geographic Information System, which allows evaluating information on the existing conditions, and on the renewable resources potential at local country micro urban scales. Particular attention has been paid to the estimation of solar radiation incident on the facades and top of the existing building by using digital elevation models (DEM, raster resolution 0,5m).
- A spreadsheet, linked to a specific database, to define the different design options in terms of input and output flows related to the land parcel where the building stands. These quantities are expressed in terms of specific impact indicators such as eMergy [2], the CO_2-equivalent emissions, primary renewable and non-renewable energy. Furthermore the flows of money relative to the same dynamics are calculated, opening new possibilities to the favorable reconciliation between environmental and economic sustainability.

The conclusion presents some of the results of the application of ELaR in the urban context of a small town outside Milan, Albairate. It shows in particular how the tool supports decisions about the energetic/environmental upgrading of existing housing. Maps on the local renewable potential have been published on the web. The use of this information (through a specific spreadsheet linked to databases on local productions) can guide the designer, making him aware of how his actions influence the local context metabolism and the environmental impacts of the building user.

INTRODUCTION

As mentioned in the abstract, ELaR is a methodology of analysis that aims at creating common basic tools shared among different disciplines which share the goal to reduce the environmental loads related to the single person. The same computer tools can support assessment procedures, related to different consumption categories such as housing, food, transport services and other consumptions activities, which all together compose the environmental loads related to the lifestyle of a person.

Since these activities are all located in a territory, Elar adopts the cadastral land parcel as basic geometric reference, and translates the activities that take place within the same parcel as input and output flows of matter and energy. All these flows have been geo-referenced, in order to enable the information to be processed by a single Geographic Information System, and so allowing th integrated assessment of the environmental load related to different consumption categories.

METHOD

The methodology briefly described above has led to testing operational tools able to perform the proposed calculations. These recent developments have been focused on activities related to the category of housing and more marginally to the category of food consumption (with the intention, in the future, to integrate data related to the categories of transport, services and other consumption activities).

Through synergic use of Geographic Information Systems, a database and a spreadsheet, an evaluation procedure for the estimation of territorial metabolism activated by different design choices has been put in place. The procedure is characterized by the different steps described below:

1) First of all, defining the limits of the local context, by including, within the spreadsheet, the geographical coordinates of the polygon vertices that marks the boundaries of an hypothetical local area.

2) Choosing the cadastral parcel, where the design proposal will be located.

3) Accessing thematic maps available on-line, which represent the existing conditions of the local area; such maps include information on potential local renewable resources and on the geometrical configuration of existing buildings. These maps, available to users through the web, give the possibility to access information on local climatic factors, in particular the conditions of solar radiation incident on the open land and buildings, rain precipitation described in monthly intervals, the availability of biomass fuel and the conditions of the soil for a possible use of heat exchangers in the ground. All the information collected in the thematic maps and referred to the chosen land parcel (that will host the project), should be added within the spreadsheet. It will use these data in the last step of the evaluation procedure to produce information about the “territorial metabolism” related to the different design choices, namely the input and output flows related to the single land parcel.

4) Entering data on the geometry of the building within the spreadsheet, and accessing a specific database to choose the materials that will make up the various components of the building, and similarly select fuels and other energy carriers that will “feed” the building in the operational stage. In order to understand the potential of the instrument in interdisciplinary assessments, different diets of the inhabitants can be assumed, choosing different foods to be consumed by the residents and different waste disposal strategies. The information included in the database are geo-referenced, in order to identify the locally sourced products.

5) After entering the data in Phase 3 and Phase 4, the spreadsheet processes the input and output flows referred to the land parcel and related to the choices made. The description of inputs and output is expressed in terms of kg or tons of matter, but also in terms of specific impact indicators included in the database, for example in kg of CO_2 equivalent, MJ of primary energy (renewable and non renewable), sej (solar emergy joule), the characteristic unit of measure in the eMergy analysis [2]. The availability of data in the database allows as well to assess the flows of money related to input and output flows triggered by the different design choices, improving the awareness of the possible economic impact on local production activities.

The processed flows have been set on an annual basis, and can be described in three different ways: dynamics counted per person, dynamics counted per sqm of dwelling, dynamics counted per building. This information structure allows assessing the impacts of the various consumption categories within the same tool. For example, the accounting of greenhouse gas emissions can be done by including in the same assessment procedure the environmental load related to different consumption categories, like housing and food. In this way the priorities that the designer must take to achieve the goal of reducing greenhouse gas emissions of the inhabitant, are easier to find (Figure 2, Figure 4).

At the same time, the information pattern allows comparing the processed data to benchmark values associated with the sustainability indicator adopted, and expressed in terms of per capita figure. Indeed, for instance, the designer can be aware of how much the aggregate contribution of housing and feeding to the green house gas emissions of the dweller can remain below or above the benchmark sustainability value. In the case of CO_2 emissions it amounts to 2000kg per capita by 2100 [3] (the evaluation to be complete should be able to evaluate the impacts of transport, services and other consumptions, but this will be the subject of future investigations).

As the input and output flows from the land parcel are geo-referenced, the tool produces specific maps, which show the geography of the impacts related to the flows. Such impacts are represented on maps of different geographical areas, global, European, national and local. They are described by circles located where drawing or emission take place. The size of the circles is proportionate to the annual flow, quantified in terms of the specific indicator adopted (solar eMergy joule, kg CO_2 equivalent, MJ of primary renewable and non-renewable energy, flows of money) (Figure 3,Figure 4).

RESULTS

This part of the text shows some of the results of the application of Elar in an urban environment, the municipality of Albairate, on the west-side of Milan. The instrument was used to evaluate the design choices applied to a residential building renovation, with the main aim to improve the energetic performance of the building and to reduce its environmental load.

The data presented in this part of the text show a comparison between two cases, a first referred to the existing situation, which describes the different dynamics related to the metabolism of the building as it is (average practice), a second (eco-consistent practice) where the energetic-environmental upgrading of the same building is assumed and a different diet for the inhabitants is suggested (a diet representative of the average food consumption per person in Italy has been considered in the “average practice” case, in the “ecoconsistent practice” case a different diet that prefers food of lower caloric content and of local derivation is proposed).

In the eco-consistent case the interventions on the building include:

- Improving the performance of the opaque envelope, through the creation of an outer layer of kenaf fibers insulation.
- Increasing openings to the south and improving the thermophysical characteristics of the transparent envelope.
- Use of solar thermal and photovoltaic panels on the roof.
- Installation of heat recovery ventilation systems.
- Use of local sourced biomass for space heating and water heating.

The intention to evaluate the sustainability effectiveness related to design choices on upgrading existing buildings, has led to pay particular attention to the representation, using GIS, of the existing building conditions and how they interacts with the local climatic factors.

The thematic maps that describe the climatic factors have been developed using cartography normally available to local governments. A DEM (digital elevation model) at 0.5 m resolution (1 pixel = 0.5 m), has been built starting from a bidimensional map of buildings profiles with roof gutter heights. The DEM has allowed to develop, through a GIS, map of the solar radiation incident on the built environment, representing the different components of direct and diffuse radiation (Figure1). Furthermore it has been possible to calculate and represent the solar radiation incident on the facades of the buildings, producing maps processed at a regular height from the ground (+1.5 m, +4.5m, + 7.5m, etc.).

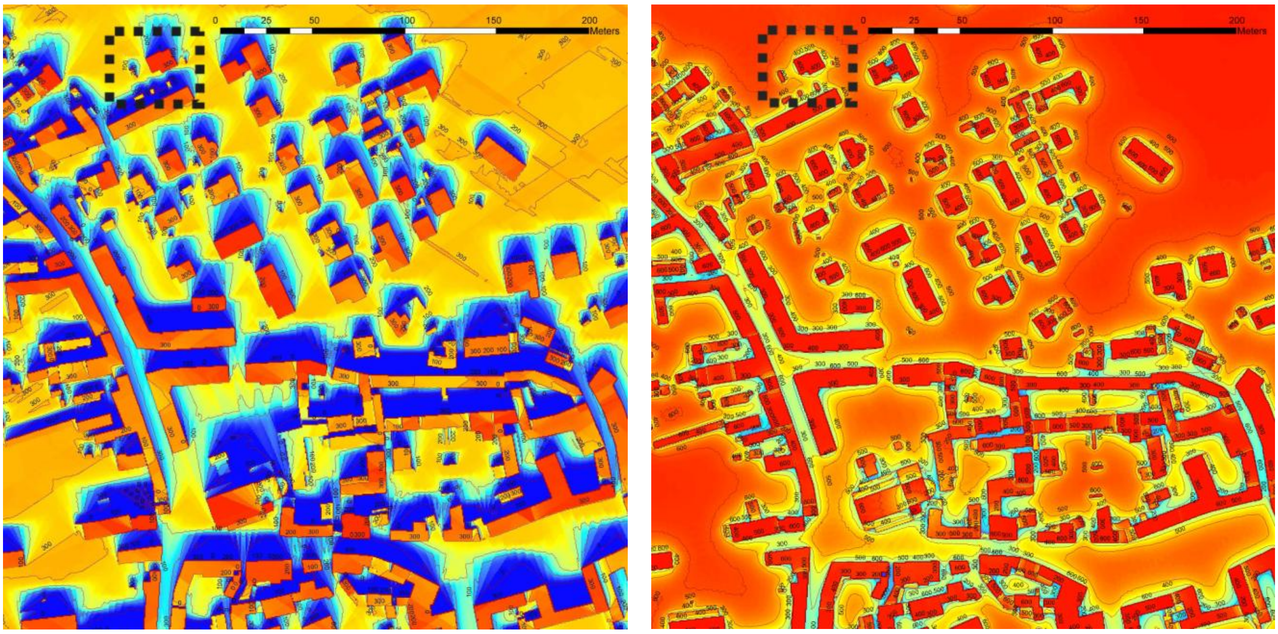

Figure 1: Daily direct and diffuse solar radiation map, average values in January, Wh/sqm. The dotted square shows the building chosen.

The following figures show the results of some of the processing performed by ELaR comparing the two cases. In particular Figure 2 shows two synthetic histograms, that put in relation the CO_2 emissions due to the consumption categories of housing and food with the sustainability level of 2000 kg of CO_2 / person [3].

Synthetic histograms are supported by more detailed histograms (on the right side of the main histograms in the figure) in which the dynamics related to different consumption categories are quantified in terms of equivalent annual flows per person. This configuration allows the designers to be able to review the priorities to be taken, aiming at achieving the sustainability of the lifestyle of the person who will live in the building (the description of the equivalent annual flows related to building materials was carried out by dividing the initial investment for the possible duration, 50 years for building materials, 30 for the equipment).

Figures 3 and 4 show, respectively, the flows of renewable eMergy and the flows of money, which are locally related to the dynamics triggered by the categories of housing and food. The maps presented are automatically generated from the spreadsheet and represent the geographies of the impacts related to the adopted indicator. In the first figure (Fig.3) the maps describe the location of renewable resources used and the amount described in eMergetic terms, solar eMergy joules [2]. In the second figure (Fig.4) the maps denounce the actual economic impact on the local context of decisions taken during the design process. They represent how the description of design choices in terms of flows per person and the geo-referencing of these, can be an effective proposal for an integrated assessment of economic viability and environmental sustainability of the project.

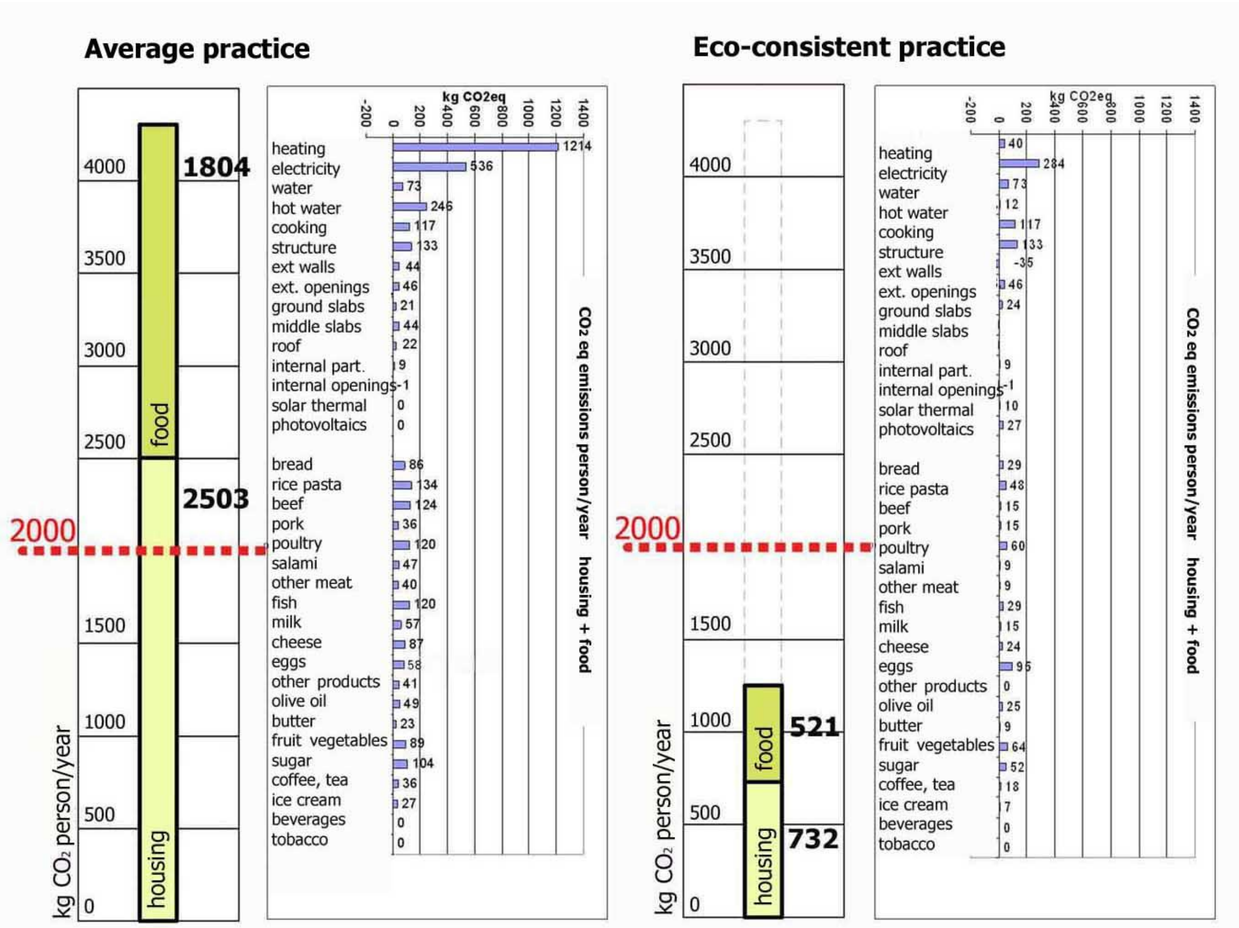

Figure 2: CO_2 eq. emissions/person-year related to housing and food. The dashed line defines the sustainable limit to the annual emissions per capita. The histograms on the left refer to the average practice, the building as it is, those on the right refers to the more eco-consistent one, the upgraded building..

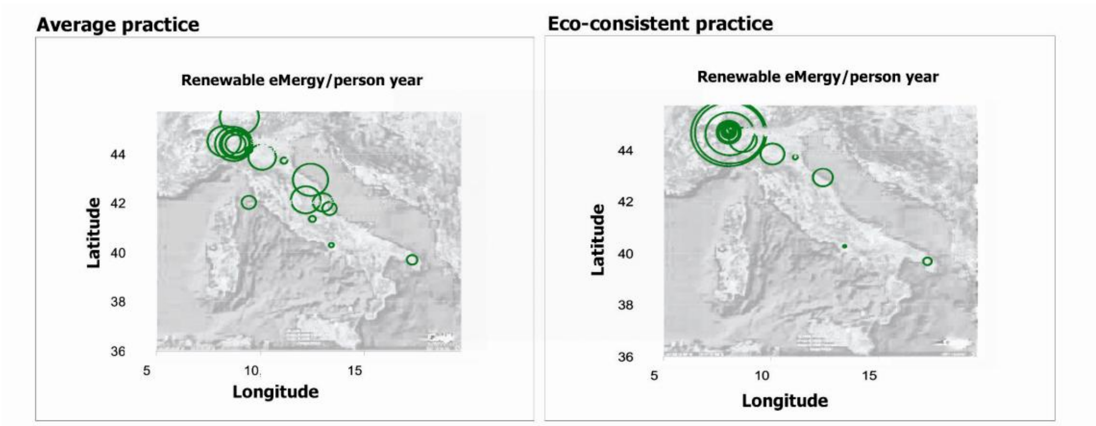

Figure 3: Maps of renewable eMergy flows activated by the average practice, the building as it is (on the left), and the more eco-consistent one, the upgraded building (on the right).

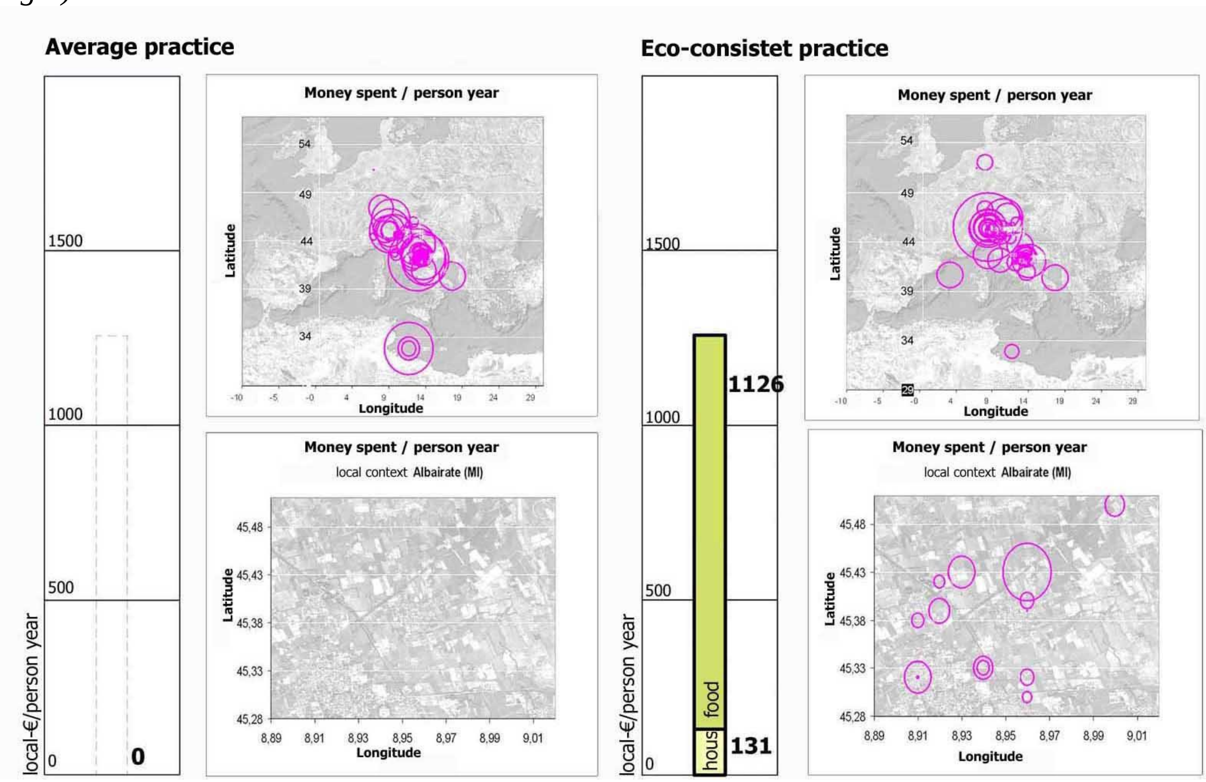

Figure 4 : Synthetic histograms and maps of annual money flows activated by the average practice (on the left), the more eco-consistent one (on the right). The histograms measures the amount of money spent inside the boundaries of the local context.

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URBAN ACTIVITIES AND CRITICAL STOCKS

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ABSTRACT

Assessing contemporary society´s burden on the planet has been an ongoing project of many research teams in many disciplines. The recent emergence and proliferation of efforts to understand the role that cities play has led to the near-simultaneous development of various frameworks, methodologies and working models that capture urban resource flows and account for expenditures by industry, households and infrastructure networks; including power, water, and transportation. This paper introduces an urban resource flow model and describes the organization of its various elements with respect to two key fields; urban economics and ecology. The central organizing principle of this framework is the delineation of three fundamental urban activities occurring within a context of socioeconomic and biogeochemical material and energy transfers. These three urban activities are the direct link to key theoretical elements of both urban economics and ecology and thus facilitate a cooperative relationship between the evolving understanding of urban resource flows and economic and ecological urban thinking.

INTRODUCTION

The study of cities has been an ongoing preoccupation of philosophers and scientists since the widespread phenomena of urbanization was noted by ancient philosophers and poets. The seemingly inevitable development of cities everywhere on earth, in every society and culture throughout time has elicited commentary regarding the nature of agglomeration in social, political and economic terms. Aristotle remarked that "...[t]he city belongs among the things that exist by nature, and…man is by nature a political animal" [1].

Throughout the 19th and 20th centuries, several strands of thought wove together to eventually bring us an understanding of urban centers as complex dynamic systems that act as political and economic foci for regions and nations and are regulated by resource flows serving a well-defined set of fundamental urban activities. This understanding came as a result of a convergence of political, ecological, and social ideas spurred on by work in the sciences, especially as related to the societal demands on energy and material resources [2, 3, 4, 5, 6]. It is not surprising that this multi-faceted concept of the city began to emerge as the world was undergoing the fundamental transition from an agrarian-based sociometabolic regime to an industrial-capitalist regime based on nonrenewable fossil fuel material and energy resources [7].

During the early 20th century, the idea that societies needed to understand and carefully manage their growth, especially as manifest by sprawling urban regions was beginning to be articulated by planners, ecologists, economists and others. For example, E.P. Odum, the American ecologist, was one of the first to understand that the rural-urban interface needed special attention. In 1969, he wrote, "...[we] have not yet risen to the challenge of the urban-rural landscape, where lie today's most serious problems." [8].

For many years now there has been a clear determination that the transformational effects of anthropogenic activities can be found in every biome on earth [9]. Recently, a proliferation of studies that characterize global resource flows has led to a better understanding of the network of material and energy exchanges that serve contemporary society and the ramifications for the environment [10, 11, 12]. We now have large scale studies that are, for the first time, tracing the extraction and consumption of the world´s resources during much of the period of human history since, and sometimes before the industrial revolution [7, 13].

Most recently, a renewed focus on cities has been prompted by the growing awareness that the majority of the global population is now urban and, as a result, global resource consumption, carbon emissions and waste dispersion is concentrated in cities [14]. This awareness has catalyzed an array of research and implementation projects around the globe that are striving to meet the needs of a growing urban population while taking on the challenges of global warming, critical resource shortages and the political and social realities of a new urban century [15].

The research work highlighted here and forming the organization of this paper takes as its departure two themes; the metabolic nature of urban systems, and the resource flows serving three fundamental urban activities. These are treated in the following sections: **URBAN METABOLISM**, and **URBAN ACTIVITIES AND RESOURCE FLOWS**.

URBAN METABOLISM

Urban metabolism is the study of material and energy flows arising from urban socioeconomic activities and regional and global biogeochemical processes. The characterization of these flows and the relationships between anthropogenic urban activities and natural processes and cycles defines the behavior of urban production and consumption [16, 17, 18].

The primary methods that are being adopted for assessing the complex dynamics and resource intensity of an urban zone are stock flow models serving a system dynamics (SD) architecture regulated by the conventions of material flow analysis (MFA). System dynamics is well known for its utility to organize and analyze the various elements of a complex scenario [19, 20]. In recent years, MFA has been used to account for the actual physical flows devoted to the urban socioeconomic engine resulting in several studies that attempt to characterize these flows [21]. Urban metabolism models are derivatives of national economy-wide material flow analysis models [22, 23]. While national-scale MFA methodologies are now well-established and offer clear conventions on border designation, flow characterization, accounting methods and definitions, the urban metabolism method has not reached consensus on these and other elements for the modeling of urban resource flows.

This lack of consensus is a major motivator behind the work presented here. While there are many elements that require attention in the formulation of a robust MFA for urban zones, a critical aspect of further development involves identifying and providing the best linkages between urban-scale flow accounting and the prevailing theoretical frameworks of both urban economics and ecology.

URBAN ACTIVITIES AND RESOURCE FLOWS

The derivation of key linkages between the urban metabolism framework and urban economics and ecology requires a brief outline of the relevant elements of these fields and an explanation regarding their relationship to physical accounting. Understanding the economies of cities and the ecologies that feed and reside within them would seem to be important aspects of urban theory and research. Yet, economists and ecologists alike are latecomers to the study of cities, having been preceded by historians and sociologists.

Urban economics

The core question for urban economics is why do people choose to locate in dense settlements? The answers thus far are derived of a fundamental cornerstone of urban economic theory; that of spatial equilibrium. Cities attract people, firms, and construction in a seemingly mutually beneficial equilibrium contained within a relatively small spatial extent. Cities exist because of the dynamics behind this spatial equilibrium. It has been the work of the urban economists and economic geographers to explain the mechanics of this equilibrium [24].

It turns out the governing attribute of urban spatial equilibrium is that a benefit in one location must be accompanied by an equilibrating cost in that same location. That is, urban economies lack the presence of arbitrage opportunities [25, 26]. In addition, the utility of a location can be shown to be:

Utility = Income + Amenities – Housing costs – Transportation costs

The concept of spatial equilibrium has led to the development of models that attempt to illustrate the dynamic relationships between wages, transportation and housing costs and amenities, all while balancing centrifugal and centripetal forces in the maintenance of the urban economy [24]. Various models have been empirically verified to show that holding income and amenities constant leads to a close correlation between housing and transportation costs, and similarly, holding transportation costs and amenities constant leads to a close correlation between income and housing costs (for example, the Alonso-Muth-Mills model) [27]. The usefulness of this conceptual framework is the ability to consider, for example, the possibility that building integrated and community-owned renewable energy production and storage within a city may be classified as an amenity by the residents of that urban district. In urban economic terms this would correlate directly with housing, transportation costs and income levels for that district. Significant work is now trained on the relationship between urban development and environmental issues [for example, 28].

Urban ecology

Urban ecology has been focused on urban ecosystems with the intent to understand and eventually shape the interaction between socioeconomic urban activities and natural ecosystems [29]. Closely related to the work in urban and regional planning that addresses the urban-nature interface, urban ecology derives its theories and methods from linking the science of natural ecosystems with sociological studies of urban systems and form [30, 31, 32].

Some of the most intriguing and potentially useful work to come out of this field are associations between urbanization and certain transformational effects on biogeochemical processes [14, 33]. For our purposes, the link between key attributes of urbanization, such as density and impermeable land cover, and particular effects on hydrological, carbon, nutrient, oxygen and other cycles is particularly useful here. The MFA/SD approach uses the latest research that has shown robust causal links between urbanization and ecological effects [34, 35].

Urban activities: Products, Buildings and Transport

Several models that attempt to describe resource flows within the economic and ecological context of urban regions have been developed (notably UrbanSim/OPUS). The use of these models for detailed analysis of specific cities and their regions is well-established. However, robust simple models that generalize dynamics of urban systems based on an accounting of resource flows are not well developed. The use of these models as avenues towards better understanding of urban typologies and characteristic urban resource consumption profiles is needed.

The model presented here delineates energy and material flows devoted to three broadly inclusive sets of urban activities (see Fig. 1):

1. the provision of habitable space (the built environment, ua_1),
2. the provision of goods and services of all types (products, ua_2) and,
3. the provision of the movement of goods and people (transportation, ua_3).

These urban activities are formulated as ***provisions*** of urban living and working. That is, the city is conceived of as a collection of necessary and sufficient provisions of habitable space, goods and services (especially air, water, food, critical materials and waste removal) and transportation.

This formalization is intended to provide a robust intellectual and operational link to the main theoretical assertions of economic economics and urban ecology. Specifically, spatial equilibrium is organized according to the production of firms and workers (goods and services) and the costs of housing (built environment) and transportation. These explicit links lend important guidance in the ongoing project to link economic models of urban growth and development with models of resource consumption that take into account natural cycles and biogeochemical processes.

Figure 1. represents this link as a flow diagram regulated by dynamic system relationships.

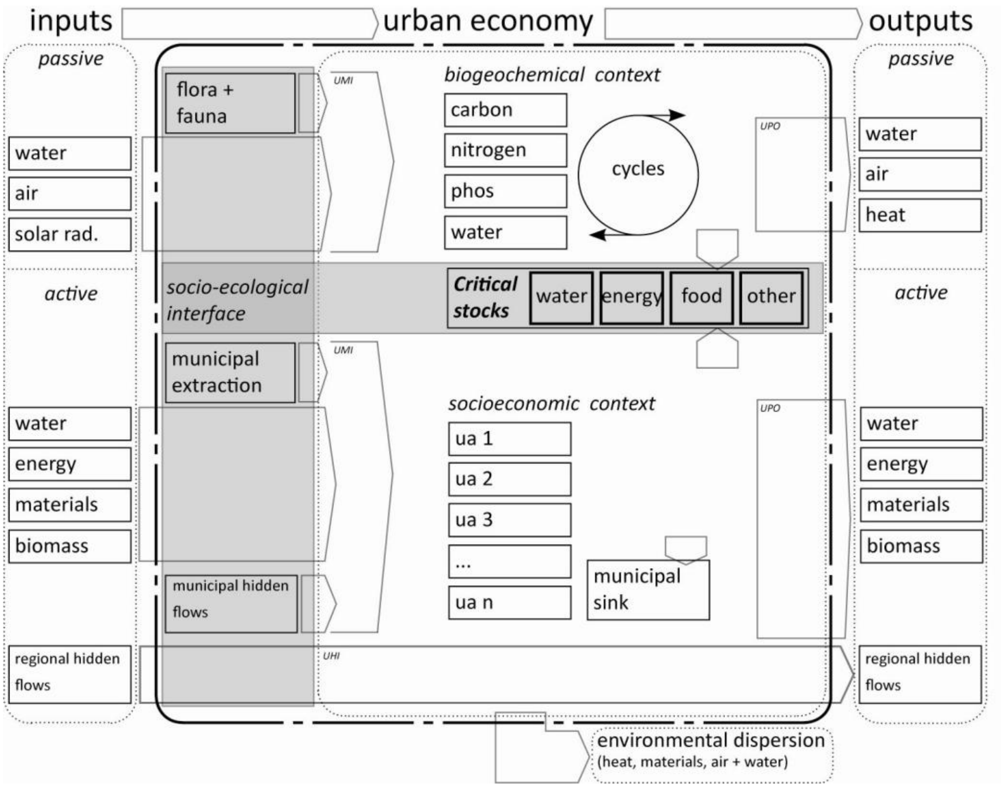

Figure 1: Urban metabolism material flow analysis model (MFA).

DISCUSSION

The framework above is organized into a stock-flow model using software that incorporates both system behavior and resource flows (energy and materials, using Anylogic® system dynamics software). Air, water, energy and fuels, and mineral and biomass materials are accounted for as they are required by the three urban activities listed above. Resource intensities are defined as densities of consumption devoted to fixed and running resource expenditures. Metabolism is defined as per capita resource consumption related to the provision of goods and services, the built environment and transportation. Individual composite resource intensity indices are defined for each class of urban activity. In this way, the three urban activities can be assessed in terms of their aggregate and per capita resource demands. Critical stocks are defined as those required to maintain a minimum urban metabolism for the health and safety of urban residents. The constraints of this paper do not allow a full rendering of results from simulation runs.

ACKNOWLEDGEMENTS

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WIND FLOW AND SUN ACCESSIBILITY IN NARROW SPACES BETWEEN BUILDINGS

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ABSTRACT

The presented work is devoted to estimating the effects of building size and arrangements on the local microclimate parameters wind speed and sun radiation. Particularly, the above factors have a significant influence on the following physical processes on the external surfaces:

- heat exchange (absorption, emission and convection) [1],
- moisture exchange (damping and evaporation) [2].

The presented results were obtained using numerical techniques for a particular building site. The joint wind and sun effect on a building façade depends among other things on the distances between buildings, their magnitude and orientation. Higher impact processes were noticed especially for a close distance between buildings. Therefore, both factors have a strong influence on the stability and regularity of physical processes in the case of narrow spaces. Finally, the correlations between sun accessibility and wind flow in the corridors were estimated for analysed cases. The highest differences in wind speed and solar distribution on the analysed façade were observed in the case of asymmetric geometry.

INTRODUCTION

Multiple transformations in urban grids, with retained historical buildings, result in local increase in town densities. Protection of cultural heritage and on the other hand increasing prices of the ground in downtowns create new modern structures in the close neighbourhoods of the old ones. If they do not have a common wall, a minimum distance between them results in creating new, inner open spaces (a few meters wide). Usually, they have the form of joining corridors but sometimes they are inaccessible. Depending on the geometry of buildings and arrangements, a change of local microclimate parameters such as sun, wind or precipitation can be observed. In comparison with fully exposed buildings in more complex urban structures the wind flow becomes disturbed and sun penetration is limited.

The magnitude of processes occurring on the external building envelope are determined by access of sun, wind and precipitation [3,4]. For fully exposed buildings located in an open space terrain, the influence of all of these parameters is easy to predict. However, for a built environment, the interactions between elements become more significant. While the solar access for a dense area is usually limited by surrounding elements, the effect of wind and falls can decrease in some particular cases. This joint effect of wind and sun can play an important role in the following cases:

- water evaporation from the surface of building components after rain,

- solar thermal energy accumulation in the outer faces of a building,
- heat exchange by convection and radiation between building and surrounding,

The results presented in the study focused on sun and wind accessibility for three case studies of building arrangement. The set of results is compared with a base case – the theoretical building in fully open space.

CASE STUDIES

In the presented study, four cases of building arrangements differing in geometry and lining shape are considered. The theoretical schemes are presented in Figure 1. The wide squared plan building is an existing one – the base case. The hatched elements play a role of a new marking in urban structure. All three modified cases can be described as follows:

- sheltered on one side (screened) - B,
- semi sheltered in two sides (semi surrounded) - C,
- sheltered on three sides (nestled) - D.

For the purpose of the presented study the dimensions of the existing building (base case A) was assumed to be 10×10×10 meters. Other cases (from 1 to 3) were created by adding new surrounding elements as presented in Figure 1. The distance between an existing and an additional building can be additionally determined by national level regulation and conditions or height and local interactions between buildings. In the analysed cases only narrow passages were taken into account. Three distances between buildings were examined ¼h, ½h and 1h (d = 2.5, 5 and 10m) (Fig. 1).

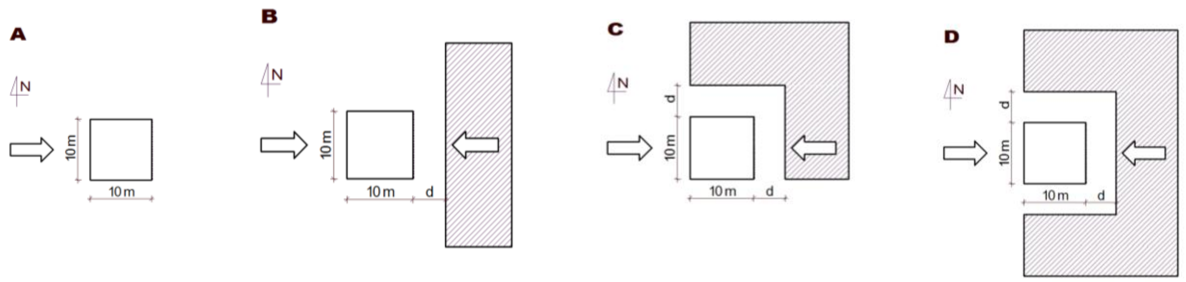

Figure 1. Analysed cases of main building and its surroundings.

For all arrangements from A to D the wind directions (white arrow) were determined including the prevailing wind for the analysed location. After initial analysis some of the cases were eliminated because of their small contribution to this analysis. The sun penetration values for the whole year were determined by latitude 52 and average declinations for each month. It gave the following boundary conditions presented in Table 1.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Max. Sun altitude [deg]	17.7	26.3	38.0	49.7	58.3	61.5	58.3	49.7	38.0	26.3	17.7	14.6
Average total solar radiation [kWh/m^2] on east oriented vertical surface.	226	262	638	877	1208	1285	1251	1032	648	421	203	163

Table 1: Main solar parameters for specific locations.

RESULTS

Solar access

The analyses of solar distribution inside the passage between buildings were limited to the direct solar radiation. The obtained results were averaged for selected months and referenced to the base case.

Results of the three analysed types of geometry are presented in Figure 1. The distance between buildings was assumed to be equal to building height. For the analysed orientation the relative good insulation was observed for the case C, where the existing building is less obstructed from the east side. On the other hand for cases B and D, the amount of direct solar energy reaching the east façade is two times smaller. For the summer months (from May till August) the differences between the three cases are unsubstantial.

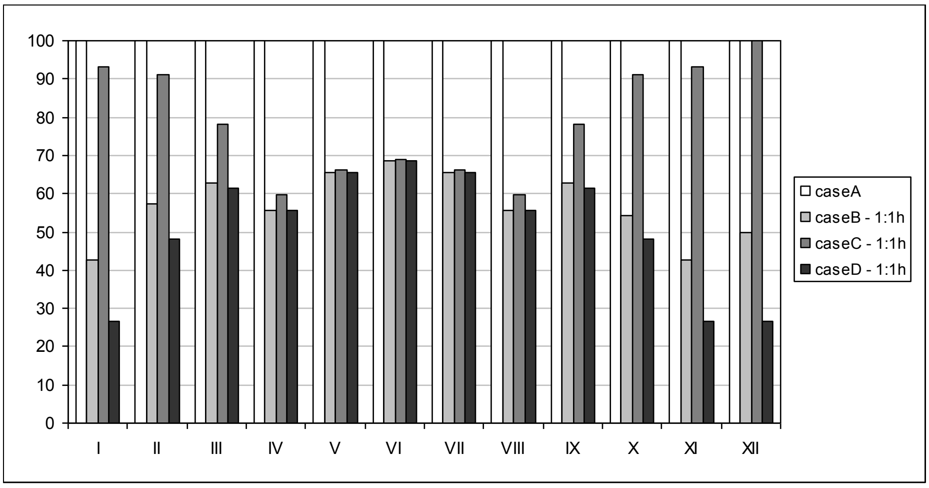

Figure 2. Comparison of solar direct radiation for analysed cases.

Figures from 3 to 5 present the influence of distance between buildings on solar direct availability in the passage. For each case the sun penetration decreases with a reduction in the distance between buildings (about 25% for ½h and 50% for ¼h). In case D, for January the amount of solar energy can be almost 10 times reduced compared with a building in an open space. In case C (opened from south-east) it is only 50%. For June the results in both cases are similar showing a reduction on the level of 30%.

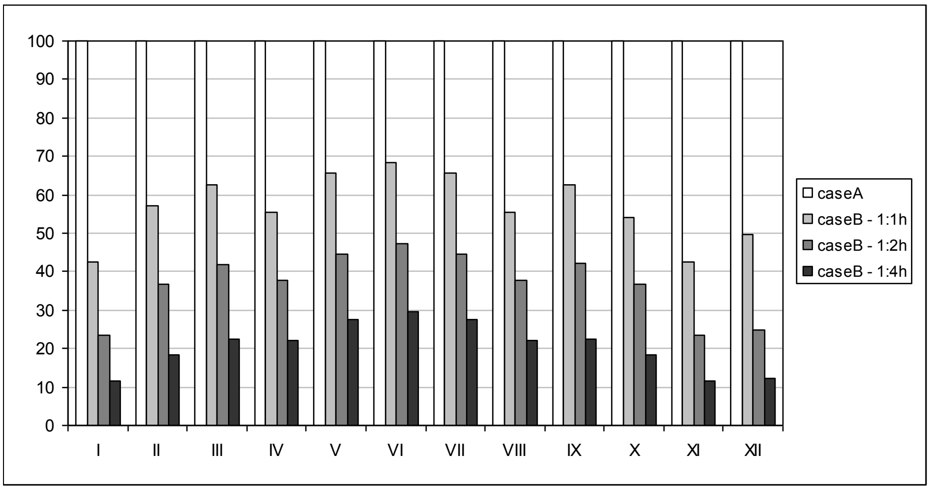

Figure 3. Comparison of solar direct radiation for different building height in case B.

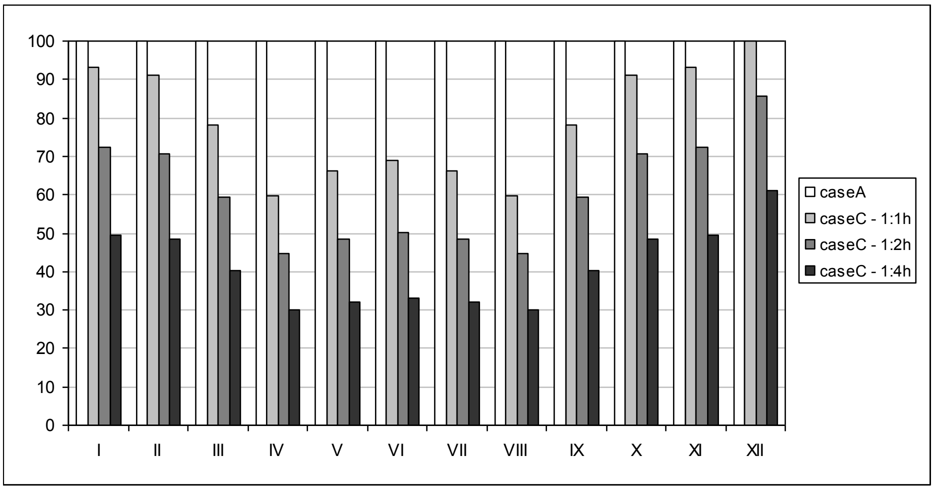

Figure 4. Comparison of solar direct radiation for different building height in case C.

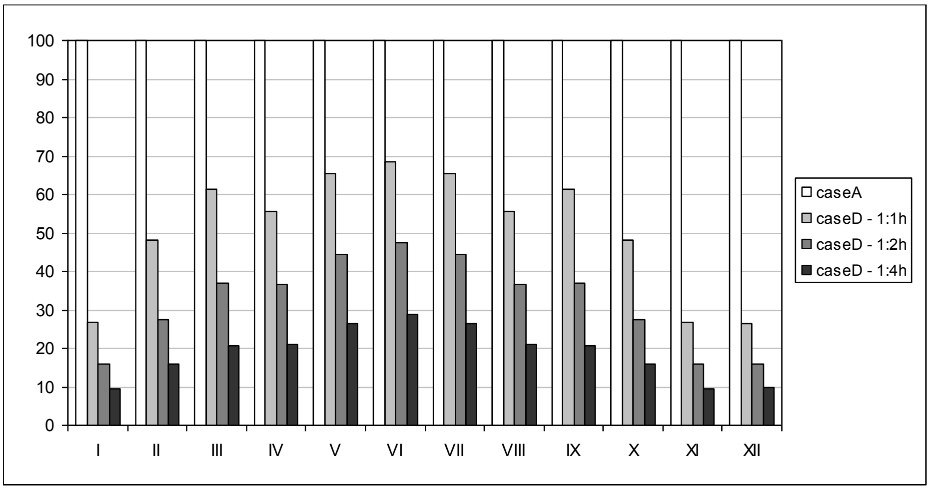

Figure 5. Comparison of solar direct radiation for different building height in case D.

Referring to the available total solar radiation and shading analyses, the amount of solar gains on the east oriented wall during the whole year is the most even in a case C.

Wind penetration

In urban areas, wind conditions are characterised by sudden changes in speed and direction. There are many parameters, which influence the wind flow, such as: buildings themselves (their shapes, sizes, positions etc.), surface roughness, turbulence or approaching wind speed profile. In the vicinity of the building, a characteristic wind flow pattern can be noticed. In front of the building a large vortex is formed caused by the air flow down the windward facade. Around the building corners the flow separates and creates corner streams characterised by large wind speed gradients. In the lee of the structure a recirculating wake is formed. The flow is unsteady with the vortices being periodically shed [5]. The presence of multiple buildings with different configurations and dimensions complicates the wind flow and gives rise to local increase in wind speed and turbulence. As a result, even for a single wall, different characteristics of wind speed and direction can be observed, which could have a considerable impact on indoor comfort and the destruction processes of the construction materials.
In order to predict a steady–state wind flow pattern around buildings, the CFD technique has been used. Analyses have been done using the realizable K - ε model developed by Shih [6]

and the wall function. In the inlet of the computation domain, a logarithmic mean wind profile has been established. As the reference wind speed, u_{10} = 5m/sec (at an altitude of 10 m above the ground level and on a field with z_o = 0.03m) has been assumed. The roughness length z_o has been assumed to be 0.25m (for rural area). Considerations were limited to the west and east wind directions. The main aim of the study was local wind condition in the narrow passage between buildings. Therefore the wind speed was analysed on the vertical plane located 0.5m from the east elevation of existing building (Figure 1).
In all analysed cases, a small distance between buildings causes an increase in wind speed with height within the whole façade. It can be clearly seen in the case of type B and D. Increasing the distance between buildings results in a more homogeneous wind speed distribution. Only near the surface layer can the small gradients be noticed while within the rest of the wall the velocity does not change visibly. Figure 6 presents wind speed distribution in the vicinity of the façade for d=2,5m and d=10m.

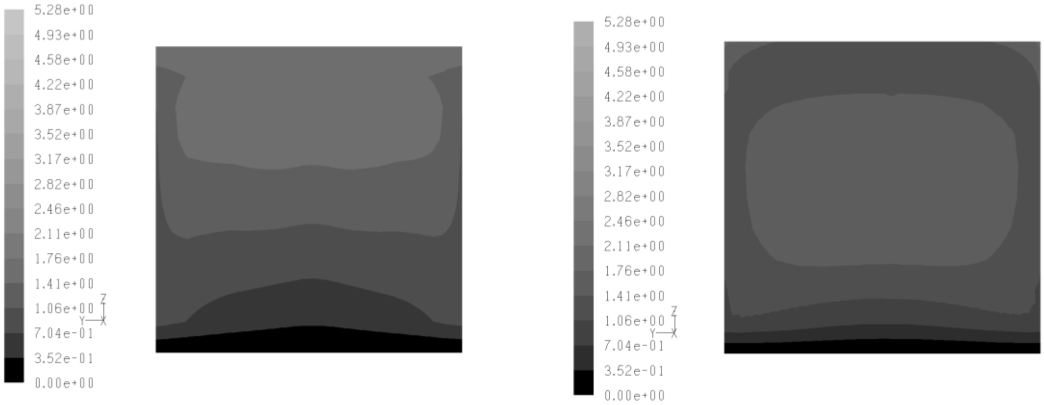

Figure 6. Contours of wind velocity in the vertical plane 0.5m from the east façade (case B, d=2.5m and case D, d=10m, east wind direction).

In the case of a semi surrounded building (type C) the strongest disturbance in wind flow can be observed. Wind speed distribution in front of the wall demonstrates considerable spatial diversification. The neighourhood buildings reflect and accelerate the flow in the passage especially when d=2.5m. Increasing the distance between buildings results in a gradual reduction of spatial differences of wind velocity and for d=10m, distribution has more even character both for a west and an east flow direction. Figure 7 presents an example of assymetric wind speed distribution in vicinity of the façade.

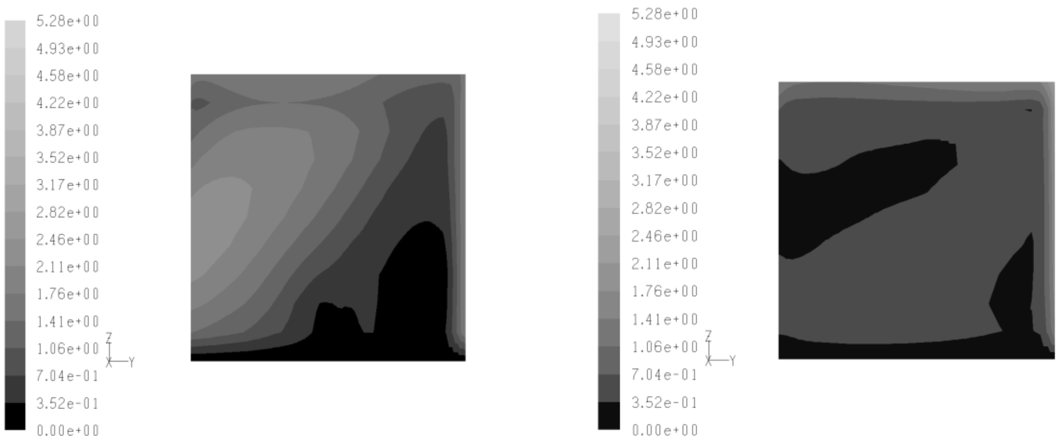

Figure 7. Contours of wind velocity in the vertical plane 0.5m from the east façade (case C, d=2.5m and d=10m, west wind direction).

DISCUSSION

In the presented paper,the wind flow pattern and the sun distribution on a façade located in a narrow passage have been assessed.

In all analysed cases, an increase in wind speed in the passage between buildings were observed. In some situations it exceeded four times the values obtained for isolated building. Depending on assumed geometry, the highest increases were recorded in the central and upper part of the wall. Variations in wind velocities were observed in case C, not only in vertical profiles but also in whole plane of the façade.

On the other hand, the shading effect during the whole year is observed in all cases. During winter a relatively high sun penetration was noticed in case C, open from south-east. For other cases, the reduction in solar radiation is limited even to 10% compared with the base case. During summer months there are no significant differences between all three analysed cases.

The presented results are part of multi-factor analyses of climate interaction on external walls. This part is devoted to wind flow and sun accessibility in spaces between buildings of complex arrangements.

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EXPLORING SOLAR-RESPONSIVE MORPHOLOGY FOR HIGH-DENSITY HOUSING IN THE TROPICS

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ABSTRACT

This paper investigates how common built-form variations in high-density collective housing design influence the amount of solar radiation falling onto building facades in the tropical region, which potentially inform design strategies that reduce solar heat gain. There is currently no lack of solar-responsive design concepts but their relative effectiveness is seldom quantified and compared. By tracing the evolution of housing design in Singapore, common built form variations in high-density housing are identified. Generic urban forms are constructed to represent these variations while other parameters are held constant. RADIANCE simulations on solar radiation are then performed on these generic forms under the aggregate skies for the cooling period of Singapore (hot-humid) and Abu Dhabi (hot-arid).

Results from the simulations show that, while south-facing slab blocks are often regarded as being favourable to the reduction of solar heat gain, cruciform towers that create convolutions on the building facades receive even less solar irradiation during the cooling period. It is also demonstrated that the traditional strategy of avoiding direct sunlight by adopting a dense urban fabric may not be favourable in terms of the distribution of solar irradiation and other non-environmental design objectives. The results call for the need of simplified assessment tools in the early design stage to verify broad-brush design concepts in an urban context.

INTRODUCTION

Evolving from simple slab blocks and perimeter blocks at the turn of the 20th Century, variations in high-density collective housing design have flourished to fulfil new aspirations for the living environment. Due to morphological complexity and mutual obstruction in a high-density urban setting, solar heat gain on building façades can no longer be assessed simply based on the orientations of individual building facades. The presence of multiple dwelling units in a single building also means that the radiant environment of different units can hardly be simultaneously optimised. As part of an on-going research, this paper investigates how common variations in high-density built forms influence the amount of solar irradiation on building facades, with the ultimate goal to derive climate-responsive housing morphology specific to high-density tropical cities.

METHOD

Construction of generic urban forms

Major built-form variations in high-density housing design are identified by tracing the evolution of the public housing in Singapore (HDB) from 1960 to date, which exhibits a rich variety in built forms. An in-depth study on HDB is therefore conducted to understand the major built-form variations of high-density housing developments [1]. **Site coverage,**

directionality, façade convolution, building clustering and building enclosure are identified [2], and the first four are studied in this paper.

To enable direct comparisons between these built-form variations, generic urban forms with the same density (Plot Ratio 3) and volume-to-façade ratio (5m) are constructed unless otherwise specified. This is achieved by composing building footprints with five 12x12m squares and a perimeter of 144m, which will then be extruded and multiplied to create the desired urban forms as exemplified by the "courtyard" and "tower" forms in Figure 1. "Virtual pyranometers" on a 1m x 1m grid are assigned to the building façades of all generic urban forms to record the direct, diffuse and global solar irradiance calculated by RADIANCE.

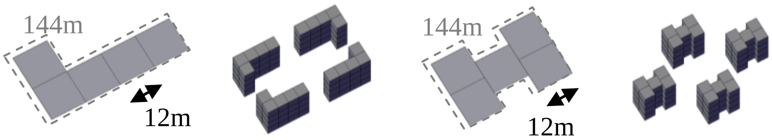


Figure 1: Constructing standardised "courtyards" and "point towers" with 12x12m squares

Construction of aggregate skies

While hour-by-hour simulation would be too computationally demanding for the scale and the quantity of the concerned built form variations, simulations merely on representative days would be too coarse for the purpose of this research. Aggregate skies based on typical meteorological year (TMY) weather data [3] are therefore constructed to cater for both speed and accuracy. Hourly direct solar radiation values are assigned to sun positions in 10-min increments [4]. The hourly distribution of diffuse solar radiation is calculated with the Perez's all-weather sky model [5]. These radiation data are fitted onto 991 angular positions on the sky vault with equal zenithal and azimuthal intervals [6], with bi-linear interpolation being performed to create a continuous sky vault for diffuse radiation (Figure 2). The aggregate sky only includes weather data from the cooling period, which is defined by the adaptive thermal comfort model in ASHRAE standard 55-2004 for Abu Dhabi, and is defined as the whole year in Singapore due to its constantly high temperature and humidity.

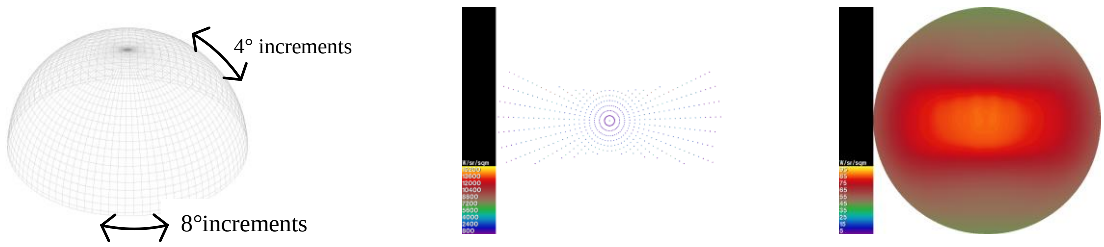


Figure 2: The 991 angular positions (left) and the angular fish-eye projections of the aggregate skies for direct (middle) and diffuse (right) solar radiation of Singapore

RESULTS

Variation 1: Site coverage

In theory, increase in site coverage will increase mutual obstructions between buildings and therefore reduce solar irradiation on building façades. To understand the magnitude of the effect, solar irradiation on rectangular building arrays with site coverage ranging from 0.08 to 0.69 as in Figure 3 are simulated and analysed. As shown in Figure 4, the reduction is modest when the change in site coverage occurs between 0.1 and 0.3, which is a typical range for housing developments in Singapore [2] and cities with similar density. By increasing the site coverage from 0.11 to 0.31 - a reduction of average building height by two-third, the direct and diffuse solar irradiations on building facades will only be reduced by 9% and 17%, respectively under the Singaporean sky (see the dash line on Figure 4). Therefore, although in theory increase in site coverage can reduce solar irradiation on building façades, the required increase is likely to be so substantial that other practical constraints such as the adequate provisions of open space and spacing between buildings would render it impossible.

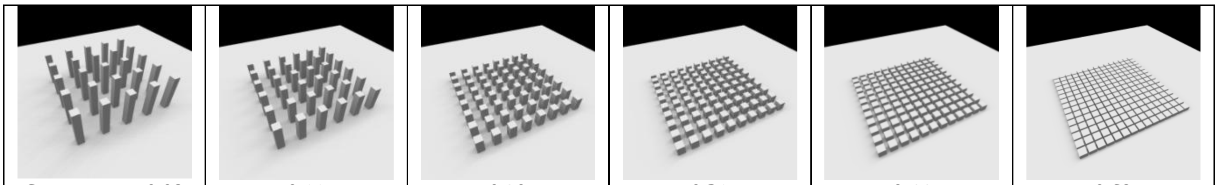


Figure 3: Regular urban arrays with different levels of site coverage

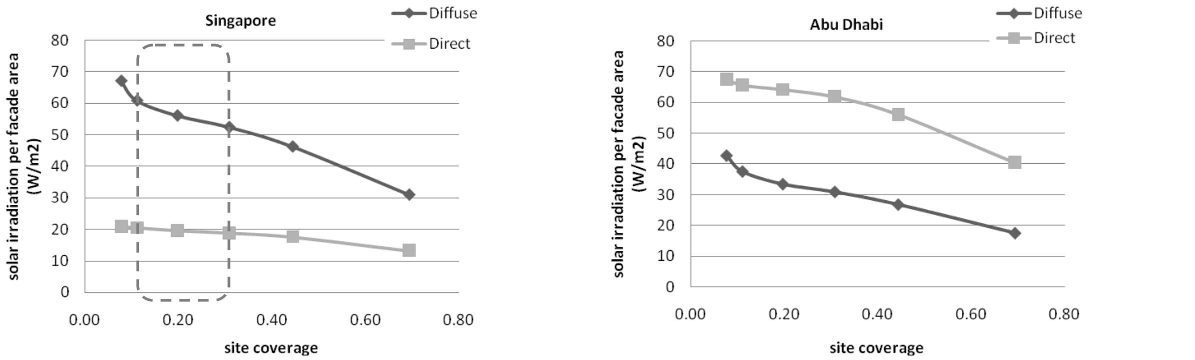
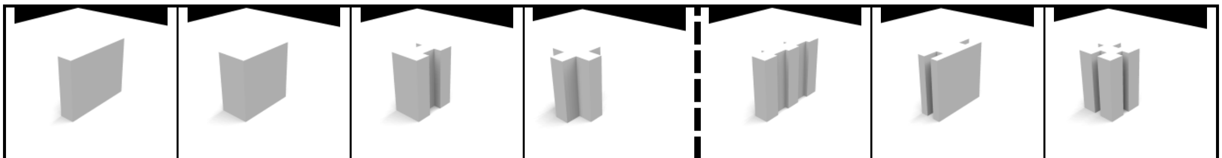


Figure 4: Solar irradiation (W/m^2) on building facades of the central block vs. site coverage

Variation 2: Directionality

It is commonly accepted that solar heat gain can be reduced by orienting the building to the south in the tropical region. In order to understand the magnitude of the effect, four generic forms are constructed to represent different degrees of south-facing while keeping other parameters (building depth and volume) constant. They are shown on the left side of Figure 5. These generic forms are rotated in 22.5-degree increments in order to show how the benefit of directionality decays when the principal façade deviates from due south.



slabreg (I-shape)	lcourt (L-shape)	pointreg (H-shape)	pointconv1 (+ shape)	slabconv1	slabconv2	pointconv2
Building depth (volume-to-façade area ratio, in m)						
5				4.3	4	
Area of south/north-facing façade as a percentage of the total façade area						
80%	67%	50%	50%	71%	80%	53%
Convolution Index						
0%	8%	20%	24%	16%	36%	50%

Figure 5: Generic forms with different levels of directionality and façade convolution

In contrast to the conventional wisdom, the directional I-shape and L-shape blocks receive slightly more <u>global</u> solar irradiation than the non-directional H-shape and "+"-shape blocks, and the difference increases further when the principal façade deviates from due South (Figure 6). While the I-shape block receives marginally less <u>direct</u> solar irradiation than others, this advantage disappears when the principal façade is turned to 22.5° from due south. This counter-intuitive result is due to self-obstruction. A less-directional block concentrates its mass around the centre of the building and is therefore less exposed to the sun and the sky vault. The building depth (volume-to-façade area ratio) is kept constant by convoluting the façades, which results in self-obstruction.

The finding suggests that lower solar irradiation on the south-facing plain does not necessarily imply that south-facing slab blocks would perform the best in reducing solar heat gain on the whole building. Given proper considerations in windows opening, self-obstruction can substitute or even outperform south-facing in minimising solar heat gain.

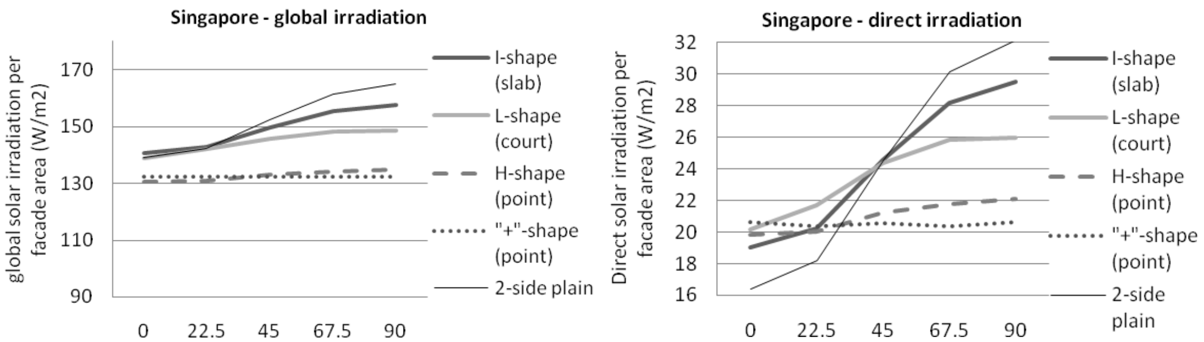


Figure 6: Solar irradiation on building facades per façade area (W/m^2) vs. orientation of principal facade (degrees from south)

Variation 3: Façade convolution

To further investigate the potential of self-obstruction in reducing solar irradiation on building façades, three additional generic forms with lower building depths (4-4.3m) are simulated to demonstrate the effect of façade convolution, which are shown on the right side of Figure 5. Façade convolution is quantified by a Convolution Index, which is defined by the authors as "the percentage increase in the perimeter of the building footprint as compared to that of the smallest convex shape that inscribes the footprint." As shown in Figure 7, although "pointreg", "pointconv1" and "pointconv2" have the most unfavourable south-facing condition in their respective groups, they receive comparatively low amount of solar irradiation, which is attributable to their high Convolution Index (20%, 24% and 50%, respectively). It illustrates that the lack of south-facing can potentially be fully compensated by façade convolution.

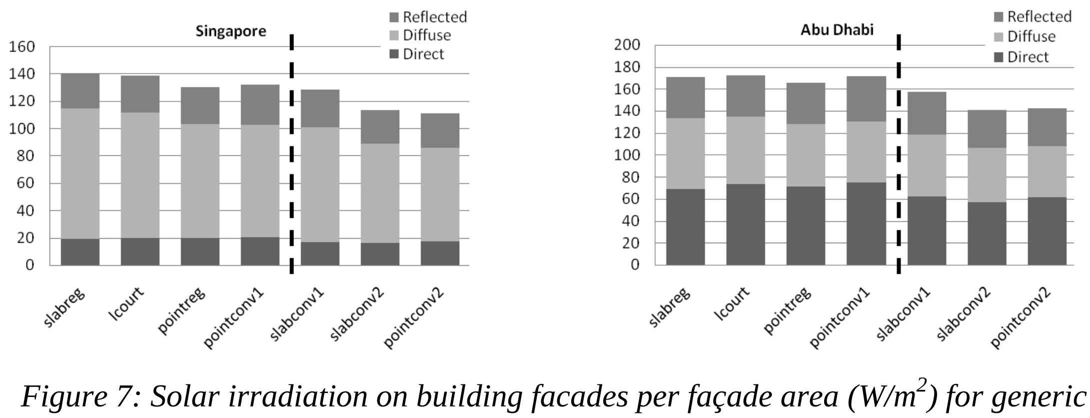


Figure 7: Solar irradiation on building facades per façade area (W/m^2) for generic forms with different degrees of convolution (dash line: change in building depth)

Façade convolution serves as an effective means to provide larger façade area to facilitate cross ventilation without increasing the risk of excessive solar heat gain, which is highly desirable in the hot and humid climate. It also results in more compact form that fits better to the high-density urban context where the bulkiness of buildings is a concern.

Variation 4: Building clustering – catering for sun-shading and view maximisation

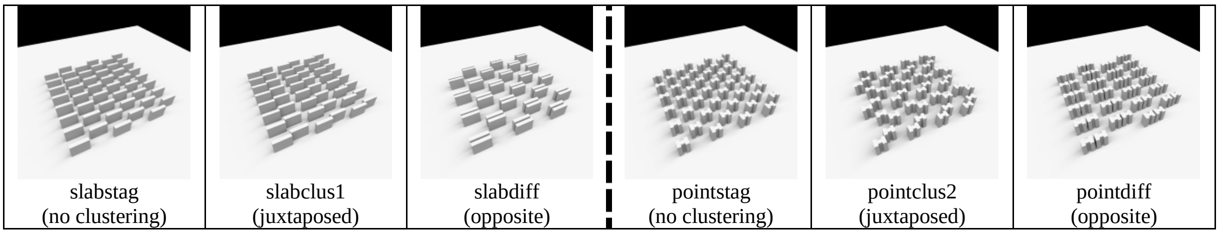


Figure 8: Generic forms representing two approaches of building clustering

Within a building group, clustering puts some buildings closer together and, at the same time, pulls some buildings away from the others. The resultant change in total solar irradiation on building facades becomes uncertain and is therefore investigated here. With "slabstag" and "pointstag" serving as the base cases, two approaches of clustering are studied. As show in Figure 8, one is to juxtapose two adjacent buildings diagonally ("slabclus1" and "pointclus2"), which does not reduce the perpendicular spacing between building facades. The other is to pair up adjacent buildings such that one building façade becomes only 12m away from another ("slabdiff" and "pointdiff").

As shown in Figure 9, only the second approach exhibits a significant effect on reducing solar irradiation on building façades. Results from "slabdiff" also illustrate that clustering buildings along the north-south direction (i.e. not along the east-west sun path) can reduce solar irradiation effectively. While building clustering reduces the flexibility of internal arrangements since the highly obstructed façades will have to be assigned with minor uses, it nonetheless provides a more open view for major uses by enlarging some building gaps.

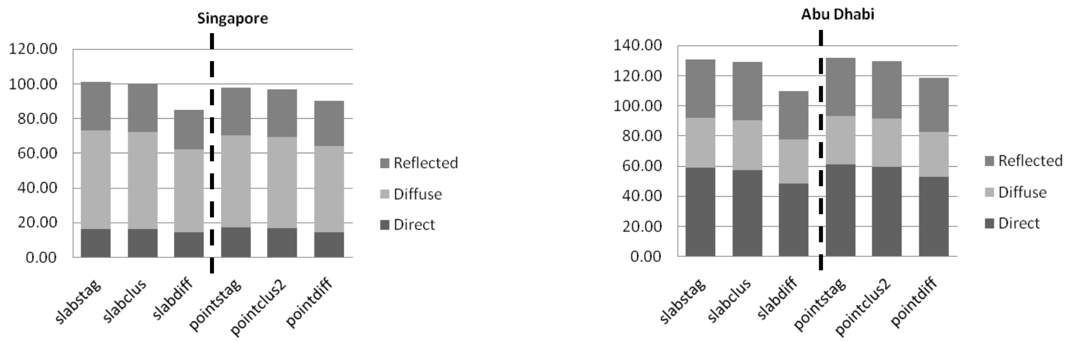
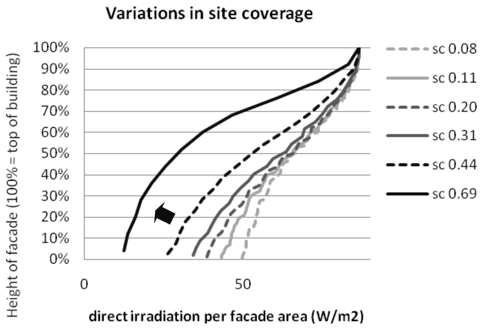


Figure 9: Solar irradiation (W/m^2) on building facades of the central block of generic forms with different clustering conditions (dash line: change in base case)

DISCUSSIONS

This paper documents part of an on-going research in quantifying the effect of major variations in high-density built form on the solar heat gain of residential buildings. **From the above results, it can be observed that morphological design strategies for reducing solar irradiation on building façade are effective only when the intervention occurs near the façade.** The traditional strategy of reducing solar heat gain by adopting compact urban form is effective only when the site coverage is increased significantly, which may not be acceptable for other design objective such as view, privacy and open space provision. The popularity of south-facing dwelling units does not automatically translate to the superiority of simple slab blocks since it offers no self-obstruction, and the benefit of lower solar irradiation decays rather quickly when the principal façade deviates from due south. On the other hand, buildings with convoluted façades shield off solar radiation by self-obstruction. Finally, building clustering can effectively reduce solar irradiation on facades, but the buildings have to be placed façade-to-facade in close proximity. All in all, the above results show that **the application of broad-brush design concepts do not always guarantee real effect.** Simplified computer-aided design methods that provide real-time feedbacks on solar irradiance on building facades are therefore desirable for the conceptual design stage. In this regard, the aggregate sky described in this paper may contribute to the development of simulation tools that provide instantaneous assessments when the built forms are being drawn.

Two additional aspects should be further investigated for more conclusive results. First, not only the total amount but also the distribution of solar irradiation is important in assessing multiple-unit residential buildings. Preliminary results suggest that, for the purpose of reducing solar heat gain, façade convolution and building clustering create a more "egalitarian" radiant environment across the height of a building than high site coverage (Figure 10). Second, the current research assumes homogenous façade design with no sun-shading device. In reality, however, window-opening strategies differ among built forms, and the effectiveness of sun-shading device is direction-dependent. These issues are currently being investigated and will be addressed as the next steps of this on-going research.



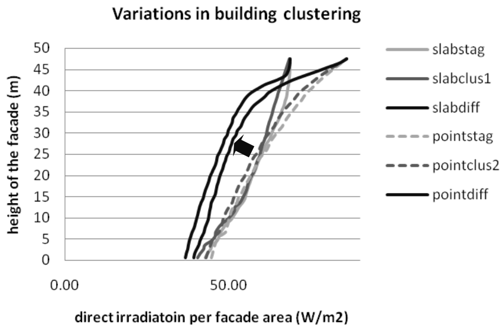


Figure 10: Vertical position on the façade vs. direct solar irradiation (W/m^2) on building facades of the central block under the Abu Dhabi sky

ACKNOWLEDGE

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ENERGY REQUIREMENTS OF CHARACTERISTIC URBAN BLOCKS

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ABSTRACT

The present article analyses energy requirements for heating and cooling typical urban blocks in the Region Ile de France. The analysis has been designed to be applicable at the agglomeration level in France through an automatic classification of urban blocks. It provides a contrasted view on the incidence of compactness and urban organisation upon energy requirements and potential solar gains.

INTRODUCTION

It is usually argued that more compact urban forms would significantly reduce energy consumption both in the building and transport sectors. Whilst this may be true at a general level, the present article proposes to measure the potential effects of the urban organisation upon energy consumption, both for new and existing settlements. In doing so it will focus on energy consumption in the building sector.

In 2004, building consumption indeed represented 37% of final energy in the European Union, which remained higher than consumption in industry (28 %) and transport (32 %). Reducing energy consumption in the building sector hence appears as an important policy target both at the European and the national level. A clear example of such policies is the European Energy Performance of Buildings Directive (EPBD) that is now being transposed by all Member States. Still it has to be admitted that, if a great deal of effort has been directed towards measures at the building level, such parameters like the location and distribution of these buildings have somehow been underestimated until now. Still these factors are key for the global energy performance of cities. Urban density largely influences energy consumption per capita as it is related to building types and compactness, mobility needs of inhabitants and enterprises and, last but not least, available transport means [1].

The present paper is centred on the share of building consumption that can be attributed to urban factors. It hence both addresses constructive and geometrical aspects of the issue along with occupation patterns in residential urban areas. Building consumption include both domestic and non-domestic building consumption . Wide differences in energy intensity according to building types have been documented [2]. Office and retail are, for instance, known to be energy intensive occupation types. On the other hand, an increased diversity of functions between retail, housing and office uses can be viewed as a way to reduce transport needs [3]. It would both contribute to reduce energy consumption and to maintain active and lively urban environments.

In an effort to single out the share of energy consumption specifically related to urban factors, the present paper suggests to compare energy consumption for heating and cooling of different types of residential blocks. The research is oriented towards a better understanding of energy consumption in existing buildings at the national level in France. As the energy reduction potential for technical solutions at the building level is now well identified [4], it claims to evaluate the weight of those factors specifically related to the urban organisation.

METHOD

All being equal, energy consumption in the residential sector highly depends upon the geometry of the urban form. Compactness indeed reduces the external built envelope and hence energy consumption , though it can also significantly reduce energy gains by the multiplication of solar obstructions.

Comparisons in this domain have usually been based on theoretical urban patterns, which tends to ignore the intricacies of actual urban settlements. Obviously the balance between gains and losses is not so easily predictable in existing patterns. It varies with a series of factors, amongst which the geometric distribution of the urban pattern, climate factors like temperature and solar path and the possible use of renewable energies (depending on roof inclination and orientation etc.). Furthermore present comparisons between different urban layouts are generally based on static analyses when the importance of temporal distributions, and especially consumption peaks, is a key factor in this domain especially when air conditioning is at stake.

Three main approaches have been proposed in the literature for addressing the relation between urban form and energy consumption.

A first approach is based on building simulation models. Steemers [5] analysed areas of 400 x 400 meters in the city of London with the LT tool enriched with a DEM model. The objective was to establish the relations between urban form and energy along with more detailed characteristics of buildings (thermal conductivity of external walls, window percentage etc.). The analysis was based on three geometric parameters : building depth, street prospect and urban compactness. A similar analysis was then performed by Ratti [6]. The selected variables were here the distance between facades, orientation of the facades and lighting obstructions. The analysis was further applied to three cities (London, Toulouse, Berlin) and once again completed by a DEM. The advantage of these approaches is that it allows to single out the impact of the urban form upon energy consumption though it solely covers energy consumption in buildings without considering transport.

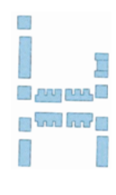
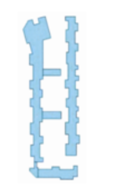
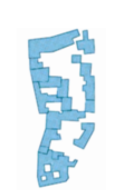
A second approach is based on a statistical approach for the prediction of building consumption . The Energy and Environment Prediction (EEP) model [7] is based on a national database that provides energy consumption for a series of 100 building typologies. The variables considered in the typology are heated floor area, facade area, window percentage and age. This tool allows to compare different energy policies at the urban level. Still the urban form is not analysed per se, but induced from the typology of buildings. The application of this model to large urban agglomerations is possible though it requires to classify all buildings of the agglomeration along the existing building typology which is not straightforward.

Finally a third approach is based on land use analyses [8]. Energy consumption are estimated for certain types of land uses : residential, office buildings etc. The advantage of these approaches is that they are covering a wide range of activities and integrating both building and transport energy consumption . Steadman et al. [9] adopted such an approach to compare different urban organisations from the analysis of the city of Swindon : compact city, dispersed settlements, polycentric development along public transport lines etc. Obviously his method heavily relies on the availability and quality of data for selected building uses and organisations (detached housing, terraced, multi-floor etc.). Furthermore the impact of urban form upon energy consumption is mainly addressed at the agglomeration level and is not of direct use for operational scales at the block level.

It is hereby proposed to adopt an intermediate approach based on energy simulations applied to representative urban blocks. An urban block is here defined as a group of contiguous land parcels delineated by streets or public spaces. It is somehow similar to the first approach described here above. Still it includes a wider diversity of urban blocks in order to cover all typologies observed in an urban region, including dispersed settlements. Furthermore the analysis will be completed by a transport analysis considering mobility patterns in different urban configurations. For obvious limitations of length the present article has been focused on energy consumption in buildings.

A typology of 25 different urban blocks was established in 1995 by IAURIF (Institut d'Aménagement et d'Urbanisme de l'Ile de France) for the classification of the urban fabric of the Region Ile-de-France [10]. This typology includes an aerial view of each urban block, an analysis of its plan, occupation mode and density. It covers both individual and collective types of housing and it has been designed and validated by IAURIF for the classification of all urban blocks of the Region Ile-the-France. It is hereby assumed that it is further applicable to other French cities ; simply the proportion of each of the 25 urban layout types will vary from one city to another. Amongst the 25 types identified by IAURIF, only 18 were effectively selected in this research. By definition, all these types consist in actual urban blocks that are assumed to be representative of a series of urban blocks of the city.

This typology is presented in Table 1, which provides the following indicators for each type of urban block : the ground floor area of buildings (sqm), the average height of buildings (nbr of levels), the surface of external walls (sqm) and the perimeter of the façade (meters). It can be seen from the table that densities vary quite importantly from one type to another as the ground floor area of type 2.3 (Cergy New Town) is 3.247 sqm with a mean height of 2.2 levels while collective "low" housing in the centre of Paris (type 5.4) has a ground floor area of 5.284 sqm for an average height of 8.58 levels.

TYPE URBAIN	1.1	2.1	2.2	2.3	2.4	4.1	4.2	4.3	4.4
DESCRIPTION	Habitat individuel à Colombet	Habitat individuel identique à Saint Nom le Bretèche	Habitat individuel identique à Cergy ville nouvelle	Habitat individuel identique à Cergy ville nouvelle	Habitat individuel identique à Colombet	Habitat individuel continu bas Cergy ville nouvelle	Habitat collectif continu bas à Rueil-Malmaison	Habitat collectif continu bas à Le Vésinet	Habitat collectif continu bas à Poissy
IND./COL.	IND	IND	IND	IND	IND	IND	COL	COL	COL
PLAN MASSE									
Date de construction	de 1915 à 1948	de 1968 à 1974	de 1968 à 1974	de 1968 à 1974	de 1968 à 1974	de 1975 à 1981	de 1915 à 1948	de 1915 à 1948	av. 1914
Emprise au sol nette (m²)	5835	9228	4225	3247	3830	3597	6413	2588	2893
Hauteur moyenne (Nbr de niveaux)	2.23	2.4	1.59	2.2	1.76	3.05	4.37	3.06	3.18
Surface de façade verticale (m²)	14373	17255	7650	6560	5947	9017	17467	5349	7220
périmètre de façade (ml)	2149	2396	1609	994	1126	986	1332	582	756

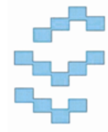
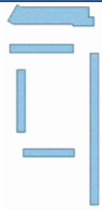
TYPE URBAIN	5.1	5.2	5.3	5.4	6.1	6.2	6.3	6.4	6.5
DESCRIPTION	Habitat collectif continu haut à Levallois	Habitat collectif continu haut à Boulogne-Billancourt	Habitat collectif continu bas à Mantes-la-Jolie	Habitat collectif continu bas à Paris, Porte de Champerret	Habitat collectif discontinu à Cergy ville nouvelle	Habitat collectif discontinu à Cergy ville nouvelle	Habitat collectif discontinu à Suresnes	Habitat collectif discontinu à Le Chesnay	Habitat collectif discontinu à Beauregard (Poissy)
IND./COL.	COL	COL	COL	COL	COL	COL	COL	COL	COL
PLAN MASSE									
Date de construction	av. 1914	de 1915 à 1948	de 1949 à 1967	de 1915 à 1948	de 1949 à 1967	de 1975 à 1981	de 1915 à 1948	de 1975 à 1981	de 1968 à 1974
Emprise au sol nette (m²)	4106	4798	2533	5284	4587	1427	1969	4711	2525
Hauteur moyenne (Nbr de niveaux)	5.19	4.89	3.73	8.58	4.15	3.92	4.89	5.88	4.86
Surface de façade verticale (m²)	14741	15646	6715	27003	10528	3385	6441	16231	10176
périmètre de façade (ml)	946	1066	600	1049	845	288	439	920	698

Table 1 – Geometrical characteristics of the 18 types of urban blocks identified by [10].

The average age of construction of buildings in each urban block (figure 1) was estimated by the research team. It has been used to approximate a mean thermal conductivity of external faces, a mean percentage of windows and a mean ventilation rate of buildings. It was then possible to perform an energy consumption analysis of these 18 types of urban blocks. The software used at this purpose was TAS (Thermal Analysis Software). It includes a geometrical 3D modeller for the estimation of solar shadings between buildings and an interface for thermal variables (climate conditions, building materials, internal conditions and periods of use of the building). It has to be stressed that the simulation considers the effective insulation rate of buildings. It is not limited to geometrical aspects but considers most probable construction techniques of each of the 18 representative urban blocks.

RESULTS

Table 2 presents energy consumption required for heating and for cooling buildings as well as potential solar gains on facades and roofs. Types are grouped in four categories for facilitating the reading of the table : discontinuous collective housing, continuous collective housing, dense individual housing and dispersed individual housing.

It can be seen from Table 2 that energy required for heating is on average 4 times higher than the one required for the cooling of the same urban block in the reference city adopted for this analysis (Paris).

Heating loads vary from 51,59 kWh/m2/an (type 6.4 – collective discontinuous housing) to 139,43 kWh/m2/an (type 2.2 – individual dispersed housing), which means a range from 1 to 2.7 for existing urban blocks considering their constructive characteristics at present. For the later case, type 1.1, 2.2 and 2.4, there is clearly an issue about whether it is more appropriate to transform existing buildings or substitute them with more efficient typologies as it is presently been done in some European countries where heating is more demanding than cooling needs.

	HABITAT COLLECTIF DISCONTINU					HABITAT COLLECTIF CONTINU (îlot)							HABITAT INDIVIDUEL DENSE			HABITAT INDIVIDUEL EPARS		
TYPE URBAIN	6,1	6,3	6,5	6,2	6,4	4,4	5,3	5,1	4,3	5,2	4,2	5,4	2,4	4,1	2,3	1,1	2,2	2,1
DESCRIPTION	Habitat collectif discontinu à Cergy ville nouvelle	Habitat collectif discontinu à Suresnes	Habitat collectif discontinu à Beauregard (Poissy)	Habitat collectif discontinu à Cergy ville nouvelle	Habitat collectif discontinu à Le Chesnay	Habitat collectif continu bas à Poissy	Habitat collectif continu bas à Mantes-la-Jolie	Habitat collectif continu haut à Levallois	Habitat collectif continu bas à Le Vésinet	Habitat collectif continu haut à Boulogne-Billancourt	Habitat collectif continu bas à Rueil-Malmaison	Habitat collectif continu bas à Paris, Porte de Champerret	Habitat individuel identique à Colombet	Habitat individuel continu bas Cergy ville nouvelle	Habitat individuel identique à Cergy ville nouvelle	Habitat individuel à Colombet	Habitat individuel identique à Cergy ville nouvelle	Habitat individuel identique à Saint Nom le Bretèche
IND,/COL,	COL	COL	COL	COL	COL	COL	COL	COL	COL	COL	COL	COL	IND	IND	IND	IND	IND	IND
PLAN MASSE																		
Date de construction	de 1949 à 1967	de 1915 à 1948	de 1968 à 1974	de 1975 à 1981	de 1975 à 1981	av, 1914	de 1949 à 1967	av, 1914	de 1915 à 1948	de 1915 à 1948	de 1915 à 1948	de 1915 à 1948	de 1968 à 1974	de 1975 à 1981	de 1975 à 1981	de 1915 à 1948	de 1968 à 1974	de 1968 à 1974
U bat W/m²,°C	2,356	2,188	2,01	2,25	2,25	2,088	2,356	2,088	2,188	2,188	2,188	2,188	1,789	1,475	1,075	2,04	1,789	1,789
Besoins chauds kWh/m²SHON,an	76,76	73,61	67,99	55,23	51,59	102,31	90,12	86,29	85,75	75,86	75,65	69,39	120,46	59,23	52,07	128,35	139,43	98,66
CLASSEMENT	10	7	5	3	1	15	13	12	11	9	8	6	16	4	2	17	18	14
Besoins froids kWh/m²SHON,an	16,37	23,22	30,34	20,34	22,4	17,97	18,28	18,12	21,96	25,85	21,35	32,53	14,79	23,58	33,8	18,59	17,42	16,48
CLASSEMENT	2	13	16	9	12	5	7	6	11	15	10	17	1	14	18	8	4	3
Apports solaires kWh/m²SHON,an	69,52	98,18	134,78	88,23	80,87	89,25	87,31	75,7	99,34	96,25	86,64	82,36	111,87	93,53	106,48	117,08	139,03	99,87
CLASSEMENT	18	8	2	12	16	11	13	17	7	9	14	15	4	10	5	3	1	6

Table 2 – Heating and cooling needs of the 16 types of urban blocks with potential solar gains

A clear difference can be further be observed between buildings constructed before and after the thermal regulation adopted in France in 1974. Those constructed after this period generally have heating consumption inferior to 55 kWh/m2 SHON/an. For buildings produced before 1974, individual housing are clearly the most energy intensive, especially for dispersed types (98 to 140 kWh/m2/an). For dense individual housing, energy consumption are contained in a range between 52 kWh/m2/an (post 1974) to 120 kWh/m2/an (pre 1974). Collective discontinuous types are the most efficient ones in terms of heating needs (52 kWh/m2/an to 77 kWh/m2/an), especially for those built before 1974 that perform much better than other types built in this period.

Cooling loads vary from 14.79 kWh/m2/an (type 2.4 - dense individual housing) to 33.8 kWh/m2/an (type 2.3 – dense individual housing), which means a range of 1 to 2.3 in the same class of urban block. This can be explained by the fact that buildings of block 2.3 are much more recent and have a lower thermal conductivity than the ones of block 2.4 (see Table 1). Generally speaking urban blocks that require most energy for heating are the most efficient in terms of cooling needs. Dispersed individual housing perform much better in this respect. This can be explained by the large external surfaces of these types of buildings. This effect is somehow limited in the case of continuous individual housing (terraced houses), which explains why this urban type is globally more efficient in terms of thermal regulation.

Finally those urban blocks that receive most solar gains (between 100 and 139.03 kWh/m2/an) are dispersed individual housing types. It means that retrofitting existing dispersed individual housing blocks may be interesting for warmer climates provided that the potential for solar gains is effectively valorised. Very dense urban blocks (type 5.1, 5.4) perform quite badly in terms of potential solar gains, even though their heating consumption is not bad for buildings produced in this period (86.29 & 69.39 kWh/m2/an).

Four sensitivity analyses were performed in order to identify most relevant variables apart the geometry of the urban block. These concerned climate conditions, ground temperature, window percentage and orientation. As regard with climate, six representative cities were selected in order to test the sensitivity of energy consumption with climate conditions. These cities were Nice, Biarritz, Bordeaux, Nantes, Paris and Strasbourg. They were selected for their representativeness of climate variations within France. It has been demonstrated that all 18 types are reacting in the same way to varying climate conditions. It has been further demonstrated that solar energy on vertical walls and roofs vary only marginally with orientation of the urban block (less than 3%). This is due to the lack of optimisation of these typical urban blocks in terms of solar accessibility.

DISCUSSION

The analysis highlights that, for existing urban blocks, the benefits of compactness are much more limited than what is generally expected by policy makers. This is also true for potential energy gains over facades. Effects of compactness may be much more important for new buildings and new urban developments where building orientations can be optimised for solar gains though

Different scenarios should now be compared and tested for these existing urban blocks : retrofitting the buildings in order to improve their thermal conductivity (for cool climates) or ventilation rate (for warmer climates) etc. The performance of existing blocks, possibly retrofitted, should then be compared to the one of “optimal” urban blocks designed to get the best of given climate conditions. This will help us to determine the potential energy gains specifically related to the urban organisation.

ACKNOWLEDGEMENTS

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FROM THE NEIGHBOURHOOD TO THE CITY: RESOURCE FLOW MODELLING FOR URBAN SUSTAINABILITY

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ABSTRACT

Agreed intergovernmental targets to reduce the emission of greenhouse gases due to predominantly urban anthropogenic activities are becoming increasingly stringent; one might even say ambitious. One crucial strategy in achieving these targets will be to improve the efficiency with which resource are consumed with our cities, which now accommodate more than half the global population. An important tool for testing whether governments are on track to reach their targets will be computer models which simulate the energetic consequences of alternative urban planning and design scenarios. In this paper we describe progress that has been made to develop one such tool: CitySim. In particular we describe the graphical user interface with which urban scenes may be described and the solver that simulates the energy flows within these scenes. We also describe work that is both underway and planned to enable users to simulate urban resource flows in a more comprehensive way and at a variety of scales, from the neighbourhood to that of the City.

INTRODUCTION

It is estimated that over half of the global population is now living in urban settlements [1], in which three quarters of global resources are consumed [2]. Energy derived from fossil fuels is key amongst these resources, so that urban settlements are responsible for the majority of greenhouse gas emissions. Given that the G8 countries have recently pledged to reduce greenhouse gas emissions by 80% with respect to 1990 levels by 2050 [3] it is increasingly important that existing urban settlements are adapted and that proposed settlements are designed to minimise their net resource consumption. Software for simulating and optimising urban resource flows will play an essential role in this process. In this paper we describe progress that is being made in one such initiative: the development of CitySim. In particular we describe the current structure of CitySim – it's graphical user interface and solver – and work that is both underway and planned to enable users to simulate urban resource flows in a more comprehensive way and at a variety of scales, from the neighbourhood to the City.

CITYSIM INTERFACE

The Java-based graphical user interface to CitySim enables users to describe and simulate an urban scene according to the following key steps:

- Definition of site location and choice of associated climate data.
- Choice and adjustment of default datasets for the typologies of buildings to be studied.
- Definition of 3D form of buildings; definition of energy supply and storage systems to be modelled; refinement of building and systems attributes.
- Parsing of data in XML format from the GUI to the C++ solver for simulation of hourly energy flows; analysis of the results parsed back to the GUI.

In developing this interface, we have been careful to design a modular platform for straightforward extensibility, in particular to support the future incorporation of modules developed for related open source applications (other 3D modellers, GIS tools etc). In developing the above native features we have focussed the vast majority of efforts in developing an efficient interactive 3D modelling tool which enables users to quickly and easily sketch and visualise building envelopes and with sufficient flexibility that even the more unusual forms may be defined.

In terms of workflow, 3D forms are immediately projected to a default height upon closing a 2D polygon of the floor plan. The height of this solid may then be easily changed. Individual faces of this solid may now be split and extruded along the surface normal, whether negative or positive; although surfaces may also be rotated and then extruded. Ridge lines may also be defined on (originally) flat roofs and the solid extruded from the roof edges to this ridge. Once the user is satisfied the building's constructional, occupational and systems attributes may be refined. The user may also create multiple copies of one or more buildings and drag these to the desired locations. These buildings may then be further transformed and / or rotated…and so on. Although this tool, which is still under development, is no replacement for a general 3D modeller such as Google SketchUp, it is reasonably fit for its purpose of quickly sketching building envelopes for the simulation of urban resource flows – see Figure 1.

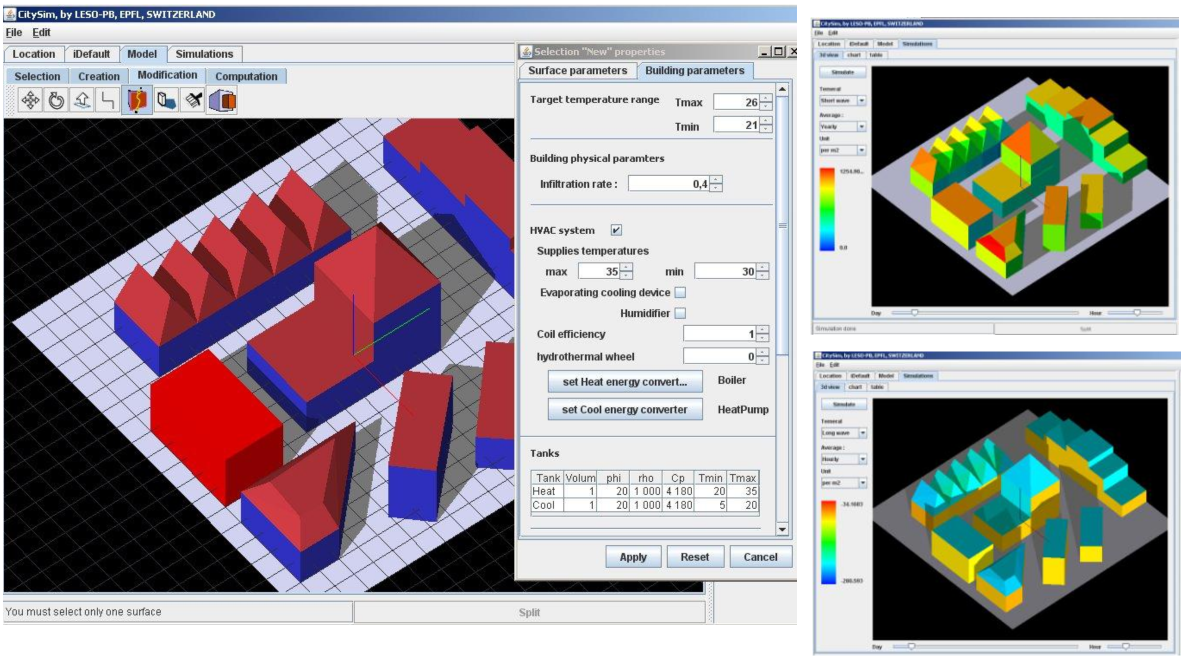

Figure 1: Screenshot of the CitySim GUI: Model definition (left) and results output (right)

Once the user is satisfied a description of the scene may be parsed to the CitySim solver. Upon completion the results from the solver may then be visualised within the GUI. In its present state we may view falsecolour renderings of the scene, for example of monthly or annual shortwave irradiation and line graphs of time against the performance variable of interest, for each building and at the chosen temporal resolution (hourly, daily, monthly).

CitySim Solver

The CitySim GUI writes a description of the user's scene to an XML file, which also contains references to a relevant ASCII climate file and to databases containing descriptions of construction composites and the thermophysical properties of each constituent element; profiles of occupants' presence and associated heat gains as well as profiles of heat gain due to use of lights and appliances and of airflow rates associated with the use of windows. Databases describing the characteristics of heating, ventilating and air-conditioning systems and of energy conversion systems are also referenced; likewise the characteristics of fuels to be combusted.

This data is then read in to the CitySim Solver, written in C++, for the hourly calculation of the building-related energy flows within our urban scene. For this a set of pre-processes are first performed to derive the necessary view information, relating each built surface to the three source of radiant energy (sky, sun and other surfaces), and to construct the matrices which solve for radiant exchanges with these sources. The radiation model is then called, at each time step, to solve the radiation matrix equation for the prediction of the irradiance absorbed by opaque surfaces as well as that transmitted through their glazed parts [4, 5].

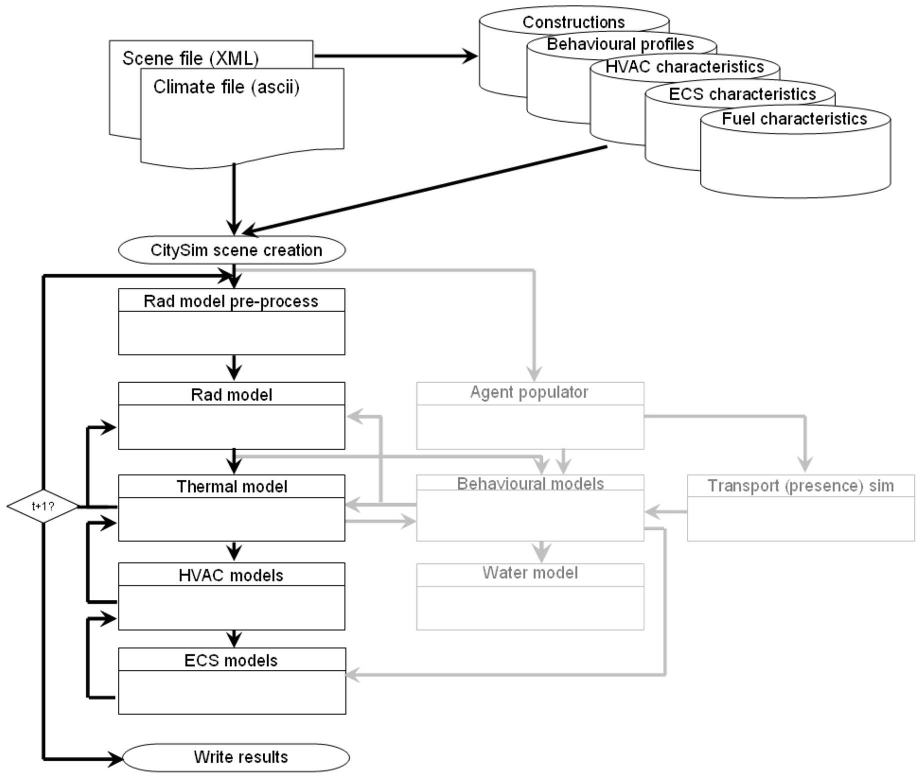

Figure 2: Conceptual structure of CitySim, with planned functionality shown in grey

A simplified thermal model is then called, to predict the energy demands required to maintain a given set point temperature for each zone of each building within our scene [6]. If our zone is mechanically ventilated, then the HVAC models are called to calculate the energy required (the product of mass flow rate and supply-room enthalpy difference) by heating / cooling sources to meet these needs. If there is under-capacity, whether through instantaneous supply and / or the supply of previously stored energy, then a new ventilation supply condition is calculated and the thermal model is again called to calculate a corrected temperature.

If there are no HVAC models then the sum of the demands of each zone is parsed directly to the relevant energy conversion system (boiler, heat pump, co-generation system etc) which may or may not satisfy this demand, so that a corrected temperature may again be calculated by the thermal model (the deficit, currently, being evenly shared between zones). At the moment, the energy consumed by pumps and fans for the distribution of heated / cooler air / water is not calculated explicitly. Rather standard specific power demands are used.

The external surface temperature, predicted by the thermal model, is also used at the next time step to solve for the longwave radiation exchange at each surface, using the view information that was calculated within the radiation model's pre-process (see [7] for a more detailed description of the CitySim solver). The calculation then proceeds, either to the next time step, or to write the simulation results to an ASCII file for analysis within the CitySim GUI.

Forthcoming Models

At the present stage of development, we have a core set of deterministic models that solve for the energy demand from buildings and the storage and supply of energy to meet these demands. At present no account is taken of the stochastic nature of peoples' presence and behaviour, which can have an important impact on both the magnitude and the temporal variation of buildings' energy demands, with corresponding implications for the dimensioning of HVAC plant and the energy conversion systems that satisfy their needs.

In the near future, stochastic models of occupants' presence [8] and their interactions with windows [9], blinds [10] and lights [11] will be integrated within CitySim. Further work is required to develop a convincing model of interactions with electrical appliances though some promising progress has been made by Page [12], Paatero [13] and McQueen [14]. But current work in this expanding field of research tends to model occupants' interactions as being independent of the activities which are being carried out. This may lead to incoherencies – with occupants interacting with several unrelated types of appliance simultaneously (use of a computer whilst cooking) or with possible interactions between types of action being ignored (e.g. cooking and the opening of windows to remove pollutants). To resolve this we intend to add a further layer to our models: predict presence, then the most probable activity and, whilst this activity takes place, the probable interactions which may plausibly take place. For this we will use Time Use Survey (TUS) statistics. In addition to this, recent work at the LESO supports the common sense conclusion that occupants' behaviours can vary significantly, according to their financial means (affecting the ownership of resource consuming appliances), their preferred activities (mentioned above) and their environmental preferences. To account for this we propose to include an 'agent populator' within our solver. By this we mean that we will create a population of individuals and assign to these individuals the key characteristics (some of which are noted above) that seem to drive occupants' behavioural diversity. This Multi-Agent Simulation of occupants' presence and behaviour then provides the opportunity to couple CitySim with a Multi-Agent Transport simulation program (www.matsim.org/).

Other planned developments relate to increasing the scope of our modelling of resource flows and the dependency of these flows on urban climate. In particular we wish to model the demand, storage and supply of water; the demand side possibly by means of a generalised form of appliance model, which considers appliances which consume water, electricity or both. There are many other modelling challenges that we would like to address, but the above (and eventually the coupling of CitySim and MATSim) represent our immediate priorities.

MODELLING SCENES OF DIFFERENT SCALE

For the modelling of small scenes of a few tens of buildings it is anticipated that the user will rely mostly on native tools to sketch and attribute buildings according to their constructional, systems and occupational characteristics, as described above. But many potential users already have preferred tools for 3D modelling – Google SketchUp for example has attracted a large following of devoted users, and for very good reasons. So work is currently under way to develop routines to support the import of DXF files which may be exported from a third party 3D modeller (and vice versa); likewise Google Earth's KML file format and the emerging CityGML file format which is attracting a growing user base.

But when it comes to large scenes, it becomes unreasonable to expect the user of CitySim to sketch and attribute all buildings to be modelled – which may potentially number several tens of thousand. For this we need to make the maximum use possible of existing sources of data.

We're very fortunate in Switzerland, in that a great deal of data describing the urban environment already exists:

– **Geometry**: Cadastral data describing the 2D footprint of all (except the most recent) buildings is available from Swiss communes. For the third dimension, LIDAR (Light Detection and Ranging) data describing point heights of solid surfaces are available at fine spatial resolution.

– **Occupation and systems**: The Swiss national Census contains useful information regarding for example the renovation status of a building, the number of apartments it accommodates as well as the occupied floor area, the type of heating system used and its fuel source. The residents' register provides further information regarding the number of building inhabitants as well as some useful socio-economic indicators.

– **Resource use**: Water and district heating and cooling networks tend to be either state owned or operated through a private-public partnership, so that a considerable amount of data is in principle available to help with the calibration of resource flow models.

We are currently evaluating the utility of these disparate sources of data to accelerate the preparation, attribution and calibration of 3D models of urban scenes, possibly supplemented with visual surveys of buildings' characteristics for a representative sample. But our work is not likely to stop here, we may also need to adapt our solver to ensure that the number of computations required to solve our resource flow equations does not entail excessive run times. This is likely to involve refinements to our radiation model (decomposition of our domain into sub-domains of manageable size) and behavioural models (using deterministic profiles or solving explicitly for a sample of inhabitants); the former feature (domain decomposition) may also be exploited to parallelise the solver.

CONCLUSIONS

In this paper we give a flavour of the current capabilities of CitySim, to support the rapid description of 3D urban scenes, the attribution of these scenes according to constructional, occupational and systems characteristics and the parsing of these scenes to a solver which dynamically simulates the building-related demand, storage and supply of energy using a family of deterministic models. We also describe work that is under way to extend both the GUI and the solver of CitySim to enable us to model scenes of varying size, from the small neighbourhood, through the district to the entire city whilst accounting for the stochastic nature of occupants' presence and interactions.

This is an undeniably ambitious programme of work, but we believe that it is crucial to be able to test the effectiveness of design and planning strategies for improving urban sustainability, particularly now that the G8 countries have committed to reducing greenhouse gas emissions by 80% with respect to 1990 levels by 2050. CitySim could play an essential role in helping governments and municipalities to ensure that they are heading in the right direction to meet their targets.

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EXPERIMENTAL INVESTIGATION OF MICROCLIMATE IN URBAN CANYONS IN TRADITIONAL AND CONTEMPORARY SETTLEMENTS: THE ROLE OF STREET GEOMETRY AND ORIENTATION

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ABSTRACT

The paper presents the results of extensive measurements which took place in two sites with different characteristics in terms of street geometry, urban density and materials, during the summer period. The first experiment site was a traditional settlement in the island of Tinos, Greece, while the second was a relatively newly built part of the capital city of Tinos. The traditional settlement is characterized by high density, high H/W ratio, undulate street pattern, covered parts of streets and extensive use of stone for both walls and for the ground. On the other hand, the newly built site is characterized be straight streets, lower H/W ratio and use of cement and asphalt for ground cover.

The experimental measurements, which include air and surface temperature, air humidity and air velocity, were carried out during the summer period simultaneously in both sites in order to obtain comparable results. The paper aims in presenting the results obtained by the comparison of the two sites and in analyzing the effect of parameters such as urban layout, street geometry and orientation on urban canyon microclimate, with special reference on the characteristics of traditional architecture of the Cycladic islands.

INTRODUCTION

Climatic response in urban design is an issue of great importance since it is associated with microclimatic conditions and thermal comfort in outdoor spaces, as well as with the energy performance of buildings. Therefore there is an increasing interest by researchers on the impacts of microclimate on pedestrian comfort as well as on the impact of several parameters that influence the microclimatic conditions in open spaces and urban canyons. Such parameters include canyon geometry, street pattern, height/ width ratio and use of materials. At the same time, existing traditional settlements in Greece are characterized by high climatic response, although quantitative studies on this issue are especially lacking.

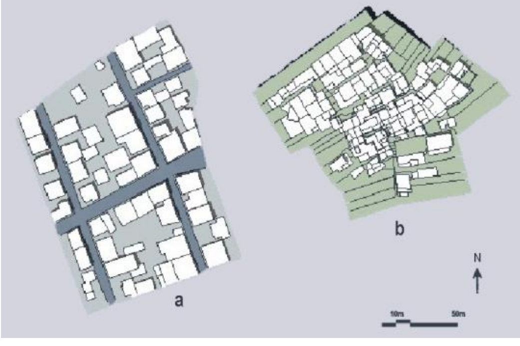


Figure 1: The contemporary (a) and the traditional (b) site

The first experiment site is a traditional settlement in the island of Tinos, Greece, while the second is a relatively newly built part of the capital city of Tinos (Fig.1). The traditional settlement is characterized by compact design, high density, high H/W ratio, undulate street pattern, covered parts of streets, extensive use of stone for both walls and for the ground and whitewashed walls. The narrow streets combined with extensive covered parts of streets contribute to cool and shaded public spaces. On the other hand, the newly built site is characterized be straight streets, lower H/W ratio and use of cement and asphalt for ground cover. The local climate is characterised by high solar intensity and strong northern winds with average speed that exceeds 9m/sec during the summer period.

METHOD

The experimental measurements, which include air and surface temperature, air humidity and air velocity, were carried out during the summer period simultaneously in both sites in order to obtain comparable results. The axes of the streets where the measurements were carried out have the same orientation in both sites (Fig.2, 3). The measurements in the traditional settlement were carried out in four streets, two of which were parallel to each other (B1, B3),

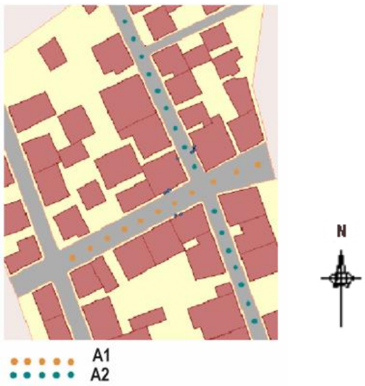


Figure 2: The contemporary settlement

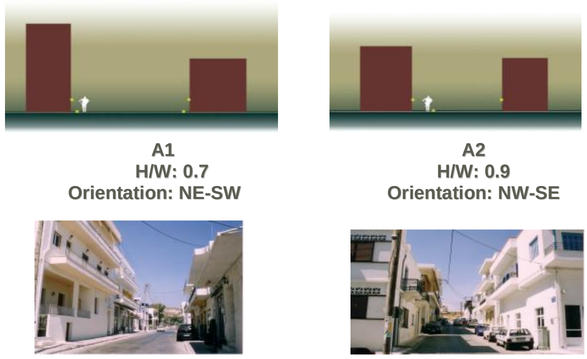


Figure 4:The streets of the contemporary settlement

Figure 3: The traditional settlement

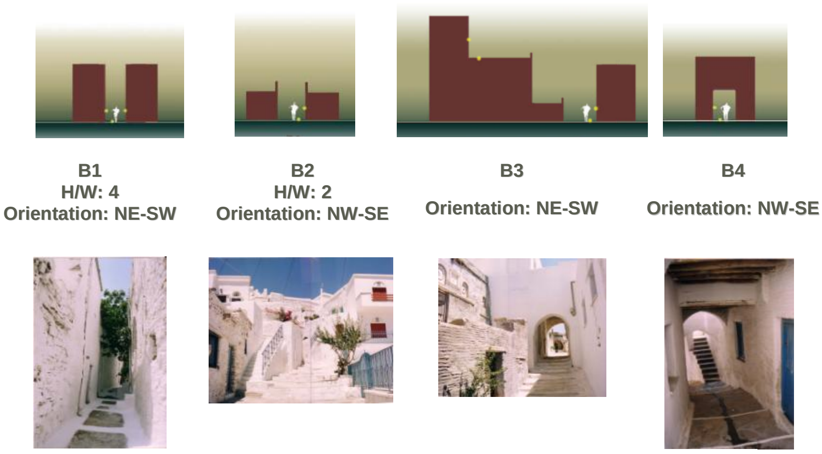


Figure 5: The streets of the traditional settlement

one was perpendicular (B2) and one was a covered street (B4). The H/W ratio is between 4 and 2. (Fig. 5) The measurements in the contemporary site were carried out in two perpendicular streets (A1, A2). The H/W ratio is significantly lower compared to that in the traditional site: 0.9 and 0.7 respectively (Fig.4). Ambient air temperature and humidity measurements were also carried out for both sites.

RESULTS

Air temperature

By comparing air temperature in streets perpendicular to each other at the traditional site (B1-B2) no significant differences were observed except for slightly higher temperatures in street B1 which is possibly due to lower wind speed, according to measurements. (Fig.7). By comparing air temperature in streets parallel to each other with different street geometry (B1-B3) air temperature in B3 was either similar to that in B1 or lower by 0.5-1.0^{o}C (Fig. 8). Consequently, although shading in B1 is higher due to higher H/W ratio, the higher air movement in B3 contributes to lower temperatures. The air temperature inside the streets was lower than the ambient temperature during morning hours (oasis effect) but higher by 0.5-2^{o}C during the night (heat island effect).

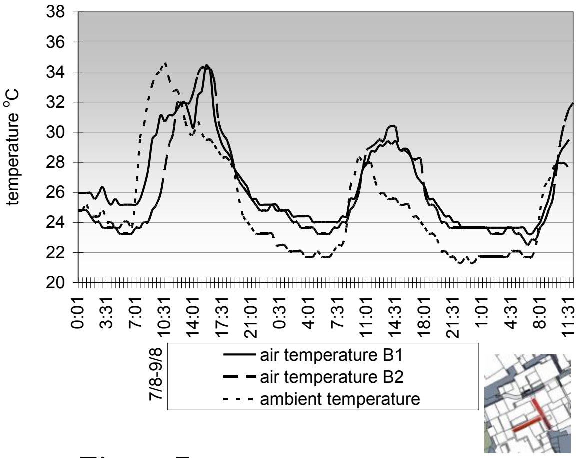


Figure 7

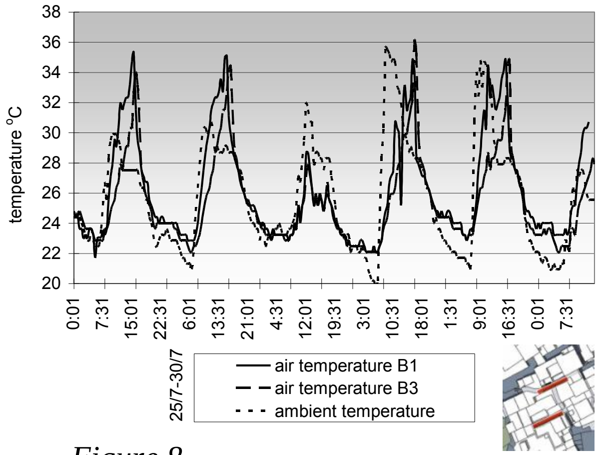


Figure 8

By comparing air temperature in streets perpendicular to each other at the contemporary site (A1-A2) no significant differences were observed, which leads to the conclusion that street orientation does not affect air temperature (Fig.9). The air temperature inside the streets was generally higher than the ambient temperature by 1-2^{o}C. According to several days' measurements in A1, the air temperature was higher than ambient temperature during the night by 0.5- 1.5^{o}C, while during the day the air temperature was either higher or similar to

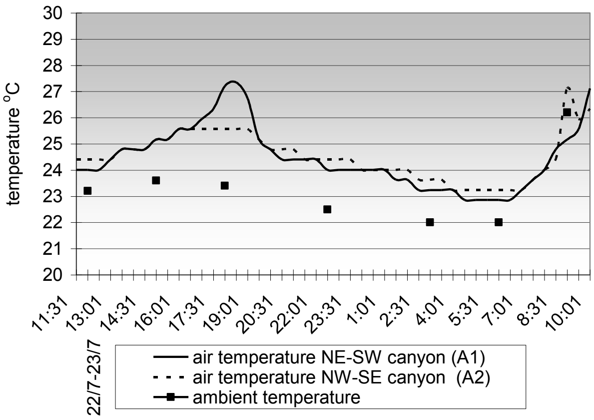


Figure 9

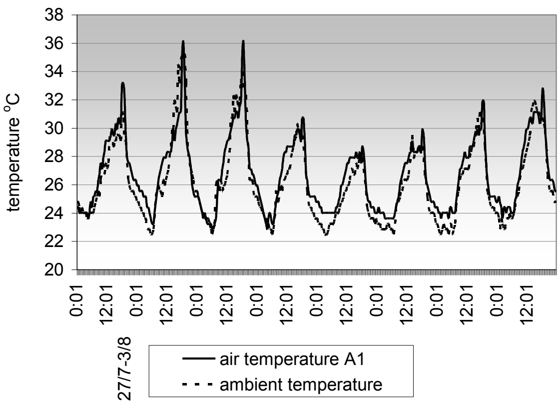
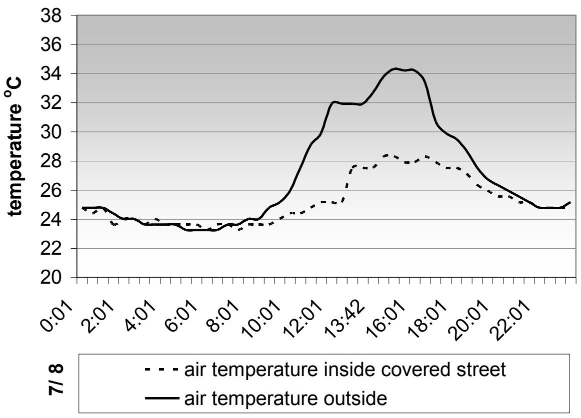


Figure 10

ambient temperature (Fig.10). Consequently, a heat island effect was observed in the contemporary site which is more intense during the night.

Significantly lower air temperatures were recorded inside the covered street compared to those outside the covered street, with the highest difference reaching 7°C (Fig.11).

By comparing the air temperature in streets in the two sites with the same orientation, that is street A1 in the contemporary site and B3 in the traditional site, lower air temperatures by 1-3°C were observed in the traditional site for almost all day. During the night, the air temperature in the traditional site is lower by 3-4°C (Fig.12).



Fiaure 11

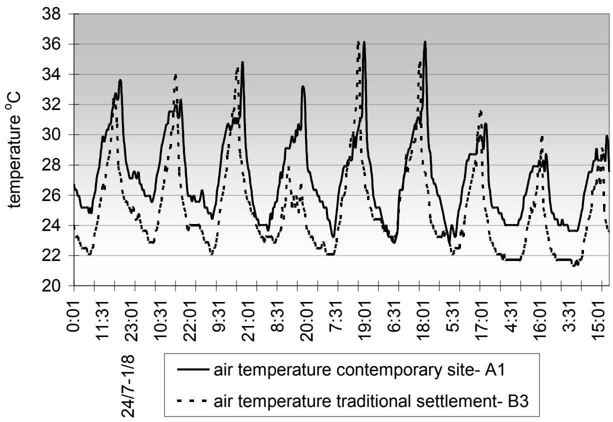


Figure 12

Surface temperature

The comparison of surface temperature inside and outside the covered street at the traditional settlement produces impressive results. The materials of the walls and of the ground surface compared are exactly the same, that is stone for the ground surface and white washed stone walls for the vertical surfaces. The surface temperature of the wall inside the covered street is relatively stable during the day and significantly lower to the surface temperature of the wall outside the covered street, with a maximum difference of 8.5°C. Similarly, the horizontal ground surface temperature inside the covered street does not exceed 25.5°C while the maximum surface temperature of the ground surface of the street outside the covered area reaches 43°C and is characterised by high temperature fluctuation during the day (Fig.13).

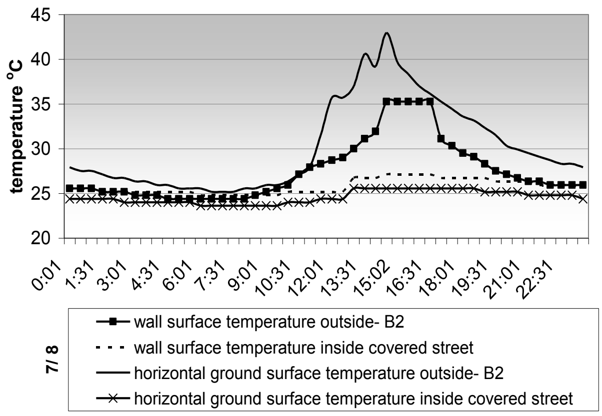


Figure 13

Figure 14 presents surface temperature measurements of the opposite walls of street A1 at the contemporary site. The H/W ratio of the canyon is 0.7 and the orientation is NE- SW. Both walls' outer surfaces are painted white. The surface temperature is expectedly affected by the surface orientation as well as the shading conditions. The southern wall has higher surface temperature during all day with the maximum temperature reaching 34°C. The northern wall has more stable surface temperature which does not exceed 28°C. The maximum difference between the opposite facades is 8°C. Figure 15 presents surface temperature measurements of the opposite walls and the horizontal ground of street B1 at the traditional settlement. The H/W ratio of the canyon is 4 and the orientation is exactly the same as the canyon at the contemporary site examined above. Temperature differences between opposite facades in the canyon at pedestrian level proved to be relatively minor. The maximum recorded temperature difference was close to 4°C. During the night the temperature differences between the opposite surfaces in the canyon was generally not significant and the temperatures recorded were very close to air temperature.

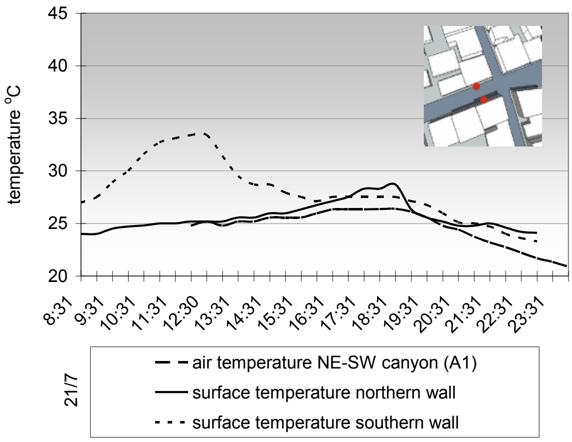


Figure 14

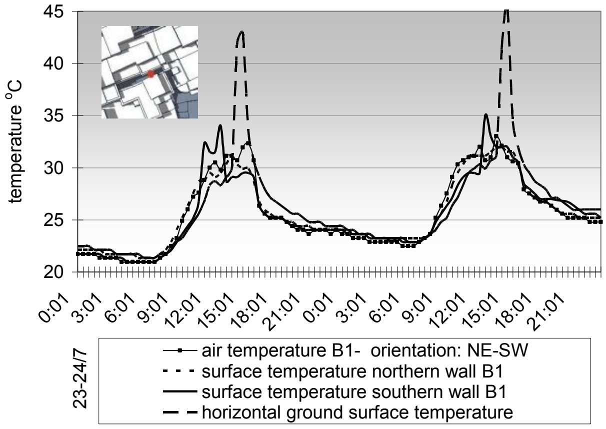


Figure 15

DISCUSSION

The above evidence suggests that, since no significant difference was observed in air temperature of street canyons with different orientation within each site, street orientation does not affect air temperature. This conclusion is in agreement to well known literature, according to which there is no clear correlation between air temperature and street geometry or orientation in street scale. Also, it has been suggested that the average air temperature is governed by more complex and regional factors than their surface temperature. [1],[2],[3],[4]. Some differences were recorded in air temperatures of streets with the same orientation, which were probably due to different wind speed which affects heat exchange. It is noted that in certain studies differences in air temperatures of streets with different H/W ratio have been recorded. In those cases, either the differences were small [5] or the streets involved had extremely high H/W ratio (7-10). [6],[7].

An oasis effect has been recorded at the traditional site during the daytime. During the night a heat island effect was observed, as the air temperature in the street canyons was 2-2.5°C higher than ambient temperature. At the contemporary site, the air temperature in the street is either higher or the same as ambient temperature during the day and the heat island effect is more intense during the night, when air temperature is higher to ambient temperature by 0.5-1.5°C. Consequently, the heat island effect during the night is more intense at the traditional settlement, due to lower wind speed, higher H/W ratio and lower sky view factor which affects cooling by radiation. These conclusions are in agreement with results reported by studies with reference to traditional settlements [7] [8].

In contrast to air temperature, significant differences were recorded in surface temperatures of vertical walls with different orientation. Surface temperatures are mostly influenced by sun exposure and shading conditions and thus, orientation, street geometry as well as certain morphological characteristics play a crucial role. Also, the surface temperatures of the horizontal ground surfaces were significantly higher to wall surface temperatures. These conclusions are in agreement with other studies [1],[5],[9],[10],[11]. The highest temperature difference recorded between opposite facades was 8^{o}C. In the traditional settlement however, temperature differences at pedestrian level between opposite facades in a deep canyon proved to be relatively minor. Consequently, high H/W ratio leads to small differences in surface temperatures of surfaces with different orientation, while surface temperatures are also close to air temperatures. These conclusions are in agreement with results on canyons with high H/W ratio. [7].

Measurements have also shown that air temperatures in the traditional settlement are lower to those in the contemporary site. The differences observed are due to difference in altitude but also to higher solar access in the traditional site because of lower H/W ratio. The more intense heat island effect which was observed in the traditional settlement during the night is compensated by lower air and surface temperatures and better pedestrian thermal comfort conditions during daytime, since high H/W ratios provide considerable shade.

Comparison of air and surface temperature inside and outside the covered street shows clearly that covered streets provide very good thermal comfort conditions during the summer period, since the maximum air, wall surface and ground surface maximum temperature difference reaches 7^{o}C, 8^{o}C and 17^{o}C respectively. Low temperatures contribute not only to pedestrian thermal comfort but also to the energy performance of adjacent buildings.

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COMPARISON OF SOLAR ENERGY PERFORMANCE ON TWO DISTINCTIVE URBAN FABRICS AT NEIGHBOURHOOD SCALE

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ABSTRACT

Climate change poses the challenge of reducing energy consumption in cities to consequently reduce CO^2 emissions. Urban planning does not fully consider this issue. An understanding of interaction between the built environment and metabolism is needed to tackle climate change in a long term through planning. The purpose of the paper is to show energy performance on the urban fabric at neighbourhood scale in the metropolitan city of Santiago. Two kinds of city layout were studied: (i) the "Le Corbusier" city model and (ii) the "Howard" city model. Both of them are typical shapes of urban growth in Latin American cities. The methodology considered energy simulation tools such as Townscope during winter season in each urban fabric. Parameters such as the H/W ratio and the orientation of outdoor spaces were used to analyse energy performance. Results show evidence of a distinctive energy pattern according to the particular urban fabric. Findings might be a useful input for urban planning guidance.

INTRODUCTION

All over the world there is a concern for environmental conservation and reducing CO2 emission to prevent climate change. Energy consumption policies become relevant to tackle those issues, particularly in the building sector. For instance, energy efficient design of a PV façade in the urban context is fundamental for reducing CO2 emissions. [1] Energy policies formulated by the Chilean government have recently focused on two objectives: to promote non conventional renewable energy (ERNC) and energy efficiency in the building sector (EE). Moreover, the Chilean government has just passed an Act to the Parliament by which at least 5% of electricity supply market must be provided with non conventional renewable energy (ERNC).

From architectural and urbanism viewpoints a bridge between both ERNC and EE policies can be constructed knowing the relation between the urban fabric and architectural envelope. The urban fabric shows the spatial configuration for solar access to the building and hence solar gains on the envelope. Thus it is possible to work with a renewable energy source such as the sun and its potential for use in architectural design to reduce energy consumption inside buildings.

Latin American cities are growing in the periphery following two typical urban fabric types: low height housing with gardens in the front and backyard and middle height housing with a collective yard in between buildings. (Figure 1) The former is traditionally classified as a garden city and the latter is classified as a block city.

In the current research energy performance means the global solar radiation incident on the built environment be it buildings or urban spaces. The urban fabric selected were city models from Le Corbusier and E. Howard such as the block city (BC) and the garden city (GC) [2]. Research has the aim to compare the solar energy performance of two distinctive urban fabrics in a neighbourhood called La Florida in Santiago city.

Figure 1: Photographs of two distinctive urban fabric: the block city and the garden city

METHOD

Urban fabric models were selected from a district located in the south east area in the Santiago metropolitan city near a meteorological station. Housing belonged to a middle-low income population. One of the parameters to characterise spatial configuration of cities and to understand energy balance flow has been the ratio between height of a building and width of street (H/W) [3]. A survey of cases was carried out to measure a ratio H/W in each type of urban fabric to discover a representative one for the block city model (BC) and for the garden city model (GC). Figure 2 shows a proportion of open space between buildings with orientation North –South and East- West according to the urban fabric. Table 1 shows a trend by which a predominant ratio in urban fabric of type BC tends to be ≥ 1 while in garden city (GC) tends to be ≤ 1.

Basically the methodology consists of four steps as follows: (i) to identify two different urban morphology arrangements in growing cities, (ii) to discover a predominant ratio H/W in each type of urban fabric, (ii) to apply the Townscope software for solar radiation modelling on the built environment, (iii) to compare solar energy performance between both urban fabric models.

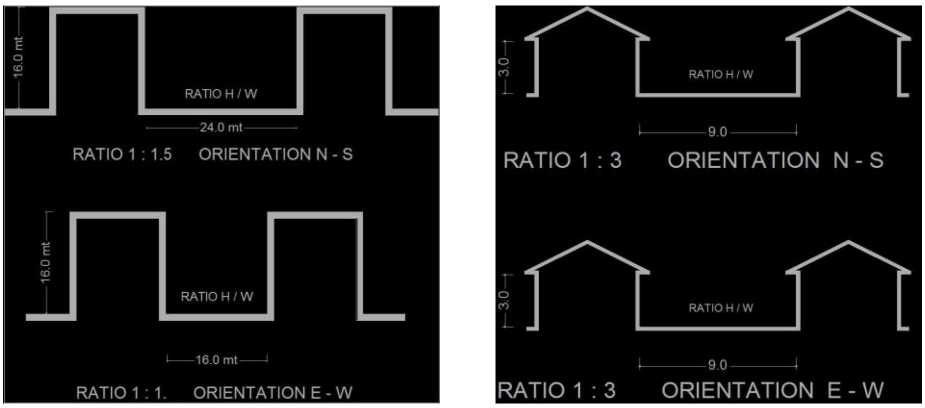


Figure 2: cross – section of the urban fabric: proportion in the block city and the garden city

Townscope is a Belgian software to support the process of decision-making in the field of urban design from a sustainable development perspective. It calculates solar access impinging on the horizontal plane which includes direct radiation energy, diffuse radiation energy (vertical sky component) and reflected energy from the surroundings. [4,5] A plan and a cross-section drawing were used to compare solar energy performance on two different urban fabrics as shown in Figure 3 and Figure 4.

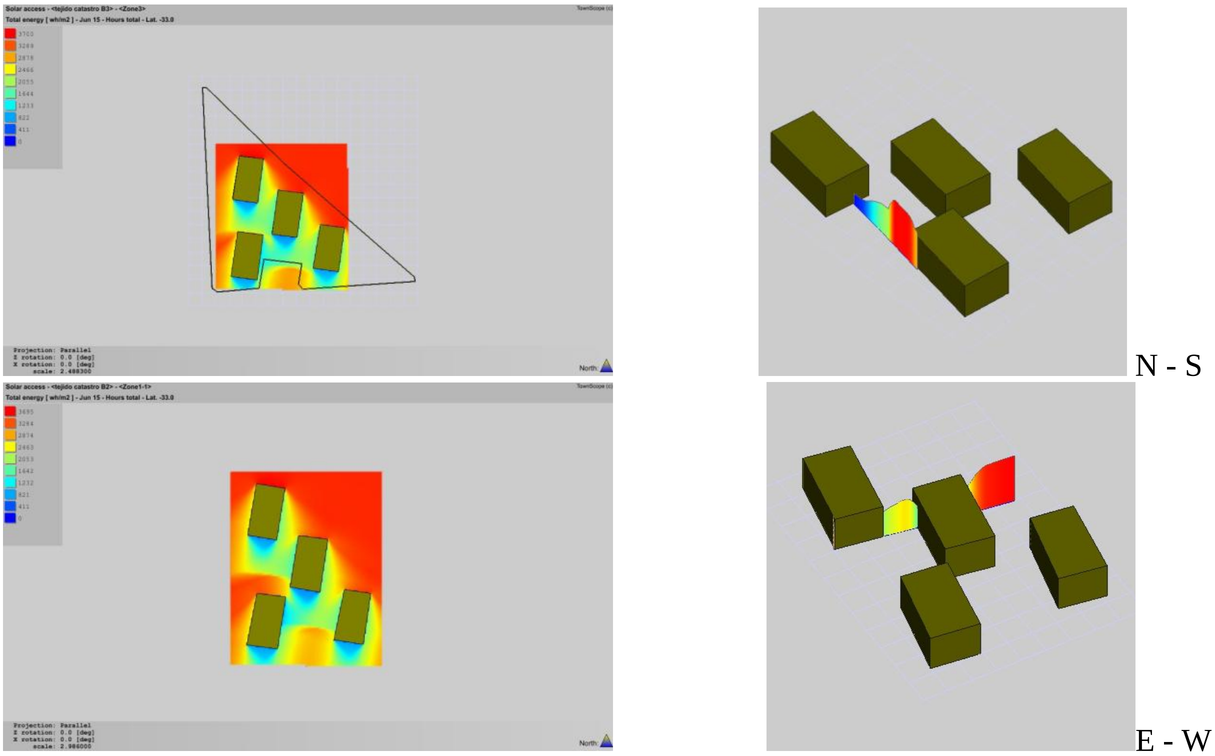
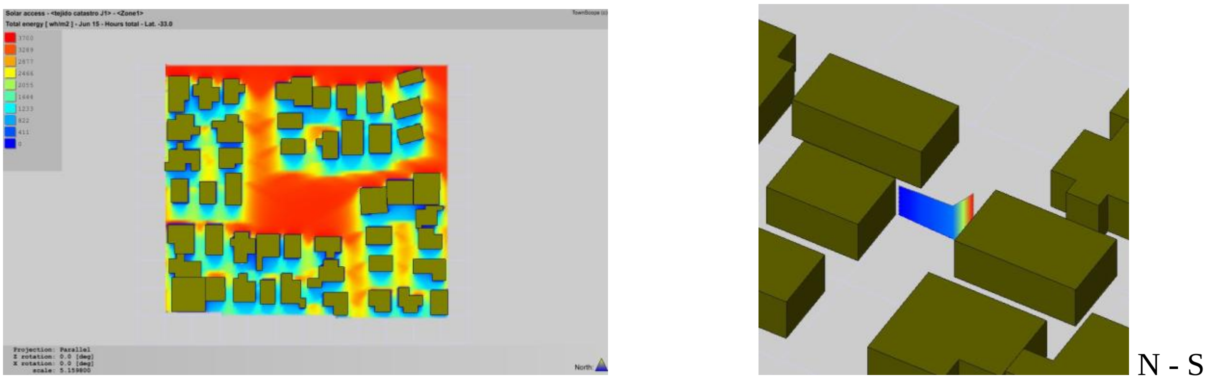
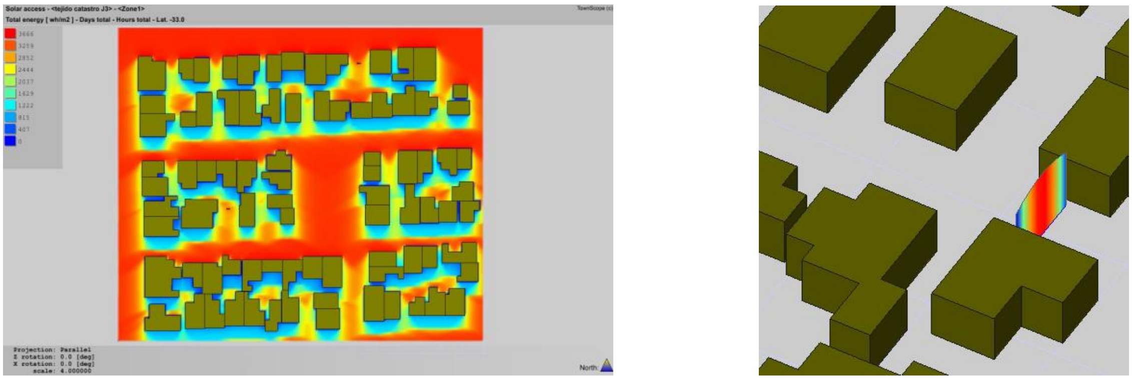


Figure 3: Solar Radiation Modelling on urban fabric: the BC model. (plan and cross-section)





E - W

Figure 4: Solar Radiation Modelling on urban fabric: the GC model. (plan and cross-section)

RESULTS

Numeric results are presented in Table 1 based on values delivered by Townscope and visualised in Figure 3 and Figure 4. Figure 3 shows that the Block city model reaches a maximum radiation at the periphery. Figure 4 shows that the Garden city model reaches a maximum radiation both in the periphery and the center. So it seems to be that energy performance is depending on the spatial configuration of the urban fabric. On the other hand, the minimum radiation is localized inside the block city model while minimum radiation is situated along with the housing volume leaving an open space with solar access in winter. It is reduced but there is still some solar radiation. Table 1 shows the magnitude of total solar energy incident on outdoor spaces of the urban fabric in winter solstice.

Urban fabric	**Total energy range (Wh/m^2) Total day ≈ winter solstice, 15 June Latitude 33°S longitude 70°W**	
	N-S orientation Outdoor spaces	E-W orientation Outdoor spaces
GC models tends to have ratio ≤ 1	2466 – 3289 2444 – 2852	822 – 2466 1222 - 3259
BC models tends to have ratio ≥ 1	1642 – 2463 1630 – 2040	821 – 2053 816 - 2040

Table 1: Comparative energy performance of urban fabric.

DISCUSSION

A comparison of solar energy performance has been made in two types of urban fabric for the winter season. The simulation was performed in Santiago city situated at 33°S – 70°W. Energy performance is different depending on the spatial configuration of the urban fabric. Once the global radiation reaches the built environment, arrangements of buildings and outdoor spaces change radiation because of obstruction. Solar incident radiation on the horizontal plane in outdoor spaces is a function of both spatial parameters: ratio H/W and orientation. Hence the thermal properties of outdoor spaces are modified by spatial configuration of urban fabric. [6] Others factor are related to material and its infrared emissions as other authors have extensively explained. [7]

By way of conclusion, the energy performance of the urban fabric depends heavily on orientation, H/W ratio and irradiance. If the H/W ratio ≤ 1 then > irradiance and if ratio H/W ≥ 1 then < irradiance. However, the orientation factor shows that the E-W minimum value is similar for both models. Hence the studied parameters have different weights and they are relevant to distinguish the energy performance of an urban fabric.

Energy performance can be modelled locally by those parameters to regulate a ratio: outdoor space – energy. It might be useful knowledge for guiding urban design and architectural envelope design. Particularly the solar access issue has potential for use in buildings with regard to both passive and active systems.

ACKNOWLEDGEMENTS

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METHODOLOGY FOR THE DESIGN OF SUSTAINABLE TOURIST RESORTS BASED ON WATER AND ENERGY FLOWS

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ABSTRACT

Tourist resorts have been planned for years without taking into account sustainable development and therefore without a previous study of the economic, social and environmental impacts produced in their influential areas. This work is centred on the latter; to be exact, it is focused on the management of water and energetic resources. After an extensive research of information and regulation currently in force, a spreadsheet is developed, an interactive tool to be used in the design process of any resort or tourist development. Although the weather and other territorial data introduced by default are from regions of Spain, the user can apply the methodology in other countries introducing specific information of the area. To start the evaluation, the user has to introduce some characteristic parameters of the resort. The spreadsheet then provides graphical and numerical results. The water analysis proposes a balance of water flows and makes a simulation to see if the resort could water green areas with recycled water, which comes from treated wastewater. The energetic analysis works out the energy savings by using both photovoltaic and thermal solar energy and estimates the reduced emission of CO_2. As a result, the methodology provides theoretical values and foresees the possible failures of the system so that the user could correct them before building the real resort.

INTRODUCTION

During the last few years, the Spanish government has introduced the concept *sustainable development* in its strategy; the aim is to increase the value of the tourist system in terms of sustainability [1]. 'The process of planning and management will be characterized by the methodological and technical rigour, a strategic approach in the long run, a wide and global consideration of the complexity of the destination and the interest of all the involved agents.' In addition, the recent Spanish regulation *Código Técnico de la Edificación (CTE)* [7] introduces new elements aimed to increase sustainability in buildings, such as the document DB-HE, centred on energy savings.

Sustainability in tourism is a concept that involves five concepts: economic, social, cultural and environmental factors as well as satisfaction of the tourists. The purpose of this paper is to present a methodology to plan resorts and tourist developments with a sustainability base, focused on the management of water and energetic resources. The methodology consists of a water and energetic analysis. What makes it different from other sustainability indicators is that not only does it evaluate a built resort but it also provides information on water and energetic flows in the design process, before the resort is built.

METHOD

A spreadsheet is developed for the evaluation of water and energetic flows of the resorts and tourist developments. It consists of three linked Excel workbooks (*General Analysis, Water Analysis* and *Energetic Analysis*) and each workbook has different worksheets. The spreadsheet was choosen to create this methodology because it allows to store data, to create tables, to make complex calculations and to introduce references from other workbooks. Moreover, users are allowed to apply the tool many times changing the main characteristic of the resort and see the results instantly.

General Analysis

The regulation *Código Técnico de la Edificación, RD 314/2006* and other local regulations are the main references for this study, so the data introduced by default are from 75 Spanish locations. However, users can introduce new data to use the methodology in other regions of the world. This workbook called *General Analysis* gathers the necessary information such as monthly precipitation, monthly air temperature during solar hours, monthly evapotranspiration, solar radiation, altitude, longitude, latitude and other data to run the water and energetic analyses. This workbook also has a sheet called *Initial Data* where the user introduces the main characteristics of the resort (number and types of hotels, houses and flats, public and private green areas and golf course area, swimming pools, restaurants, shopping areas and other possible facilities). The sheet *Initial Data* is repeated in the workbooks *Water Analysis* and *Energetic Analysis* as a linking element but there, the sheets are blocked and they are automatically updated when the user enter the characteristics in the general one.

Water Analysis

The *Water Analysis* workbook produces a balance of water flows. Figure 1 shows a diagram with the different types of water and their origins. The idea of this analysis is to make a simulation to see if the resort could water green areas and clean the pavement with recycled water and rainwater.

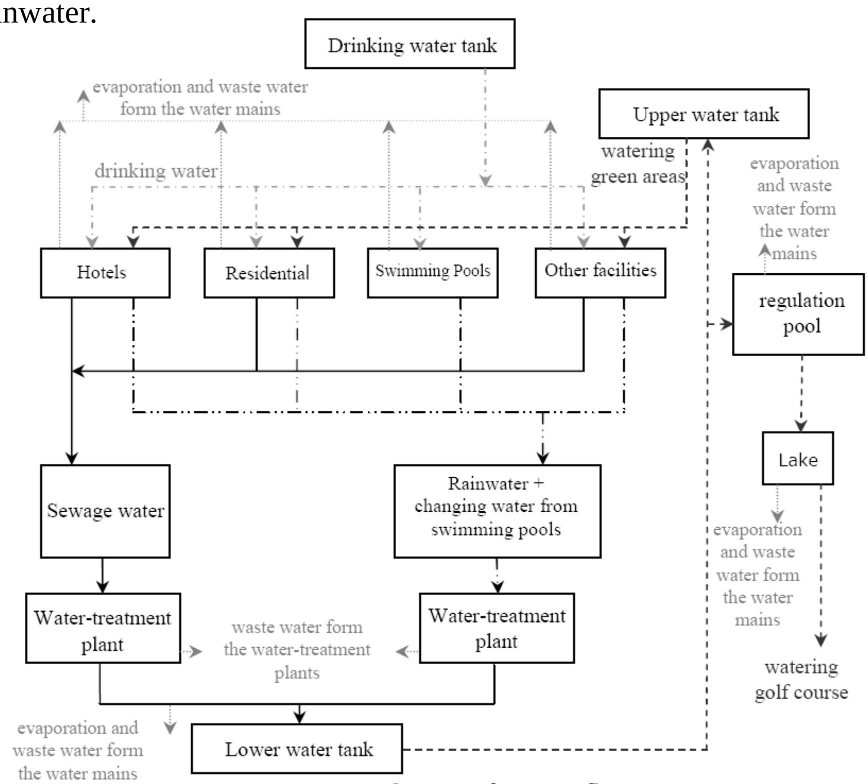


Figure 1: Balance of water flows.

Inputs and outputs of the balance are summarized in Table 1, and some sheets of the workbook estimate them and the others develop the balance and show the results. To calculate the consumption of water from homes, hotels and facilities there are predetermined daily ratios (litres/person) of consumption and the user only need to introduce coefficients of monthly occupation to adequate the occupation of the resort during the year.

WATER INPUTS	WATER OUTPUTS
Surface runoff from the green areas	Water to the golf course
Surface runoff from road surfaces and roof	Water to the private and public green areas
Sewage water from the residential area, the hotel area and other facilities.	Water lost in the consuming process, the mains, the water-treatment plant, etc.
Water from the changing water of the swimming pools	Water loss from evaporation

Table 1: Inputs and outputs of the water balance.

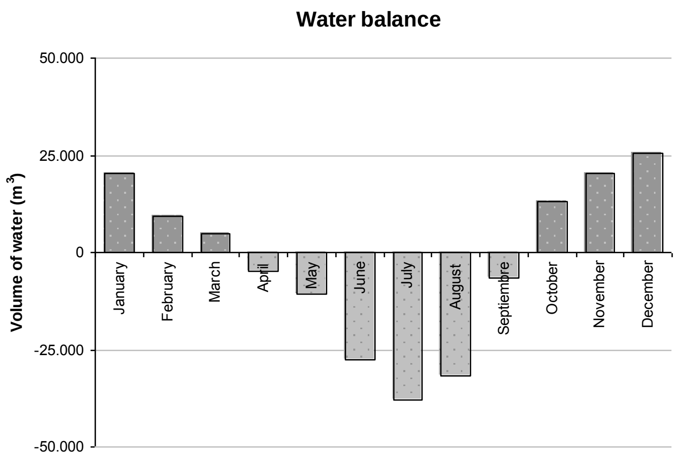
Energetic Analysis

This analysis is based on the integration of solar energy in both applications: photovoltaic energy and solar thermal energy. The CTE forces the installation of solar thermal energy in new buildings whereas photovoltaic systems are obligatory only in some of them. On the one hand, following the same procedure to calculate the consumptions for the water balance, the hot water consumptions are estimated with similar ratios and the worksheet provides the number of solar thermal collectors and the optimum angles to install them. The method followed in this study is *f-chart*. It also gives optimum angles for the photovoltaic panels and the generated electric energy. Furthermore, it works out values of the reduced emissions of CO_2 thanks to the application of both solar energies.

RESULTS

Water balance

The results of the water balance are presented in different graphics and tables and there are graphics and values for all types of waters. Figure 2 shows an example of a monthly water balance and Figure 5 its values while Figure 4 represents a daily accumulated balance with a restriction of a maximum volume of stored water. This restriction is necessary because it must take into account that the system (including tanks and lake) has a limit of capacity to store water. As the user changes the characteristics of the resort, the graphics automatically update.



	Output water the course golf (m^3/month)	Input wastewater from the buildings and pools (m3/month)	Input runoff form green surfaces (m3/month)	Input surface runoff from roof and pavement (m3/month)	Total balance (m^3/month)
January	11.134	56.091	0	10.640	**20.351**
February	20.373	54.549	0	7.280	**9.305**
March	31.385	64.587	0	8.120	**4.878**
April	42.477	66.457	0	7.000	**-4.910**
May	50.893	68.780	0	8.680	**-10.831**
June	65.214	70.620	0	3.080	**-27.458**
July	75.051	72.215	0	1.680	**-37.848**
August	69.323	71.943	0	2.240	**-31.889**
Septiembre	45.898	66.142	0	9.520	**-6.573**
October	25.636	60.396	0	15.400	**13.094**
November	14.749	58.448	0	12.040	**20.444**
December	11.585	64.509	0	9.240	**25.513**
TOTAL (m^3/year)	463.717	774.737	0	94.920	-25.923

	Output water loss form evaporation (m^3/month)	Output water lost in the mains and treatment plant (m^3/month)	Output water to green private areas (m^3/month)	Output water to green public areas (m^3/month)
January	907	13.346	10.695	10.298
February	823	12.366	9.660	9.302
March	909	14.541	10.695	10.298
April	882	14.691	10.350	9.966
May	913	15.492	10.695	10.298
June	888	14.740	10.350	9.966
July	919	14.779	10.695	10.298
August	919	14.837	10.695	10.298
Septiembre	889	15.132	10.350	9.966
October	914	15.159	10.695	10.298
November	882	14.098	10.350	9.966
December	908	14.750	10.695	10.298
TOTAL (m^3/year)	10.753	173.931	125.925	121.253

Figure 3: Monthly water balance values.

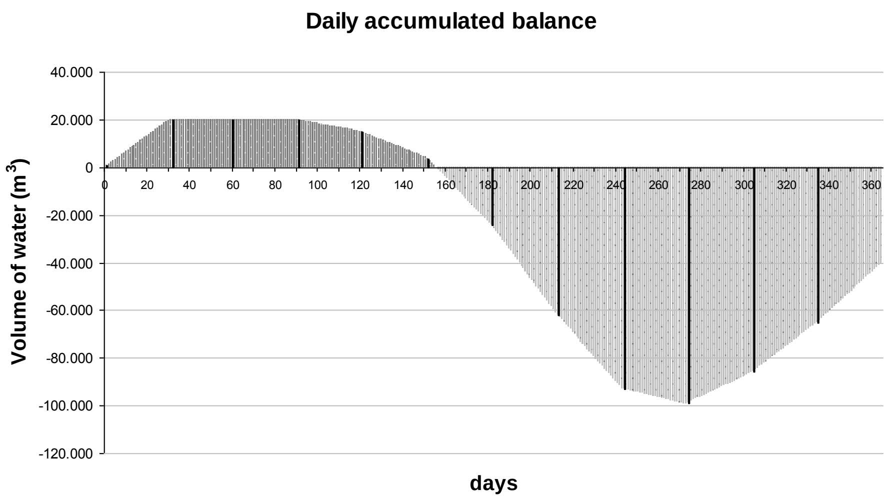


Figure 4: Daily accumulated balance with 20.000 m^3 as a maximum volume of restriction.

Energetic balance

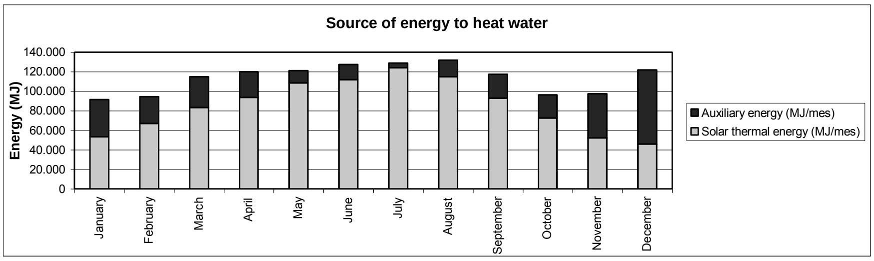
Firstly, the energetic solar thermal balance provides, for each latitude, optimum angles for the inclination of thermal collectors depending on seasonal use (Figure 5).

	Latitude = 37,79º	Daily incident energy for different angles (MJ/m^2)											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
	0º	10,1	14,8	16,6	20,4	24,2	25,6	27,7	23,5	18,6	13,9	9,8	8,1
	5º	10,8	15,7	17,3	21,0	24,7	25,9	28,3	24,2	19,5	14,9	10,6	8,7
	10º	11,4	16,4	17,9	21,4	24,7	26,1	28,5	24,7	20,3	15,8	11,4	9,4
Summer →	15º	12,0	17,0	18,4	21,6	24,9	25,9	28,5	25,1	21,0	16,5	12,1	9,9
	20º	12,5	17,6	18,8	21,8	24,7	25,9	28,3	25,1	21,4	17,2	12,7	10,4
	25º	12,9	18,1	18,9	21,8	24,4	25,3	28,0	25,4	21,8	17,8	13,2	10,9
All the year →	30º	13,2	18,4	19,1	21,6	24,0	24,8	27,4	25,1	21,9	18,2	13,7	11,2
	35º	13,5	18,5	19,1	21,2	23,2	24,1	26,9	24,7	22,1	18,6	14,0	11,5
	40º	13,7	18,6	18,9	20,8	22,5	23,0	25,8	24,2	21,9	18,8	14,3	11,7
	45º	13,8	18,6	18,8	20,2	21,5	22,0	24,7	23,5	21,8	18,9	14,5	11,9
Winter →	50º	13,8	18,5	18,3	19,6	20,6	20,7	23,5	22,8	21,4	18,8	14,6	12,0
	55º	13,7	18,2	17,8	18,6	19,4	19,2	22,2	21,6	20,8	18,6	14,6	12,0
	60º	13,6	17,9	17,3	17,5	17,9	17,7	20,5	20,4	20,1	18,3	14,5	11,9
	65º	13,4	17,5	16,4	16,5	16,5	16,1	18,8	19,3	19,3	17,9	14,3	11,7
	70º	13,0	16,9	15,6	15,3	14,8	14,3	16,9	17,9	18,2	17,4	14,0	11,5
	75º	12,6	16,1	14,8	14,1	13,1	12,5	15,0	16,2	17,3	16,7	13,6	11,3
	80º	12,2	15,4	13,8	12,6	11,4	10,8	13,0	14,6	16,0	15,8	13,1	10,9
	85º	11,6	14,5	12,6	11,2	9,7	8,7	10,8	12,9	14,7	15,0	12,6	10,4
	90º	11,0	13,5	11,5	9,6	7,7	6,7	8,6	11,0	13,4	14,0	12,0	10,0

Figure 5: Optimum inclination angles for collectors depending on the seasonal use.

The CTE divide Spain in different climate zones and this classification gives the minimum contribution of solar thermal energy to heat water. With the consumptions of hot water and introducing for each installation the type of auxiliary energy, the seasonal period to use it, the inclination angle and the total surface of collectors, the worksheet calculates the production of hot water from solar thermal energy and indicates if fulfil the CTE requirement. Moreover, it shows the quantities of reduced emissions of CO_2. The results are presented with graphics and energetic values for each building (Figure 6) and also summarized for the residential area, hotels and facilities.

		January	February	March	April	May	June	July	August	September	October	November	December	Solar contribution
Hotel (5*)	Demanda ACS (MJ/mes)	91.409,88	94.472,00	114.848,31	119.932,94	121.293,88	127.588,23	128.911,37	131.841,17	117.381,17	96.390,55	97.250,58	121.879,84	0,75
	Energia solar (MJ/mes)	53.363,49	67.102,36	83.420,94	93.607,06	108.575,14	111.890,12	123.930,29	114.789,12	93.112,31	72.450,69	52.248,60	46.002,25	
	Energia auxiliar (MJ/mes)	38.046,39	27.369,63	31.427,37	26.325,88	12.718,74	15.698,11	4.981,08	17.052,05	24.268,86	23.939,86	45.001,99	75.877,58	



Hotel (5*)	
Consumption annual hot water (m^3)	6.882,48
Consumption annual hot water (MJ)	1.363.199,90
Surface collectors (m^2)	300
Inclination angle of collectors	15º
Annual solar contribution (MJ)	1.020.492,38
Necessary auxiliary energy (MJ)	342.707,53
System of auxiliary energy:	GAS
Solar contribution	**74,86%**
Annual reduction of CO_2 (kg)	99.015

Figure 6: Example of a presentation of results for solar thermal energy. Hotel 5.

As regards the photovoltaic results, users can choose between different photovoltaic modules (or introduce a new one) and introduce some characteristics of the system (number of modules, angle of inclination and orientation, etc.) for every building where it is compulsory by the CTE to put a photovoltaic solar system but also for other the buildings. Similarly to the solar thermal energy, the optimum angle of inclination for the panels is given. The worksheet returns the generated electric energy (kWh) and the reduced emission of CO_2 depending on the photovoltaic system chosen.

Residencial area (total)		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total anual	Surface (m^2)
Block of flats 1	Photovoltaic production (kWh)	10.449	13.829	17.173	20.424	25.036	25.630	28.656	24.311	18.621	14.380	9.811	8.380	216.700	31,5
Block of flats 2	Photovoltaic production (kWh)	33.513	44.355	55.080	65.505	80.298	82.203	91.911	77.975	59.725	46.121	31.468	26.876	695.031	94,4
Block of flats 3	Photovoltaic production (kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0
Detached houses 1	Photovoltaic production (kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0
Detached houses 2	Photovoltaic production (kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0
Detached houses 3	Photovoltaic production (kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0
Terraced houses 1	Photovoltaic production (kWh)	10.807	14.304	17.763	21.125	25.895	26.509	29.640	25.146	19.261	14.874	10.148	8.667	224.138	251,7
Terraced houses 2	Photovoltaic production (kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0
Terraced houses 3	Photovoltaic production (kWh)	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0
Total RESIDENCIAL	Photovoltaic production (kWh)	54.769	72.489	90.016	107.053	131.228	134.342	150.207	127.432	97.608	75.375	51.428	43.923	1.081.100	377,5

Anual reduccion of CO_2	**406.189 kg**	**Photovoltaic production surface photovoltaic panels**	**2.863,5 kWh / m2**

Figure 7: Example of a presentation of results for photovoltaic energy. Residential area.

CONCLUSIONS

The methodology presented is a tool based on sustainable criteria to improve the design of tourism resorts. It follows some of the indications of the recently endorsed Spanish *Codigo Técnico de la Edificación* and it is designed to be used for any kind of resort placed in Spain, because it contains a base of data with information from different areas. It can also be used to evaluate resorts which are already running.

Applying the water analysis during the design phase allows us to see if green areas, golf and the cleaning of streets of the resort will be possible with the water consumptions of the resort, replaced water from swimming pools and rain water. It gives theoretical estimations from all the flows of water of the resort. The daily accumulated balance gives the opportunity to dimension the resort according to the capacity of water accumulation. Nevertheless, it has to be taken into account that some factors, for instance rainfall, will be variable from one year to another.

As far as the energetic analysis is concerned, the methodology estimates optimum inclinations to use solar energy either in thermal uses for heating water or in photovoltaic uses to sell it, afterwards, to the electric main. It will be possible to design the inclination of the roof of buildings in advance with optimum inclination to maximise the production of hot water and electricity.

Applying technical sustainable solutions (according with the *Strategy for sustainable development* [1] proposed by Spanish Government) to the tourism in general is highly demanding. In fact, this methodology provides tools that allow designers to make use of natural resources such as water and energy more efficiently. However, the waste products that generated by the resort have for the moment been left aside. In that sense, the methodology remains open to future wide extensions with the analysis of waste generated products and social implications.

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Building and Urban Integration of Renewables

ENERGY PERFORMANCE OF EXTERIOR-INSULATED CONCRETE WALLS EMBEDDED WITH MINI SOLAR COLLECTORS

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ABSTRACT

This paper assesses the feasibility of using mini solar collectors to improve the energy performance of low R-value (≤1.2 m^2K/W) exterior-insulated concrete walls.

A simulation analysis shows that mini solar collectors covering less than 20% of a wall's face can increase the equivalent R-value of an exterior-insulated concrete wall by more than 50%. Four types of collectors are trialled in north-facing test walls at Christchurch, New Zealand, over a nine month period (Jul'06-Mar'07). The most effective collector reduces wall conduction by more than 50% during winter and increases the equivalent R-value by more than 3.0 m^2K/W. Collectors can transform a wall from being a heating load to being a source of 'free' heat during spring.

Mini solar collectors are shown to be a feasible alternative to insulation for improving wall energy performance. Further performance improvements can be made by minimising their solar heat gain during cooling periods and reducing convection within their cavity.

INTRODUCTION

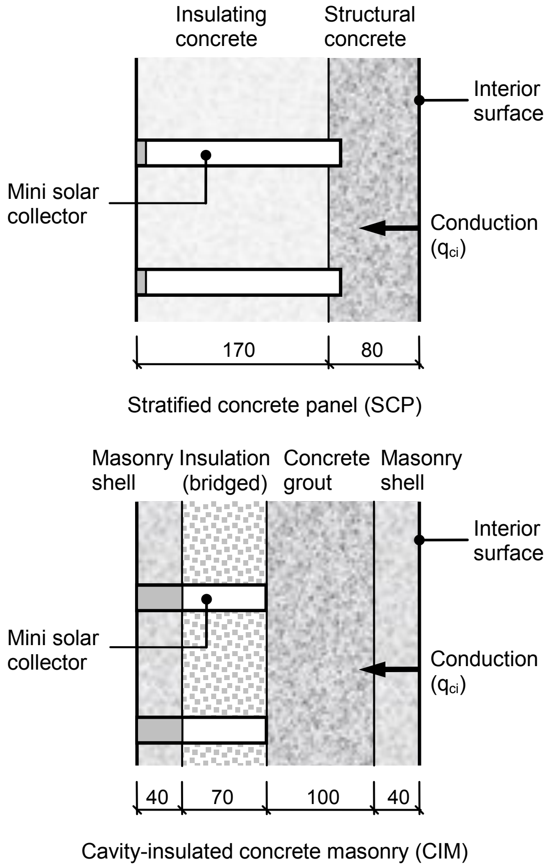
This paper is an initial assessment of the feasibility of improving the energy performance of low R-value (≤1.2 m^2K/W) exterior-insulated concrete walls, in particular novel stratified concrete panels [1] and cavity-insulated masonry [2], by embedding mini solar collectors into their outer layer(s).

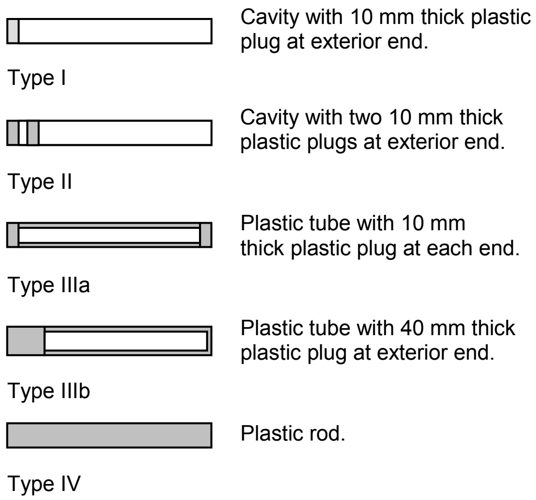
Stratified concrete panels (SCP) and cavity-insulated masonry (CIM) satisfy the current minimum R-value requirements of the New Zealand Building Code [3] for high thermal mass walls (0.3-1.2 m^2K/W depending on building type and location). However, these walls need to be able to satisfy more demanding R-value requirements to future-proof their access into the New Zealand building market and to enable them to be widely used in other countries.

Supplementary insulation may be added to SCP/CIM to form a composite wall with higher R-value. However, insulation placed on the exterior side of a wall needs to be protected from the elements, which is costly, while insulation on the interior side reduces the effectiveness of a wall's thermal mass. Another option is to perform an R-value trade-off calculation or a modelling analysis to show that a proposed building has satisfactory energy performance even though the SCP/CIM fails to satisfy minimum R-value regulatory requirements. There is merit in modelling to determine the effect of thermal mass on building energy performance. However this approach does nothing to improve the underlying performance of SCP/CIM.

Mini solar collectors (Figure 1) were conceived as a low-cost alternative to supplementary exterior insulation. They are discrete semi-transparent elements that transmit solar radiation from the exterior surface to, or near to, the inner thermal storage layer(s). They 'work' in a similar way to transparent insulation but differ in two important ways. They collect solar energy from part, not all, of a wall's exterior surface. And they penetrate a wall's insulation layer, which may reduce its R-value, whereas transparent insulation increases R-value.

The effectiveness of a mini solar collector depends on its solar and heat loss characteristics, the thermal characteristic of the wall in which it is embedded and the indoor and outdoor climates. A simulation analysis is undertaken to investigate the effect of these factors on wall energy performance. Four types of collectors (Figure 1) are analysed. Promising designs are trialled to further assess the feasibility of using collectors to improve wall energy performance.





Material	Density (kg/m^3)	Thermal conductivity (W/mK)	Specific heat (J/kgK)
Structural concrete	2200	1.3	900
Insulating concrete	800-1200	0.167-0.275	900
Masonry shell	2200	1.3	900
Concrete grout	2200	1.3	900
Plastic*	1200	0.2	1300
Insulation (bridged)	350	0.074	900

* Refractive index and extinction coefficient of plastic equal 1.5 and 0.01 mm^{-1} respectively.

Figure 1: Types of model walls and collectors.

EQUIVALENT R-VALUE

The steady-state R-value (R-value) is not a suitable indicator of the energy performance of the walls analysed in this paper because it does not account for the effects of thermal mass or solar heating on wall heat conduction. A new performance indicator that accounts for thermal mass, solar heating and insulation, the equivalent R-value, is developed below.

The equivalent R-value is defined as the R-value of a massless wall that has the same energy performance, in the absence of any solar heating (i.e. zero solar absorptance), as the real wall, when the walls are exposed to the same indoor and outdoor climates and both have unit area.

Treating the energy performance of a wall as the conduction load it imposes on heating and cooling equipment, then the equivalent R-value, R_{eq}, may be found from

$$R_{eq} = \frac{3600 n_{aux} A_w \Delta T_m}{q_{con}} \quad (m^2K/W) \qquad (1)$$

where q_{con} is the conduction load, ΔT_m is the temperature difference driving conduction in the massless wall, A_w is the wall area (=1 m^2) and n_{aux} is the number of heating and cooling hours (i.e. hours when auxiliary heating or cooling is required).

Wall conduction is a load on environmental control equipment only when auxiliary heating or cooling is required, so the conduction load over a period of n hours may be found from

$$\frac{q_{con}}{A_w} = \sum_{i=1}^{n} h_i q_{ci,i} - \sum_{i=1}^{n} c_i q_{ci,i} \quad (\mathrm{J/m^2}) \qquad \begin{cases} h_i = 0 & \text{if auxiliary heating is not required} \\ \quad = 1 & \text{if auxiliary heating is required} \\ c_i = 0 & \text{if auxiliary cooling is not required} \\ \quad = 1 & \text{if auxiliary cooling is required} \end{cases} \tag{2}$$

where $q_{ci,i}$ is the conduction at the wall's interior surface (+ve towards outdoors) during the ith hour of the period.

In the absence of solar heating, conduction in a massless wall is driven by differences in indoor and outdoor air temperatures, assuming long wave radiation heat transfer can be treated like convection. So the temperature difference in Equation (1) may be found from

$$\Delta T_m = \frac{\sum_{i=1}^{n} h_i (T_{ai,i} - T_{ao,i}) + \sum_{i=1}^{n} c_i (T_{ao,i} - T_{ai,i})}{n_{aux}} \quad (\mathrm{K}) \tag{3}$$

where $T_{ai,i}$ and $T_{ao,i}$ are the hourly mean indoor and outdoor air temperatures, respectively.

Heating and cooling hours

The simple balance point temperature approach is used to determine heating and cooling hours. In a well-ventilated building, auxiliary (mechanical) cooling is required only when the outdoor air temperature approaches the cooling temperature. So a cooling balance point temperature equal to 22^{o}C is used here.

The requirement for auxiliary heating depends on the building's thermal characteristics, the level of solar and internal heat gains, the heating temperature and other climatic factors. Values ranging from 7^{o}C–18^{o}C have been observed in US houses [4] and even lower values are possible. A mid-range value of 12^{o}C is used for the heating balance point temperature.

With this heating and cooling model, wall conduction does not contribute to the load on heating and cooling equipment when $12^oC \leq T_{ao} \leq 22^oC$, so the h and c functions in Equations (2) and (3) are

$$c_i = \begin{cases} 0 & \text{if } T_{ao,i} \leq 22^o\mathrm{C} \\ 1 & \text{if } T_{ao,i} > 22^o\mathrm{C} \end{cases} \tag{4}$$

$$h_i = \begin{cases} 0 & \text{if } T_{ao,i} \geq 12^o\mathrm{C} \\ 1 & \text{if } T_{ao,i} < 12^o\mathrm{C} \end{cases} \tag{5}$$

The heating and cooling hours of an actual building may differ from those predicted by Equations (4) and (5). Nevertheless the equivalent R-value is expected to be a good indicator in a wide range of buildings, although further research is required to confirm this.

Hourly conduction and indoor climate

Conduction at the interior surface of a wall, $q_{ci,i}$, may be simulated or measured values. The boundary conditions attributed to the interior surface when simulating conduction are

$$G_{i,i} = 0 \ \ \mathrm{W/m^2} \tag{6}$$

$$T_{ai,i} = \begin{cases} 22^{o}C & \text{if } t = 13\text{-}18 \\ 20^{o}C & \text{if } t = 7\text{-}12 \text{ or } 19\text{-}24 \\ 18^{o}C & \text{if } t = 1\text{-}6 \end{cases} \quad \text{where } t(=1\text{-}24) \text{ is the hour of the day.} \tag{7}$$

where $G_{i,i}$ is the hourly mean irradiance and $T_{ai,i}$ is the hourly mean indoor air temperature (Note: daily mean indoor air temperature = 20^{o}C). Prescribing the indoor climate simplifies the task of simulating the equivalent R-value as only the wall needs to be modelled. Further research is needed to determine how well the simulated equivalent R-value indicates the energy performance of a wall exposed to an indoor climate that differs from the above.

SIMULATION ANALYSIS

The ESP-r (11.4) program is used to determine simulated equivalent R-values for walls at Christchurch (43.5^{o}S). Heat flows in a section of a wall, comprising a collector and five layers of opaque material (Figure 2), are modelled over a 'typical' year. Layers penetrated by the collector are divided into eight or nine segments and each layer/segment is modelled as a thermal zone. Wall mass is assigned to x-z surfaces and a zone's surfaces are thermally 'connected' to mimic solid material. Solar radiation in a collector is either distributed uniformly over interior surfaces or focussed at the far end. Literature [5] indicates that airflow in the cavity of a Type I-III collector is largely suppressed. So cavity heat transfer is modelled as combined radiation and pure conduction.

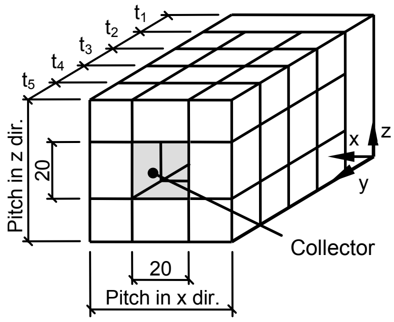


Figure 2: ESP-r model.

Simulations are conducted for plain walls and walls embedded with solar collectors that cover just 16% of the wall face area. The results (Table 1) indicate that mini solar collectors can significantly improve wall energy performance and that:

- the equivalent R-values of plain SCP and CIM walls are approximately double their steady state R-values. The difference is due to thermal mass and (exterior surface) solar heating.
- double-cover collectors are generally more effective than single-cover collectors. However the capability to transmit solar radiation to the end of the collector (i.e. focussed solar distribution in Table 1) has a greater effect on wall energy performance.

Wall type	Mini solar collector[1]			R-value of plain wall[2] (m^2K/W)	Equivalent R-value[2,3] (m^2K/W)			
	Type	Length (mm)	Solar distrib.		N	E	S	W
SCP	-	-	-	1.2	2.8	2.5	2.3	2.6
	I		Uniform	1.2	8.9	3.7	3.0	4.5
	-	-	-	1.0	2.1	1.9	1.8	1.9
	I	185	Uniform	1.0	4.7	2.5	2.2	2.6
	II	185	Uniform	1.0	6.0	2.5	3.3	8.0
	IIIa	185	Uniform	1.0	9.5	2.9	2.9	3.7
	IIIa	185	Focussed	1.0	20.1	2.9	2.2	8.7
	IV	185	Uniform	1.0	3.7	2.3	2.0	2.6
	-	-	-	0.8	1.5	1.4	1.3	1.4
	I	185	Uniform	0.8	2.7	2.9	1.6	2.2
CIM	-	-	-	1.2	2.3	2.0	1.9	2.1
	IIIb	110	Uniform	1.2	3.2	2.4	2.2	2.7

Table 1: Simulated equivalent R-values of stratified concrete panel (SCP) and cavity-insulated masonry (CIM) walls at Christchurch (43.5^{o}S).

Note:
1. Pitch in x and z directions equal 50 mm. Collectors cover 16% of wall face area.
2. Interior and exterior surface resistances equal 0.09 m^2K/W and 0.03 m^2K/W respectively. Insulating concrete density equals 800/1000/1200 kg/m^3. for R1.2/R1.0/R0.8 SCP walls
3. Solar absorptance of opaque wall surfaces equals 0.5.

TEST WALL TRIAL

North-facing test walls (Figure 5) were trialled at Christchurch over a period of nine months (Jul'06-Mar'07) to further assess the effect of solar collectors on wall energy performance. The R-values of the plain SCP and plain CIM walls are ~0.9 m^2K/W and ~1.2 m^2K/W respectively. The SCP walls (Nos. 1-7) are essentially identical, apart from their collectors. Likewise for the CIM walls (Nos. 8-9). The walls are unpainted but are waterproofed with a clear sealer. Their constructions are similar to those shown in Figure 1.

The indoor air temperature adjacent to the walls was maintained at ~20^oC throughout the trial, while the monthly mean outdoor air temperature varied between 7.4^oC in July to 17.9^oC in February (Figure 4). Conduction at the interior surfaces of the walls was measured with Hukseflux HFP01 heat flux sensors and a Campbell Scientific CR10X datalogger.

All of the collectors reduce monthly mean conduction throughout the trial, especially during the evening (Figure 6). Type IV collectors produce the greatest reductions, followed by Type III, with the Type I producing the smallest reduction (approx. 10% and 25% in August and September respectively). The 'best' collector (200 mm rod) reduces conduction by approximately 70% in August and turns a SCP wall into a heater from September onwards.

Equivalent R-values of the plain SCP and CIM walls, based on the whole trial (hours with T_{ao}<12^oC or T_{ao}>22^oC), are 1.9 m^2K/W and 2.5 m^2K/W respectively (Figure 3). These are more than double the walls steady state R-values – the increase due to thermal mass and solar heating effects. Collectors increase the equivalent R-value of the SCP wall to 2.2-3.5 m^2K/W, depending on collector design, i.e. an increase of 13-85%. With collectors, the CIM wall has an equivalent R-value of 2.9 m^2K/W, i.e. a 19% increase.

From Figure 3 it can be seen that the collectors, apart from the Type IIIa, reduce wall energy performance over Jan-Mar. Unwanted solar heat increases the cooling load over this period.

DISCUSSION

The results confirm that mini solar collectors may be used as an alternative to supplementary insulation, for improving the energy performance of exterior-insulated concrete walls. The equivalent R-value of east- north- and west-facing walls may be improved by more than 50% with simple collectors that cover less than 20% of a wall.

It appears that convection within the cavities of Type I and III collectors reduced the energy performance of the associated test walls (Nos. 5, 6 and 8). Solar heat collected during summer also reduced wall energy performance. Therefore there is scope for developing mini solar collectors that are significantly more effective than those tested in this study.

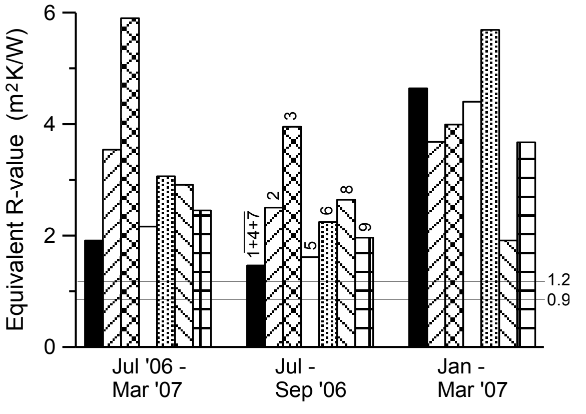


Figure 3: Equivalent R-values of test walls.

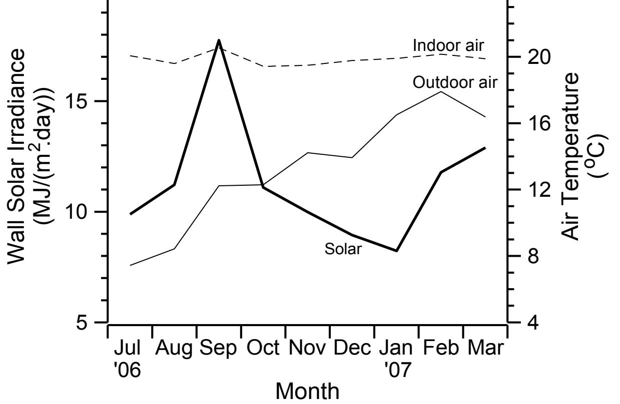


Figure 4: Climate over the trial period.

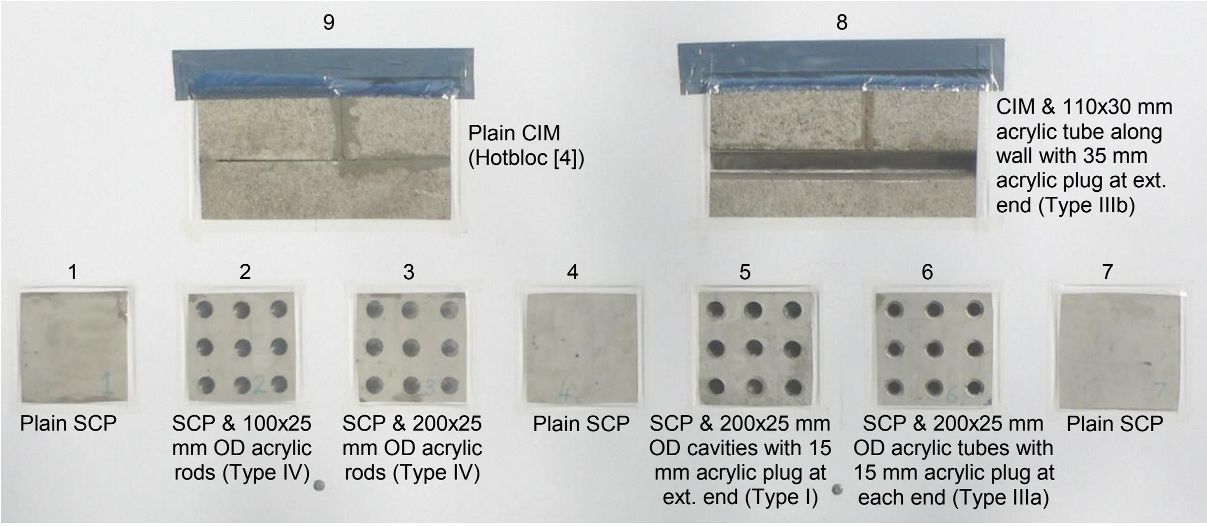


Figure 5: 250 mm thick stratified concrete panel (SCP) and 240 mm thick cavity-insulated masonry (CIM) north-facing test walls at Christchurch (43.5°S). Collectors cover 15-16% of walls 2, 3, 5, 6, and 8.

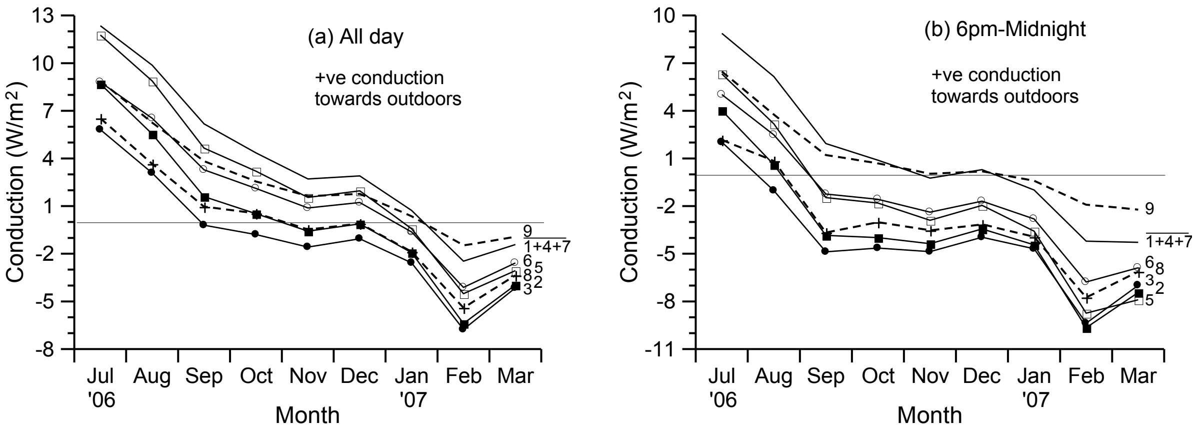


Figure 6: Monthly mean conduction at the interior surfaces of test walls.

ACKNOWLEDGEMENTS

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DESIGN OF A NET-ZERO ENERGY HOUSE: TOWARDS SUSTAINABLE SOLAR COMMUNITIES

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ABSTRACT

The Alstonvale Net Zero House (ANZH) is one of the twelve winners of *EQuilibrium*, a design competition launched in 2006 by Canada's federal housing agency. The ANZH was created with the objective of achieving annual net-zero energy (a particularly stringent criterion under Canadian climatic conditions), while minimizing environmental impact and providing a healthy and comfortable indoor environment for its occupants.

Over the next few decades, the challenge of satisfying the world's needs in a sustainable manner while protecting the environment will require an innovative and comprehensive approach not only to the design of buildings and communities, but also to transportation and food production. An understanding of this reality led the ANZH design team to widen the scope of the project to include local mobility and crop growing (in the exterior garden and a solar greenhouse). This concept may be extended with amplified benefits at the community scale. This paper describes the principles and design methodology behind the ANZH, largely based on computer simulations and on environmental, technical, practical and financial considerations.

INTRODUCTION

The *EQuilibrium Initiative* was organized in 2006 by Canada Mortgage and Housing Corporation (CMHC), Canada's federal housing agency. This design competition was created to showcase the potential of existing technologies to achieve residential buildings that are highly energy efficient, incorporate renewable energy production and have low impact on the ecosystem, while maintaining a healthy and comfortable indoor environment. Achieving or approaching the net-zero energy objective was one of the key criteria considered. Twelve winning submissions were selected in early 2007, among them the Alstonvale Net Zero House (ANZH) [1], a 230-m^2 two-storey house located in Hudson (45°30' N, 74°09' W), near Montréal, Québec, designed for a family of four. The ANZH is now in an advanced phase of construction (Figure 1). Over the last two years, the design team has revisited the design [2], widening the scope to include food production and local transportation, based on the following considerations. Figure 1 shows the breakdown of the house's electrical energy consumption (see text for details).

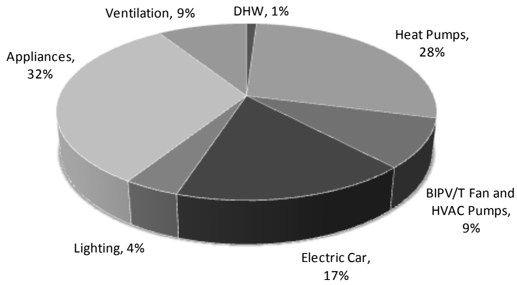

Figure 1: State of construction of Alstonvale Net-Zero House (May 18th, 2009) and breakdown of the ANZH electrical energy consumption (9.000-9.200 kWh).

Considerations

In 2006, nearly 487 EJ (1 x 10^{18} J) of primary energy were consumed globally, up from 367 EJ in 1990 [3]. This corresponds to an increase of 33% over 15 years. A reference projection of the International Energy Agency (IEA) forecasts a global annual energy consumption of 712 EJ in 2030 [4], an increase of almost 50% in 25 years. According to the IEA, fossil fuels will likely remain the basis of the world's energy supply in the next few decades [4]. Although no scarcity of fossil fuels is foreseen in the near future, their exploitation will be undertaken at unprecedented costs and with major detrimental repercussions on the environment, of which rapid climate change associated with the emission of greenhouse gases is perhaps the most widely known. The finite nature of fossil fuels will eventually impose a transition towards renewable and sustainable energy systems, which will be more or less abrupt depending on our capacity to anticipate and prepare for it.

Including hydroelectric generation, renewable sources provide about 7,8% of the world's total primary energy (38,8 EJ); this number is expected to increase to 10,3% (79,5 EJ) by 2030 [5]. However, this is still a relatively modest contribution. Among renewable energies, only solar energy has the potential to fully supply the world's energy needs; if only 0,1% of the incident solar radiation could be converted at 10% efficiency, it would still be more than 4 times the world's generating capacity [6]. Despite this potential, factors such as the low density of solar radiation and its variability, the high cost of photovoltaic panels, and the difficulties of large-scale deployment (including lack of infrastructure for transmission lines) suggest that it is not viable to expect *centralized* photovoltaic power plants to provide a substantial fraction of the world's energy needs in the short-term.

Approximately 8,4 EJ of secondary energy were used in Canada in 2006 [7]. Residential buildings account for 16% of this value, while commercial and institutional buildings account for about 13%. The transportation sector uses about 29% of Canada's secondary energy, more than half of which is used in passenger transportation. Canada's emission of greenhouse gases (GHG) was estimated at 478,4 millions of tons of CO_2 equivalent. Residential and commercial buildings emitted 27,2%, and the transportation sector 36% of the total GHG emissions. The building and transportation sectors therefore represent comparable fractions of Canada's consumption of secondary energy and GHG emissions.

Another important sustainability challenge is the dependence of the industrialized food system on fossil fuels [8], which are used in the manufacture of fertilizers and pesticides, operation of machinery, and transportation of produce, sometimes over thousands of kilometres. Intensive use of fossil fuels in agriculture made the Green Revolution possible, but has made food supply largely dependent on their availability [8]. Food production is also threatened by land and soil degradation in certain areas.

It has become apparent from the considerations presented above that although the original goals of the ANZH project point in the right direction, a more comprehensive approach is needed. This project therefore proposes: (a) a house with a net-zero energy design; (b) additional photovoltaic capacity to charge an electric vehicle; and (c) food production on-site with an optimized greenhouse/solarium linked to the house energy system.

KEY PRINCIPLES OF THE ENERGY SYSTEM

Passive solar design and a high-performance building envelope. The ANZH was designed with high insulation values in the building envelope to reduce heating loads, the most important fraction of the energy used in Canadian homes. The Canadian housing simulation software HOT2000 [9] was used as the tool to select the insulation values through several iterations (5,6 RSI in the walls, 12 RSI in the ceiling and 4,6 RSI under the floor slab). Although the ANZH will be considerably better insulated than typical houses in Montréal, these figures are not extreme. The studies with HOT2000 indicated that beyond a certain point, additional insulation did not reduce heating loads significantly (other factors, notably infiltration and ventilation, become dominant), and thus was not economically justifiable.

Passive solar design is essential to the ANZH. Advanced windows (triple-glazed, argon-filled, with low-e coating) cover about 42% of the south façade of the house, and around 7 and 10% of the east and west façades. The solar heat gains passing through these windows (RSI 1,2 and g = 0,57) will cover the entire heating load on sunny days in winter. Overhangs will block solar heat gains in the summer to prevent overheating. A motorized theatre curtain will help block excess solar radiation in the shoulder seasons while reducing heat losses at night. Passive thermal storage is increased by using concrete floors (20-cm thick on most of the first floor and 6,5-cm thick in the rest of the house) and a masonry wall in a buffer space across from the south-facing windows, which forms an atrium connecting both floors. It is estimated that passive solar design will account for more than 50% of the gross heating needs. A heat recovery ventilator will maintain air quality. No mechanical cooling will be used: a motorized window on the west façade and an east-facing damper on a solar chimney will be opened to enhance natural convection currents in the summer.

Building integrated photovoltaic/thermal (BIPV/T) system. The cornerstone of the energy supply is the grid-connected BIPV/T roof, consisting of 48 photovoltaic panels, arranged in three rows of sixteen 175-W panels, with a total installed capacity of 8,4 kW. Exterior air is drawn through a channel under the PV panels to extract heat from them, thus cooling them and improving their performance. A row of glass panels located above the PV panels functions as a solar air-heater; a low emissivity absorber surface placed under the glass reduces radiation heat losses. The original PV power was increased from 5,5 kW to allow extra power for an electric vehicle and provide some flexibility, although this somewhat reduces the final air temperature. A variable speed fan will vary the flow rates between 400 and 900 L/s. High flow rates provide more efficient heat extraction, while lower flow rates allow higher temperatures to be obtained. The control system will select the fan speed based on the required thermal energy and temperature, and on the fan power consumption.

RETScreen [10] has been used to estimate the yearly generation of the photovoltaic array. This array is expected to generate about 10.000 kWh per year, of which 70-75% will be used for the needs of the house. The temperature rise in the channel was determined by dividing the channel into several control volumes and writing one-dimensional energy balances for each control volume. The BIPV/T mathematical model was written first in a Mathcad [11] program and then as a MATLAB M-file [12]. The final BIPV/T exit temperature depends on several variables including solar radiation, exterior temperature, flow rate and wind speed. It has been calculated that the exit temperature could be 40 °C higher than the exterior air temperature.

This BIPV/T system is based on the fact that solar radiation provides a significant amount of energy during a few hours per day. As much of this energy as possible is collected in the form of electric power and heat. On a sunny day, solar heat gains will satisfy most or all of the heating needs of the house; the energy collected with the BIPV/T will be used for future days.

The BIPV/T roof design requires optimizing the area occupied by the PV modules and the glass panels, the roof slope and the type of PV panel. To this end, factors such as the energy needed for the house and its peripherals, incident solar radiation, snow shedding and melting in winter, aesthetics and envelope performance must be considered.

Heat exchanger and hybrid-source heat pump system. A manifold near the top of the roof collects the BIPV/T air. A ducting system with very small pressure losses brings the air to an air-to-water heat exchanger just before the variable-speed fan. Both the fan and the heat exchanger will be located in the ceiling of the garage. The heat exchanger will serve as the source of a heat pump system with two compressors [13]. The heat removed from will vary between 6 and 22 kW. When thermal energy is required, and the BIPV/T air temperatures are below a certain limit (about 5-8°C), a 75-m deep ground loop will serve as the backup heat source. The ground loop is expected to provide about one third of the auxiliary heating needs.

Passive and active thermal energy storage (TES). Thermal energy from the BIPV/T roof will be stored in a 4500-L water tank (active TES) which supplies heat to a radiant floor heating system. About 150 kWh can be stored in the reservoir, corresponding to one day's worth of heating with a moderate heating load (6 kW). The tank may also be charged directly from the heat exchanger when BIPV/T temperatures are high enough. The thermal mass of the house (of which the concrete floors are a major component) works as a passive TES system, which may be charged either with solar heat gains, or with the radiant floor heating system.

Predictive and smart control features. Publicly available weather forecasts will be downloaded every twelve hours and integrated into the control system. Forecasts will be used to: (a) plan the collection, storage and delivery of the energy collected by the BIPV/T depending on current and future conditions; and (b) reach prescribed set-points modelled to follow diurnal cycles, taking into account the large time constants of the house (on the order of several hours). A central control system will coordinate the operation of the electrical and mechanical equipment, allowing the implementation of load management strategies.

Domestic hot water (DHW) supply and other measures. An array of 40 evacuated-tube solar collectors will supply about 90% of the DHW needs (the rest will be covered with an instant water heater). The solar collector is assisted by water conservation (low flow showers, faucets with aerators) and by a heat exchanger used to extract thermal energy from the gray water from the shower drains. High efficiency appliances and lighting systems account for approximately 3.500 kWh consumption per year.

The interaction of the different systems and the house was modeled with Simulink [14], MATLAB's tool for dynamic simulation. Both typical climate files for Montréal and sequences of test days were used. The operation of this house is estimated to require about 25% of the energy used by a conventional house in Canada.

BEYOND THE HOUSE

As previously mentioned, the capacity of the PV system was increased to provide energy to the ZENN [15], a low-speed plug-in electric drive vehicle designed for neighbourhood use. Assuming that the vehicle will be charged three times per week, and each charge takes 9-10 kWh, it is expected that approximately 1.500 kWh per year will be used for the car. The car batteries will also serve as an emergency supply for critical loads in the house in case of a grid power failure (vehicle-to-house concept). The inverters to be installed have anti-islanding protection, but are also capable of using battery power to supply essential loads. A team from CanmetENERGY Varennes (Natural Resources Canada) is currently developing the house-to-EDV electrical connection as part of a large-scale project on load management [16].

The ANZH will also incorporate local, sustainable and organic food production in an outdoor garden and within a net-zero energy solar greenhouse, currently under development. The greenhouse will be used to extend the growing season and for food processing and storage. Students from McGill University's School of Environment have selected appropriate crops for the plots and the greenhouse [17]. The 40-m^2 greenhouse will have motorized blinds to control solar gains and clear glazing to make it a pleasant space for use in winter. A solar air system will facilitate storage of excess solar gains in the soil [18].

Despite being largely independent, the greenhouse may share energy resources with the ANZH by connecting a hydronic circuit (i.e., one of the radiant floor heating pipes) from the TES tank in the house to its thermal mass. The house and the greenhouse will be electrically linked and also connected to the utility grid through the main meter [16].

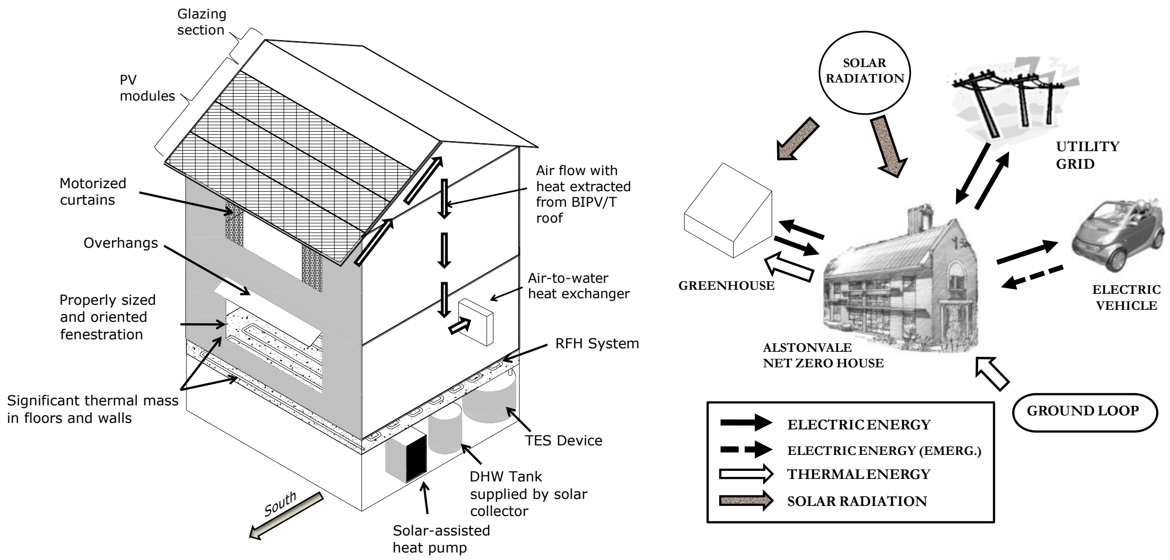

Figure 2. Conceptual representation of the ANZH energy system (solar thermal collectors not shown), and energy exchange possibilities between the house, the greenhouse and the EDV.

TOWARDS SOLAR COMMUNITIES

The ideas presented here, applied to a single house, can be implemented with amplified benefits at the community scale. Economies of scale are valid both financially and in the energy design. For example, seasonal storage is more easily applicable to many houses, collective transport can be implemented, and smart micro-grids allow electric power sharing between houses, reducing peak demand of the power supplied by the utility.

CONCLUSION

The ANZH has been presented as a prototype of a home that will not only satisfy its own energy needs, but will supply the means for local transportation and a substantial portion of the food of its occupants. The completion of the project is planned for the autumn of 2009. The ANZH will be monitored during a 6-month period (open to the public), and during the first year of occupation. Variables to be monitored include temperatures of the concrete floor and room air temperatures, PV generation, overall electrical balance, electrical consumption of the main equipment, and performance of the mechanical equipment.

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ABOUT DIFFICULTY TO MODEL ENERGY DEMAND AT LOCAL SCALE

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ABSTRACT

Modeling energy demand at local scales (district, city or region) becomes more and more relevant in view of massive implementation of energy efficiency actions and energy solutions based on renewable. For instance, the knowledge of energy needs for space heating, cooling or domestic hot water production enables to imagine solutions adapted to these scales, either to reduce the needs or to meet them through local resource (solar production for a district, integration of biomass in a district heating network, local micro wind turbines for a neighborhood, combination of various local energy sources …). Many tools have been developed at the building scale in the past but the quantity and the availability of data necessary to perform calculations make them maladjusted to the scales considered here. Furthermore, several tools have been developed in the last decade (EEP, SUNtool, Enerter, End-Use Simulation Model at City Scale…) in order to tackle energy issues at urban or regional scales. The aim of this work is to illustrate the importance of the input data and their type in the scale change (from building to city).

INTRODUCTION

An important number of tools have been developed during the last decades at building scale [1] but even if a transfer of these models into bigger scales is possible (e.g. in the case of a patrimony approach) it is often difficult due to coupled physical phenomena (e.g. urban microclimate), social interactions, behaviour of inhabitants… In most of cases it is necessary to adapt the existing models (reduced models) and to combine the resources (statistical and physical models). It is also necessary to specify the objectives and the end use of the results produced by the model. This introduces the concept of typology of objectives. A model which will be used to evaluate the sustainability of a neighbourhood won't be built like a model designed to evaluate retrofitting actions or to forecast the energy consumption and environmental impact (COMFIE [2], SUNtool [3]…).

Much research works have allowed various tools to be built in energy modelling at building scale [1] : TRNSYS, DOE2, ENERGY+, COMFIE … The complexity of modelling a single building stops not only at the number of variables needed (e.g. 26 for a single room for Hudson & al. [4]) but also in the difficulty of obtaining the data when the tool is used for existing buildings. Different classification of building simulation models can be made based on several criteria like objectives (new buildings, improvement of existing ones…), algorithm used (approach nodal, modal, analytical…), end users (researchers, architects, engineers…)… For instance, COMFIE [2] is a tool built from energy balance equations coupled to reduction methods for hourly simulation. It is used to provide energy needs, temperature profiles and power profiles. Another solution often met is resistance-capacitance method, applicable in short-time building control design (Hudson & al. [4]). This method is not rare and can be more or less complex (e.g. Gouda & al. [5]). Crawley & al. [1] has list and studied the differences between the different models. A classical approach to study the existing models is the sensitivity analysis [6..8] which allows the most important parameters to be identified.

The tools presented above are used to design new constructions or evaluation of retrofitting actions but some issues necessitate to be studied at a larger scale. For example, policy makers must know the effect of potential actions of refurbishment on a part of the city or the neighbourhood. This need has for consequence the development of new energy analysis methodologies like the energy demand management defined by Capasso & al. [9]. More recently the approach behind a tool like SUNTOOL [3] is an interesting option to model energy demand at local scales. It is an answer of the coupled phenomena mentioned previously and that must be taken into account at this scale. SUNtool provides an evaluation of electricity and thermal energy demand to support analysis of alternative sources of energy and urban regeneration. The tool is composed by a Solar Radiation Model (built from a Simplified Radiosity Algorithm), a simplified dynamic thermal models (a reduced model from the physical laws of energy balance on the envelope), stochastic models (occupancy, windows opening model, appliances model for water and electricity consumption, lighting and blind use model, plant and equipment models…). A detailed sensitivity analysis and a test of the different sub-models has been performed [10] and even if the author presents some surprising tool results, the potential for future development make this kind of tool a powerful path of future research. In a same way, the Energy and Environment Prediction model (EEP) [11] is composed of 5 sub-models: Housing energy, Non-domestic energy, Industry, Traffic flow and Health. The main objective of this tool is to simulate the use of energy in a built environment to apply sustainable decisions to minimise CO_2 and other emissions [12]. The energy sub-model is based on the UK government Standard Assessment Procedure (SAP) [13] which makes it more adapted to the specific requirements of UK authorities. For Jones P. & al. [11] the data needed to make a simulation is a constraint since the procedure for collecting data in order to perform a simulation at city scale is considerable: 18 person-months approximately for 55,000 dwellings. Some new research by the authors are trying to improve the collect of data by GIS pattern recognition, but the accuracy of the method (less than 60%) is still low for the purposes of modelling energy demand. The works made by Shimoda & al. and Yamaguchi & al. [14..17] also integrate statistical and thermal models to built a simulation tool at the city scale (Statistical Estimation of Energy end Use). Dynamic energy simulation (resistance and capacitance model) is made for the each representative building of different classes. The National Time Survey is used to simulate the appliances consumption, linked to occupants' energy usage activity and the energy use schedule. The tool simulates 380 categories based on the household and building type. The whole energy demand of the city is reconstituted by adding the consumption of the representative buildings proportionally to their numbers. The use of the National Survey allows the efficiency actions that should be implemented to be identified. A weighted factors method is used in one of these works (Yamagushi & al. [18]).

The objective of this work is to analyze difficulties of the urban scale energy demand modelling. The importance of different factors is underlined: availability of input data, types of data and objectives at the genesis of the tool development. The consequences of the change scale on the importance of these factors are analysed. The study is performed at building scale and neighbourhood (city) scale. Six representative tools at the building scale and four at the neighbourhood scale are analysed. Both the literature results and further sensitivity analysis have been used. Complementary sensitivity analyses have been performed with COMFIE [2] (Building scale) and SUNtool [3] (neighbourhood scale) which are quite representative of their categories. The present study focuses only on the energy issue, waste and water issues haven't been studied but the approach is similar.

Methodology

			References										Analysis			
			City-Level				Building-Level									
		Objectives of the Model	A, B, C, D	A,B	B,C	B,C	D	E	E	F	G,H	H				
			Weighted Parameter Factor													
No.	Classification	Parameter	Mod. 1 - Suntool	Mod. 2 - EEP	Mod. 3 - Yamaguchi	Mod. 4 - Shimoda	Mod. 5 - COMFIE	Mod. 6 - Hudson	Mod. 7 - Gouda	Mod. 8 - De Witt	Mod. 9 - Lam	Mod. 10 - Motillo	αCL (Alpha City-level)	αBL (Alpha Building Level)	αDA (Data Availability)	Influence Factor
1	Geometrical	Floor surface	1	2	2	1	1	1	1				0,750	0,381	4,5	60%
2	Statistical	Number of buildings	3	3	3	3							1,000	0,000	5,0	55%
3	Data	Thermostat temperature	1		1	1	1				3	3	0,500	0,476	4,0	52%
4	Statistical	Weather data	3		1	1	1	1			1		0,583	0,381	5,0	53%
5	Geometrical	External building surface	1	2			1	1	1		1		0,375	0,476	3,0	44%
6	Data	Fuel of Energy Source	1	3	1	1							0,750	0,095	3,0	44%
7	Geometrical	Glazing ratio	3	2			1	1			3		0,458	0,333	3,0	42%
8	Geometrical	Total surface of building	1	1		1	1		1				0,500	0,286	4,0	43%
9	Data	Infiltration rate with outdoor air	2			1				3	1	3	0,375	0,381	1,0	36%
10	Data	Lighting intensity	1		1						3	3	0,333	0,381	1,0	34%
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
80	Data	Water heating efficiency (%)										1	0,00	0,10	1	6%

Table 1: Characteristics of the input parameters of the models. (10 of the 80 studied are presented to make the figure easy to understand). See figure 2 for definitions of A, B, C,....

Parameters met in the different works of the literature analysis or in the tool directly analysed in the study are listed in the *table 1* (total number = 80 parameters). A *Weighted Parameter Factor* was defined in a scale going from 1 to 3: the higher the value is the more influential the parameter is in the final result of the simulation. When this influence was not correctly identified by the authors of the works, an analysis of the objectives of the tool and of the related works was made. An effective sensitivity analysis has been performed for Mod.1 and Mod.5. The availability of the parameter -which has been identified as an important issue- is quantified through the α_{DA} factor. This factor is based on the facility for a parameter necessary for the simulation to be quantified (*table 2*). A scale from 1 to 5 is adopted to quantify this availability.

1	Info available only with measure tools in site at household level
2	Info available only by direct surveys in site by household (bills included)
3	Info available by external building surveys (photographs, thermographs, syndicate) or available by certain zones in city-sector
4	Info available by city-scale measure systems (GIS photographs) or using basic statistics (water services make by state offices)
5	Info available easy in most of the cases (construction permits, cultural factors)

Table 2: Availability of parameter value for building/city energy models used in the analysis.

Parameters α_{CL}, α_{BL} are built using the double *equation 1*:

$$\alpha_{CL,BL} = \left[\frac{A}{B}\right]_{CL,BL} \times \beta_1 + \left[\frac{C}{3\times B}\right]_{CL,BL} \times (1-\beta_1) \qquad (1)$$

In this equation, A is the sum of the articles in which a parameter is cited in the reference analysis, B is the total number of articles and C the summation of the *Weighted Parameter Factor* for each parameter. β_1 is a weighted percentage equal to 50% which gives the same importance to the *Weighted Parameter Factor* and the citation of the parameter in the articles. CL and BL are put for City-Level and Building-Level respectively. Then, an *Influence Factor* is built based on weighted average of α_i. It quantifies the influence of the parameter considered, taking into account: its availability, the influence in the final result by reference analysis and the influence of the scale (CL or BL). All the values of α_i and *Influence Factors* are summarized in the *table 1* where parameters are sorted out by importance of the *Influence Factors.*

RESULTS

The *Influence Factor* can then be used to underline how important the scale and the availability of the data are in the influence of parameters in the simulation of energy demand. An example is shown for several parameters on the *figure 1*.

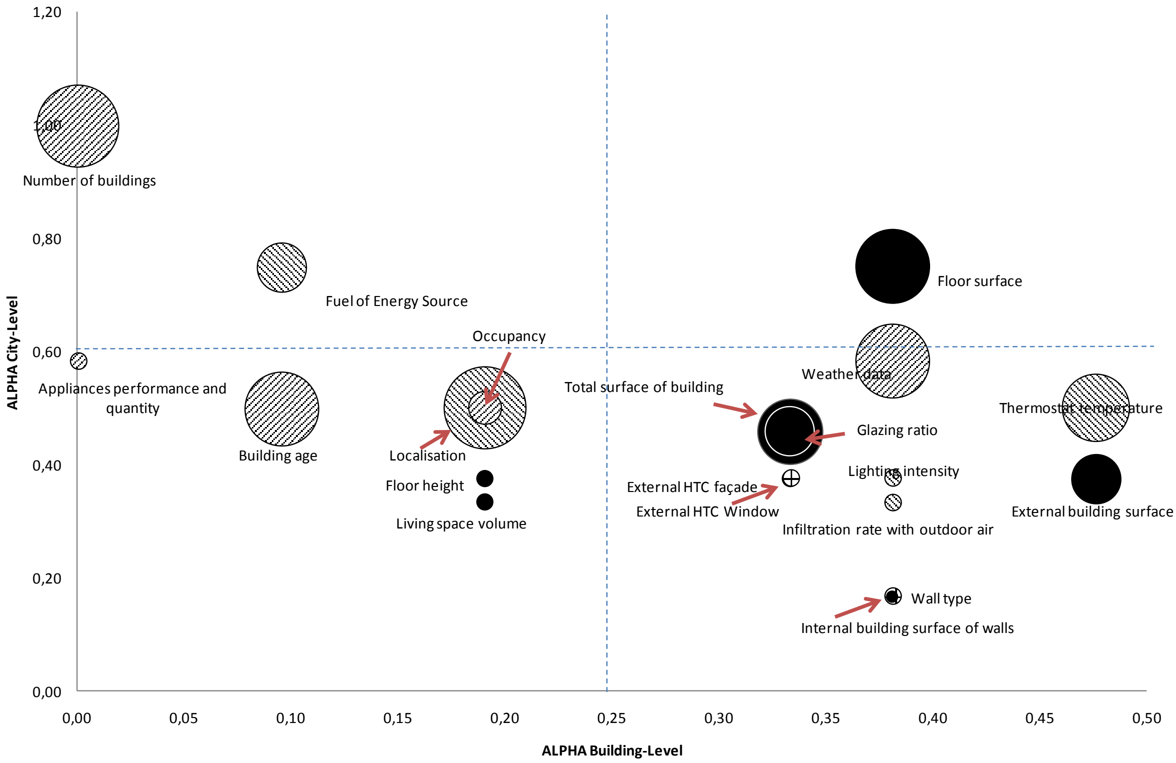

Figure 1: Scatter graph to rank the parameters. Going from the low values to the high values on the x-axis underlines the importance of the parameter at the building scale. Going from the low values to the high values on the y-axis underlines the importance of the parameter at the neighbourhood scale. The bubble size of each parameter shows the data availability, bigger the bubble is more available the data is (table 2). The "colours" relates the classification explained in table 3.

Some elementary results allow the approach to be validated. For example, the "*number of buildings*" is an important parameter at the city scale whereas its importance is null at the building scale. Furthermore, statistical and high available data are used in city-scale models, compared to the building-scale where thermal and geometrical data are privileged. It can be note the "*glazing ratio*" or the "*floor surfaces*"… are important at both scales and are not so difficult to determine (size of the bubble). The composition of the envelope ("*wall type*" on *figure 1*) is important at the building scale but not so easy to know. But this information is generally substituted at the neighbourhood scale by the "*building age*", easier to determine (particularly by a statistical approach) and the performance of the envelope is linked to the thermal regulation of the period considered. This can be identified as a classical scale change method. Another result shows the difference of objectives between the models of each scale. In most of the cases, building simulation tools aim to determine the energy consumption due to the performances of the envelope and the systems. At the neighbourhood scale, mainly due to a size effect but also because of the various possible objectives of this scale studies (see below), it is necessary to add the "*appliances performance and quantity*" which is here again difficult to determine and when it is possible mainly by a statistical approach *(figure 1)*.

	Criterion for the classification of the individual parameters	
	Thermal	Thermal characteristic of buildings or environment (possibly statistical).
	Statistical	Values coming from statistical analysis (they can also be thermal or geometrical values)
	Data	Data that must be measured or identified on the site or that are inherent of certain appliances or machines (efficiency rates, type of energy source, etc).
	Geometrical	Values relative of the geometry of the building or sector (possibly statistical)

Table 3: Classification of individual parameters.

The important issue of objectives at the genesis of the tools is illustrated by the *figure 2*. Objectives (often multiple) of each tool have been identified and classified (A to H in *table 1 and figure 2*). For each class of objective the importance of the type of data is summarized in *figure 2*. For example, at the neighbourhood scale for the objective D the parameter "*appliances performance and quantity*" which is not easy to determine, can be neglected, but not for the objective C. This illustrates how it is important to take into account the objectives and the type of data to simplify the models while raising their accuracy for the aim followed. It can be also noted that an objective of "*energy savings*" or "*evaluation and planning*" requires a homogeneous combination of type of data. When the objective is to reduce "*CO_2 emissions*" the thermal properties seem to be less important.

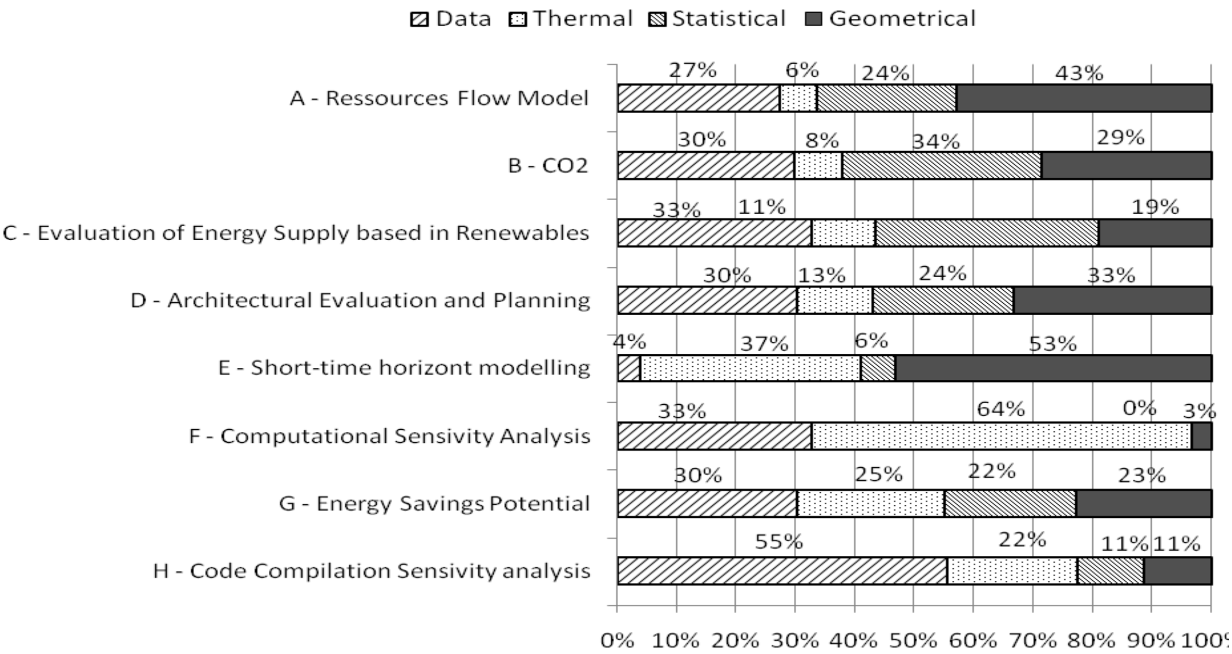

Figure 2: Typical objectives of the models used in this analysis and their percentage of type of data (table 3).

CONCLUSIONS

Actually most of the models claim they could help modelling all situations in energy demand, CO_2 emission reduction, waste minimization, optimization of energy resources.... The study presented here, by an analysis of the sole issue of data, underlines how it can be illusory to hope such a tool. Data availability, their relative importance which depends of the objective, their type, made impossible to answer precisely to all the situations and objectives. Some answers are given at both scales on data availability, on family of data linked to the objectives of the usual tools, in order to help for future developments.

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PHOTOVOLTAICS VS SOLAR THERMAL: VERY DIFFERENT BUILDING INTEGRATION POSSIBILITIES AND CONSTRAINTS

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ABSTRACT

The every day increasing interest for renewable energies results in a constantly growing market demand for active solar systems, both for electricity (photovoltaics) and for heat production (solar thermal).

This trend, added to the new promotion policies recently set up by the EU, let foresee an increased interest for all the sun exposed building surfaces, resulting in a new debate on how to optimize their use for the production of solar electricity and/or solar heat.

This paper will show that although similarities in the integration on the building envelope of solar thermal and photovoltaic systems do exist, there are also major differences that need to be considered. Both technologies deal with the same building skin frame, and have similar surfaces and orientations needs. On the other hand they have different intrinsic formal characteristics, different energy transportation and storage issues, different insulation needs, shadow influence, etc...
The impact these technology peculiarities have on the building implementation possibilities will be described, to support making the best use of the available exposed building surfaces.

1. INTRODUCTION

Solar thermal and photovoltaics are complementary and equally crucial technologies to minimize building fossil energies consumption and related CO2 gas emissions: PV is needed to produce the electricity for appliances and artificial lighting, solar thermal is needed to provide heat for DHW and can be used for space heating (in the near future also for cooling) (Tab.1).

BUILDING ENERGY NEEDS	CORRESPONDING SOLAR TECHNOLOGIES	
	PASSIVES	ACTIVES
SPACE HEATING	PASSIVE SOLAR	SOLAR THERMAL
DOMESTIC HOT WATER	-	SOLAR THERMAL
ELECTRIC APPLIANCES	-	PV
LIGHT	DAYLIGHTING	PV
(SPACE COOLING)	(FREE COOLING)	(SOLAR THERMAL / PV)

As both PV modules and solar thermal collectors produce energy from the sun and need to be placed on the sun exposed areas of the building skin, the issues related to their integration in the building envelope are often treated together, assuming they are part of a unique problematic. This simplification may be acceptable for very small solar systems and where the needed surfaces are much smaller than the exposed areas actually available. But in most cases to optimize the use of the available - finite- exposed surfaces, the specificities of each technology should be taken into account, especially in buildings with high solar fractions.

Photovoltaics and solar thermal are fundamentally different, as one is designed to transform the solar radiation into electricity, and the other is designed to transform it into heat: two different energies, with very different transportation and storage issues. This brings different formal and operating constraints, leading to different building integration possibilities.

To help architects implement both types of systems while using optimally the sun exposed surfaces of their buildings, we will analyse the ways the characteristics of these two technologies affect building integration.

2. SIGNIFICANT COLLECTORS FORMAL CHARACTERISTICS

Both fields of solar thermal and PV count several technologies interesting for building integration: monocrystalline, polycrystalline and amorphous in the field of PV; glazed flat plates, unglazed flat plates and vacuum tubes collectors in the field of solar thermal. Unless differently specified, the following considerations refer to the most diffused ones in EU, i.e. crystalline -mono and poly- cells for PV and glazed flat plates collectors for solar thermal. To keep the message clear and short, distinctions will be made only when considered important.

2.1 Shape, size, flexibility

The basics shape, size and dimensional flexibility of the PV modules are fundamentally different from the ones of thermal collectors.

The size and shape of PV modules are very flexible since they result mainly from the juxtaposition of single squared silicon cells (mono or polycrystalline) of approximately 10 to 12 cm side. Modules can come in the size of less then 0.1 m2 (few cells) up to 2 m2 (more than 60 cells). Thanks to the flexibility of the internal connexions and the small cells' size, made to measure module can be provided in almost any shape (at higher price in this case). Moreover the possibility of partial transparency is offered through glass-glass modules. Amorphous modules can also offer a new level of freedom by being built over flexible metal or plastic sheets.

Solar thermal collectors are much bigger (1.5 to 3 m2) and their shape definitely less flexible. This derives mainly from the need of a non flexible hydraulic circuit fixed to the solar absorber to collect the heat: the freedom in module shape and size would require reconsidering every time the hydraulic system pattern, which is generally difficult and expensive. The lack of market demand for architectural integration is also a cause of this poor offer up to recently. The case of evacuated tubes is different: the panel size and shape result from the addition of evacuated tubes: length from 1 to 2 m, diameter from 6 to 10 cm. In most cases though only standard modules are available.

> *<u>Impact on building integration</u>*
>
> *Ideally, the shape and size of the solar module should be compatible with the building composition grid and with the various dimensions of the other envelope elements. The lack of flexibility associated to the large size of solar thermal collectors reduces dramatically the possibilities of proper implementation.*
> *The higher shape and size flexibility of photovoltaics modules and their small size make it easier to deal with both new and pre-existing buildings.*
> *These different flexibilities imply very different constraints when choosing the shape and placement of the collectors' field(s) , especially for façade integration.*

2.2 Module structure, thickness, weight

The thickness and weight of PV and solar thermal modules are also totally different. PV modules are thin (0.4 to 1cm) and relatively light (7-12 kg/m2), while solar thermal ones are much thicker (4 to 10 cm) and heavier (around 20 kg/m2).

PV mainly consists in thin laminated modules encapsulating the very thin silicon cells layer between an extra white glass sheet (on top) and a composite material (Tedlar / Mylar) or a second sheet of glass.
Solar thermal collectors are composed by multiple layers in a sandwich structure: glass sheet / air cavity / metal absorber / hydraulic system / insulation. Evacuated tubes have a different structure: an absorber core protected and insulated by a glass tube.

> *Impact on building integration*
>
> *The difference of weight between the two types of modules present mainly different characteristics in handling (1 person vs. 2 persons for the mounting), but doesn't have a relevant impact on the under construction structure.*
> *The thickness on the contrary does affect the integration possibilities, especially in facades. While the thinner PV modules can be used as sun shading on facades, and easily implemented as a cladding, the thickness of solar thermal makes the sun shading application problematic and the use as cladding more delicate, especially in retrofits. This is also true, on a lesser degree, for the roof applications.*

2.3 Visible materials / surface textures / colours

The external layer of both PV and solar thermal modules consists in a sheet of extra white glass. The glass surface can be smooth, textured or acid etched, but always let see the internal layer: the silicon cells in PV, the metal absorber in solar thermal.

The structure, the geometry and the appearance of these layers are very different: the metal absorber of solar thermal collectors is generally continuous and covers the whole module area, while for PV the cells can be arranged in different patterns, also playing with their spacing.

PV crystalline cells have a flat surface, mainly blue or black, with a squarish shape. The absorbers of thermal collectors are characterized by a more or less corrugated metallic surface, coated in black or dark blue.
Evacuated tubes are different, as described in section 2.2.

> *Impact on building integration*
>
> *Due to the above described characteristics of their absorbers, flat plate thermal collectors can be implemented only on opaque areas of the building envelope (roof or facades), while PV modules can be mounted also on transparent ones. When mounted on a glass/glass module the cells can be freely spaced with a resulting variable module transparency, well adapted for atrium / veranda/ sheds or glazed facades applications.*
> *The structure of evacuated tubes, could allow the mounting on the transparent envelope areas, as sun shading for instance. This type of application is very rare though, due to the lack of products developed for this specific use.*

3. ENERGY TRANSPORT AND STORAGE

As PV modules produce electricity and solar thermal produces heat, they have to deal with different energy transportation, storage and safety issues.

3.1 Energy medium and transport

Electricity can be transported easily and with very small losses through thin (0.8-1.5cm diameter), flexible electric cabling. It can then easily be transported for long distances, so that the energy production doesn't need to be close to the consumption place.
Heat is transported by water (charged with glycol to avoid winter freezing) trough the rigid piping of the hydraulic system. Heat transportation is very sensitive to losses, meaning on one hand that the piping system has to be very well insulated (resulting diameter: 3 to 8 cm), on the other hand that the heat should be used near the production place.

> *Impact on building integration*
>
> *Compared to the small size and flexibility of electrical cables, the rigidity, size and need for insulation of solar thermal piping requires much more space (and planning care) to be accommodated in the building envelope.*
> *The different types of energy transport bring also different building safety measures: preventing water leakage damages for solar thermal, prevent fire propagation for PV.*
> *Water pressure issues should also be considered when dimensioning the solar thermal system, in particular when defining the vertical field size*
> *But the fundamental difference rising from the different transport issues is that while solar thermal needs to be installed close to the place where the heat is needed, PV can be installed anywhere, even very far from the consumption place.*
> *This should be taken into consideration when working on sensible urban areas, like historical city centres or protected buildings.*

3.2 Energy storage

Because of the different ways these energies can be transported, their storage issues are radically different, affecting strongly the implementation possibilities.

The electricity produced by the PV modules can be injected practically without limits into the grid. As a result the sizing of the system is totally independent from the local consumption and the energy produced can exceed by far the building electricity needs.

On the contrary, the heat produced by thermal collectors has to be stored close to the consumption place, usually in the building storage tank. In practice, the storage capacity of the water tank is limited, usually offering no more than a few days autonomy. Furthermore solar thermal collectors are sensitive to damages resulting from overheating, so that ideally the heat production should not exceed the storage capacity.

> *Impact on building integration*
>
> *The sizing principles of the two types of systems are completely different: Solar thermal systems should be dimensioned according to the specific building needs and to the storage tank capacity, to avoid overproduction and the accompanying overheating problems.*
> *PV is totally independent from the building energy needs, and can be dimensioned just according to the size of available exposed areas, or according to architectural criteria for instance.*

4. Operating constraints

4.1 Operating temperatures and related insulation needs

Suitable operating temperatures are again different between the two technologies, for PV the lower operating temperature the better, for solar thermal the higher the better (still avoiding overheating).

Impact on building integration

This difference affects once more the integration possibilities in the building envelope: PV modules should be back ventilated for a higher efficiency; solar thermal absorbers require back insulation to minimize heat losses. Integrating the collectors directly in the building envelope layers, possibly without air gap is ideal in this sense for solar thermal, while freestanding or ventilated applications would be preferable for PV.

4.2 Shadows

Impact on building integration

For solar thermal, the heat losses resulting from partial shadowing are just proportional to the shadow size and don't cause any particular production or safety problem. Photovoltaics on the other hand can be very sensitive to partial shadowing: the electricity production may be greatly affected by partial shadows if special care is not given to the modules placement and string cabling. The energy losses are generally higher than shadow ratio, with possible risks of modules damage if its impact is not well considered during the system design phase.

5. CONCLUSIONS

As shown above, there are clear differences in the characteristics of solar thermal and photovoltaics systems, leading to different approaches when integrating them in the building envelope. A synthetic overview is presented in the table hereafter:

		PHOTOVOLTAICS	SOLAR THERMAL
FORMAL CHARACTERISTICS	MODULE SIZE	0.1 to 2 m2	1.5 to 3 m2
	SHAPE / SIZE FLEXIBILITY	High flexibility	Low flexibility
	THICKNESS	0.4 cm to 1 cm	4 to 10 cm
	WEIGHT	7-12 kg/m2	20kg/m2
	MODULE STRUCTURE	laminated modules	sandwich modules
	MATERIALS	Glass / silicon cells / Tedlar -Mylar or glass	Glass / air / metal absorber / hydr.system / insulation
	SURFACE TEXTURES	External glass: smooth / acid etched / structured. Silicon cells: variable patterns, possible transparency	External glass: smooth / acid etched / structured. Absorber: slightly corrugated, opaque metal sheet
	COLOURS	Black / blue.	Black / dark blue
TECH. CHARACTERISTICS	ENERGY MEDIUM	Electricity	Hot water
	ENERGY TRANSPORT	Flexible cabling (0.8-1.5cm diameter). Low energy losses.	Rigid insulated piping system (3-8 cm diameter). High energy losses.
	ENERGY STORAGE	Unlimited, into the grid	Limited to building needs / storage capacity of the building tank.
	WORKING TEMP.	The lower the better (back VENTILATION required)	The higher the better (back INSULATION required)
	SHADOWS IMPACT	Reduction in performances higher than shadow ratio; risks of permanent damage to the panel.	Reduction of performances proportional to shadow size, no damage to the panel.
	ENERGY PRODUCTION	80- 120 kWh/m2 per year	450-600 kWh/m2 per year
	COST (CH - 2007)	600.- to 1000.-CHF/m2	200.- to 600.- CHF/m2

Several considerations can be derived from these observations, which cannot all be presented in this paper.

We would like to underline one major outcome that concerns the positioning options induced by the different storage constraints:
As there are no limitations in the storage of the energy produced by PV, its annual energy production should be optimized by locating and orienting the PV where its sun exposure is maximized (tilted or flat roofs mounting in most cases) (Fig.1).

On the contrary, solar thermal systems should be dimensioned according to seasonal heat usage and to storage capacity, trying to maximize the useful heat collection while avoiding over production and related overheating risks.

This brings one interesting option for solar thermal integration. In EU mid latitudes where the solar radiation varies dramatically during the year, the maximum summer production can be twice the winter one. To avoid summer overheating, tilted solar thermal systems are usually undersized (solar fraction s around 50%). A good way to increase the whole year solar fraction while limiting overheating risks is to mount the collectors vertically, using the facade areas. The heat production would then be almost constant during the year, making it possible to dimension the system according to the real needs (Fig.1). This allows solar fraction of up to 90 %, while opening the way to building facades use.

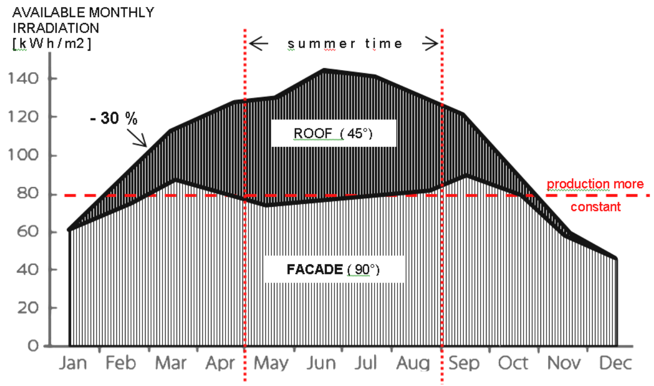

Fig. 1: Comparison of the monthly sun radiation available on a 45° south oriented tilted surface vs. a vertical south oriented surface in Graz, Austria (47°latitude).
Data from W.Weiss, I.Bergmann, AEE-Intec.

If for photovoltaics there is a large offer of products suitable/conceived for building integration, exploiting the flexibility of the technology, the situation is different for solar thermal. The big size of the collectors now available, their lack of dimensional flexibility as well as the dark irregular appearance of their absorber makes it difficult to integrate solar thermal, particularly on facades. This is an issue that should be solved urgently, especially in the light of the previous considerations:

New solar thermal products conceived for building integration should be developed, matching the offer available in the PV field, to help answer to the booming demand of architectural integration of solar in buildings.

This is even more important considering the lower cost and higher efficiency of this technology compared to PV.

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THE USE OF UNDERGROUND THERMAL ENERGY STORAGE AS PART OF A LOW CARBON MASTERPLAN FOR LONDON'S MUSEUM DISTRICT.

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ABSTRACT

The architectural and cultural heritage of most cities is significantly enhanced by existing historic buildings. The preservation and evolution of such existing buildings, whilst retaining their architectural character, can be intrinsic to the success and identity of the city and hence forms a vital component of achieving sustainability in the urban environment.

Demand reduction and energy efficiency in existing buildings is essential to addressing preservation of resources and mitigation of climate change. It is predicted that by 2050, 60% of the building stock in the UK will still be comprised of buildings which exist today; with two-thirds of these predating the introduction of energy related Building Regulations in 1985.

In the UK the thermal demands of buildings in a given area of a city often comprise simultaneous cooling and heating demands, owing to the presence of newer highly insulated, airtight, buildings with high internal heat loads alongside older buildings with little insulation and high air infiltration rates. The UK climate also experiences significant seasonal variation and this is reflected in the varying thermal energy loads of buildings across the year. These basic phenomena give rise to potential for the transfer of heating and cooling loads between buildings and between seasons, with the introduction of urban thermal networks and inter-seasonal thermal storage.

Underground Thermal Energy Storage (UTES) uses a system of boreholes and heat pumps to store excess energy from summer below ground for use in winter heating applications. Similarly cooling potential (or 'coolth') from winter can be stored in order to provide free low-carbon cooling in summer. By introducing UTES, interseasonal heat and coolth sharing opportunities can be exploited while maintaining a thermal energy balance over the course of a year. Aquifer Thermal Energy Storage (ATES) is a form of UTES that utilises slow-moving below ground aquifers as the storage medium; storing the thermal energy in water significantly increases the efficiency of the system.

This paper provides insight into research undertaken as part of the development and implementation of a 'carbon masterplan' for London's South Kensington Cultural and Academic Estate. It considers the issues faced in implementing energy efficiency and carbon reduction measures for historic existing buildings with significant architectural and cultural value, that need to remain operational throughout the process.

In particular, the paper focuses on recent studies into the use of ATES and its potential when used with Combined Heat and Power (CHP) generation, using the underground energy store as a thermal accumulator for excess heat from the CHP plant in summer to achieve significant carbon emissions savings.

The first stage project findings, based on model load profiles, show that there are opportunities for substantial benefits in terms of creation of a low carbon infrastructure that deals with both new and existing buildings in a mixed urban or campus environment; and that ATES and CHP used in combination may give rise to up to 40% reduction in carbon dioxide emissions.

INTRODUCTION

This paper summarises the results of work carried out as part of the Invest to Save programme organised by the Department of Culture, Media and Sport (DCMS) and funded by the Treasury as part of a UK Government initiative to help cultural and arts buildings to driver down their carbon di-oxide emissions.

The original response to the call was led by Simon Tilleard of the Natural History Museum. The technology proposal was led by Richard Shennan.

The project brings together most of the major institutions that occupy the land of the 1851 Commission, set up after the Great Exhibition of 1851. The project partners include Royal Albert Hall, Imperial College London, Science Museum, and the Victoria and Albert Museum, as well as the Natural History Museum.

The large Victorian Museum buildings are unable to be altered internally or externally without destroying the architectural heritage.

METHOD

Building Load Profiles

In order to analyse the way in which the buildings can work together over a year with an underground heat/cool accumulator, load profiles were constructed for a selection of buildings across the estate. The UK Environment Agency recommends that all ground-connected systems achieve an approximate seasonal balance in order to avoid thermal degradation of the resource. Approximate load profile models for a selection of buildings across the estate were constructed based on a combination of available metering data, and benchmark figures.

Evaluation of the underground storage potential

An existing borehole outside of the Natural History Museum was used to assess the aquifer potential, with supporting analysis from other boreholes in the London chalk. The aquifer is located at approximately 70m below ground level.

Assessment of existing systems

A key element of the study is to develop a phased migration strategy from the buildings and infrastructure that currently exists to a low carbon neighbourhood over time. It is not possible for entire city neighbourhoods with different owners, building conditions and investment structures to simultaneously upgrade their building services systems. An assessment was therefore carried out of the existing assets, and a proposal was developed to allow these assets to be incorporated into the evolving district scheme, resulting in incremental progress at each step within the context of the low carbon masterplan.

Development of schematic design solution

The option that has been developed here is a combination of CHP plant and an ATES system to achieve the optimum efficiency to supply heating and cooling in a distribution network while also delivering part of the electrical supply. Furthermore, this particular option has been compared with a conventional CHP scheme in order to show the main benefits achieved.

In order to understand the benefits reached by adopting the innovative combination of CHP and ATES, a conventional CHP scheme has been considered as part of a typical district scheme using a centralized gas boiler and conventional electrical chiller.

ATES plus CHP concept

The concept is that where a network has a net deficit of heat over a year, the optimum size of the CHP system can be increased over the conventional base load sizing. The excess heat generated in summer, instead of be dumped through a cooling tower, is downgraded in terms of temperature and diverted to the underground thermal energy storage. The total heat input to the store is therefore the sum of the net heat rejection from cooling and the excess heat from the CHP over summer base load.

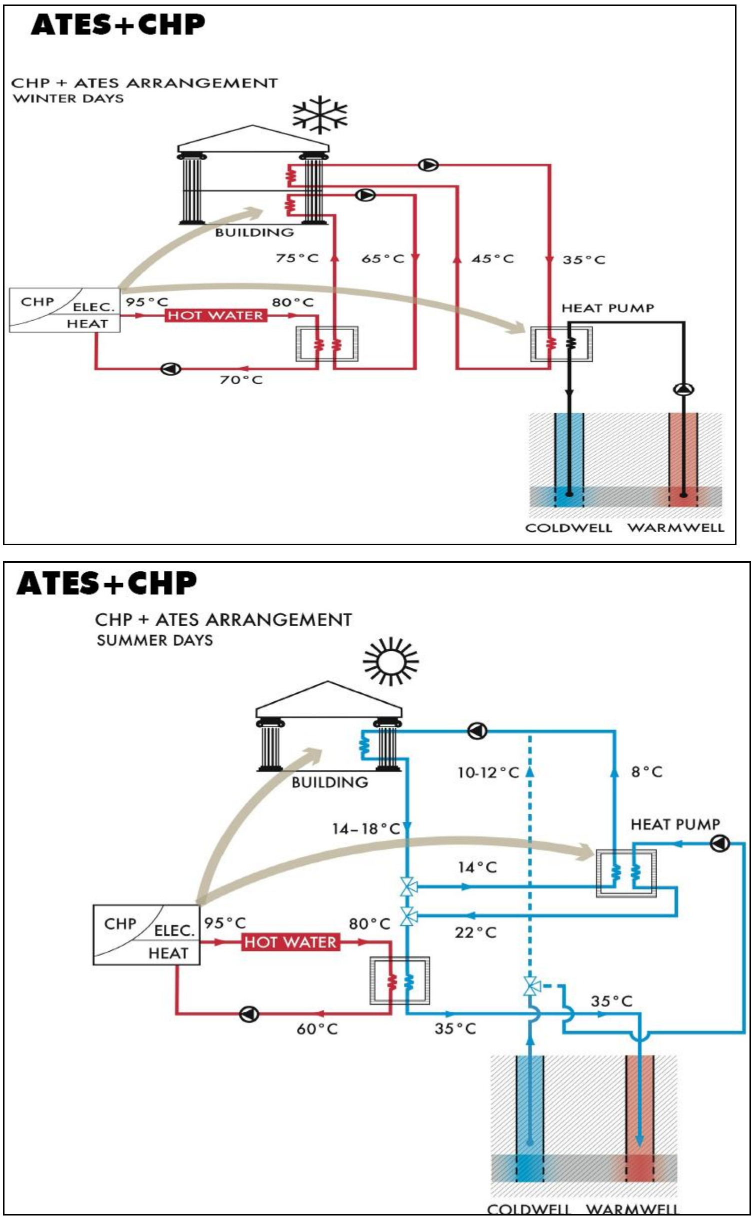

Figure 2: summer and winter operation.

Under this model there are two sources of heat for space heating; the heat pump drawing on water from the warm underground energy store, and the available CHP heat. This configuration is therefore well suited to any system that includes existing buildings with higher temperature or heat requirements.

The higher temperature circuits can be used for existing buildings or systems such as panel radiators. Lower temperature circuits are suitable for air-based systems or low temperature radiant systems.

For a mixed district scheme such as the 1851 Commission, some buildings could use higher or lower temperature exclusively provided that the overall balance is achieved.

This schematic solution retains the high COP of the heat pump while allowing higher return water temperatures on the CHP circuit.

The distribution of heat pumps will be determined by phasing and economic sizing. Minimum load centres or phases of around 0.5 MW cooling capacity are preferred. Well water circuits are run in uninsulated polythene pipework, leading to simple low-cost installation.

In summer, cooling is available either through direct heat exchange from the well circuit or by running the heat pump as a water chiller. In both cases the heat rejection from the buildings is diverted into the warm store along with the excess CHP heat, over and above any summer demand such as domestic hot water.

New building services systems would be sized so that cooling systems can work effectively at a cold water temperature of 10ºC to 12ºC, allowing 'direct' cooling at a COP of around 25 (twenty five).

RESULTS

Load Profile results

The buildings across the estate as a whole demonstrate a net annual requirement for heat if they are summated, due to the predominance of heating loads in the Victorian museum buildings, and despite the introduction of large cooling loads from some of the buildings of Imperial College and also the Royal Albert Hall.

The existence of a net demand for heat led to the development of the idea of integrating Combined Heat and Power into the scheme.

The results suggest that the mix of buildings and loads has a significant impact on overall efficiency. For this project further cooling demands will be sought. In the wider context, this gives rise to the proposition that urban heat planning could be used to actively locate new buildings with cooling-dominated load profiles physically close to existing buildings, including residential, that have heating dominated loads, to allow inter-seasonal heat storage systems to deliver large scale reductions in Carbon-dioxide emissions.

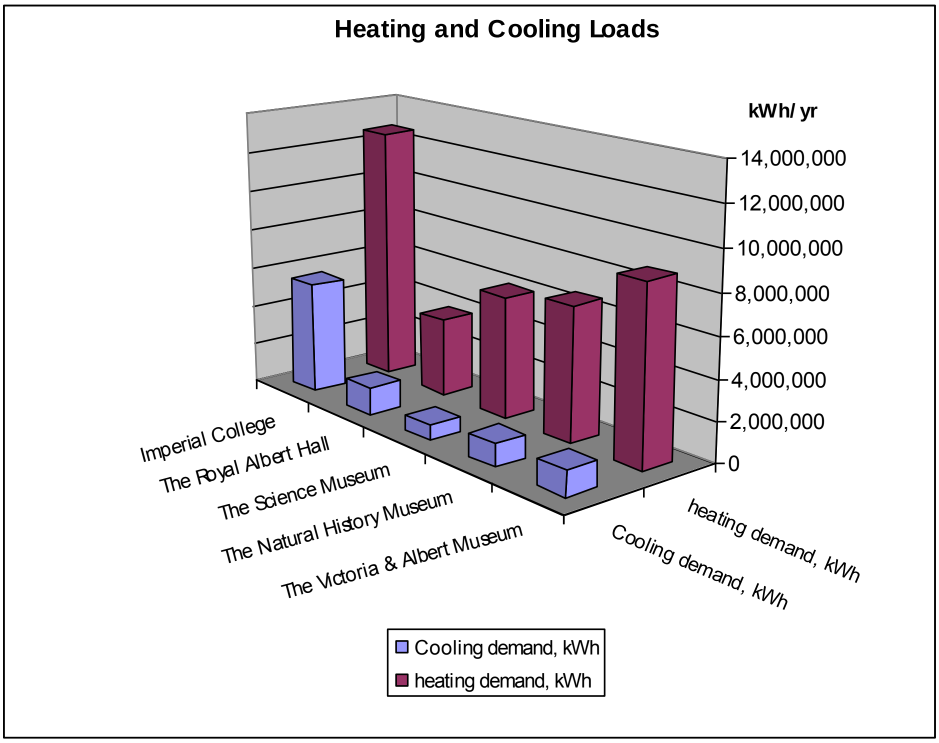

Figure 3: The load profiles show a predominance of heating loads.

Balance of delivered energy for optimised system

The results show that the optimum system has a larger size CHP as a result of the use of the ATES accumulator. All of the heating could be delivered through a combination of ATES and CHP. The use of gas boiler and of conventional chiller can be reduced to zero after completion of the migration strategy.

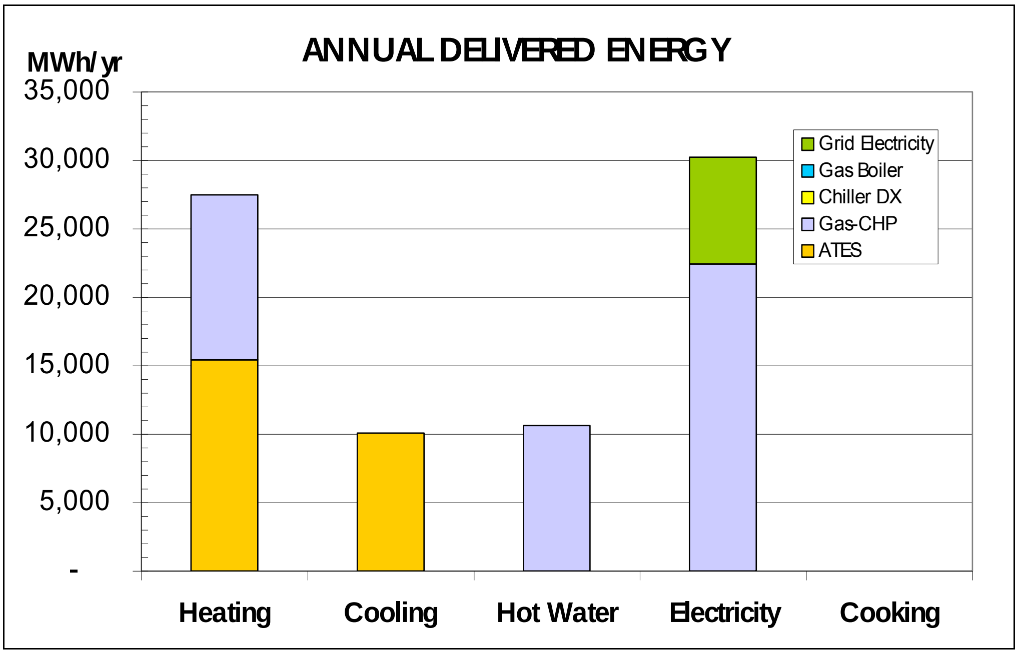

Figure 4: Gas boiler and chiller are replaced entirely by CHP and ATES.

The optimum balance is dependent on the load profiles.

Carbon Dioxide savings

In an earlier stage of the study the use of ATES for heating and cooling showed a potential reduction in carbon di-oxide emissions of over 30% compared with a conventional benchmark heating and cooling system.

By introducing the connection to CHP, and allowing the economic sizing of the CHP to be increased, the potential saving is close to 40%.

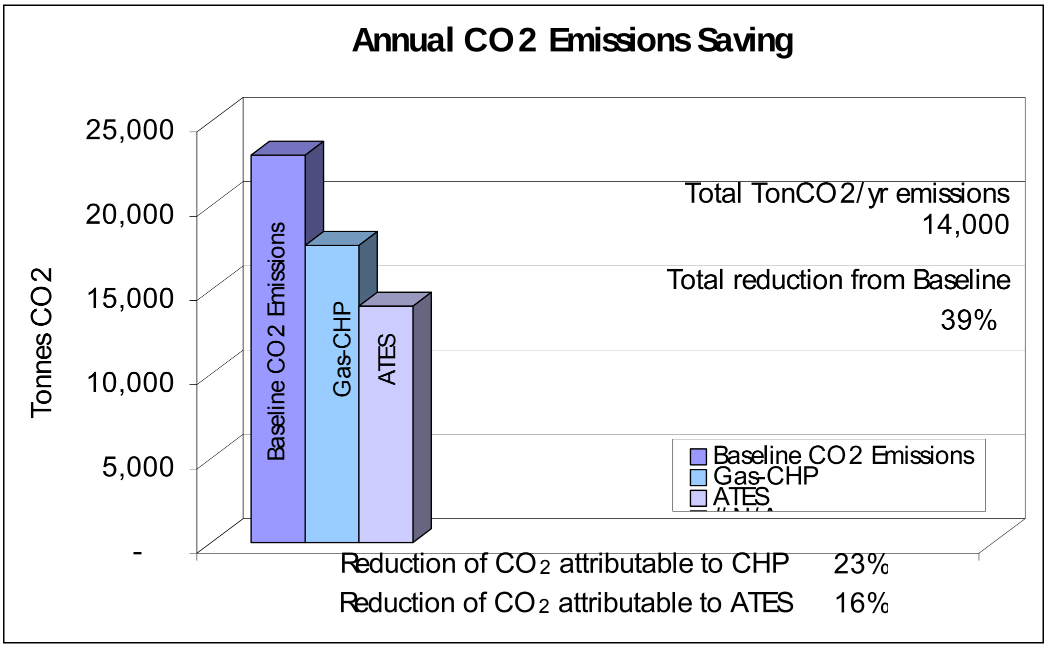

Figure 5: by extending the technology across a city district, the savings become very significant.

DISCUSSION

The work has highlighted the potential advantages of a district scheme with interseasonal thermal accumulator using ATES. For other load profiles, particularly those dominated by cooling, different mix would be required, possibly including absorption chillers.

The study has identified the need to understand and respond to the priorities and perceived risks for each of the partners in order to get different owners and institutions working towards a common aim.

The next stage of the project will include studies of through-life cost optimisation and funding/operational mechanisms.

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LIFE CYCLE ASSESSMENT OF A POSITIVE ENERGY HOUSE IN FRANCE

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ABSTRACT

The « positive energy house » concept combines energy saving, e.g. applying the passive house approach, and electricity production using a renewable resource, leading to a positive primary energy balance on a yearly basis. Compared to a standard house, more materials and components are used (thicker insulation, triple glazing windows, renewable energy systems…), this is why the environmental relevance of this concept is often questioned.

In order to contribute to answer this question, a life cycle assessment (LCA) has been used to evaluate the environmental impacts of such buildings, including the fabrication of components, construction, operation, maintenance, dismantling and waste treatment. This paper presents results in the case of a positive energy building, showing also the influence of the choice of the heating system on various environmental impacts considered in this assessment (e.g. global warming potential, radioactive waste production, photochemical oxidant formation potential, cumulative energy demand, abiotic depletion potential).

The case study concerns two attached passive houses built in Picardy, France, in which renewable energy systems are studied theoretically: the real houses include solar water heating but no renewable electricity production. The envelope has a high insulation, high air-tightness and very low thermal bridges. The technical equipment includes a heat recovery ventilation and an earth-to-air heat exchanger. In this study, PV solar panels mounted on the roof have been added so as to obtain a positive primary energy assessment. For these houses, three different heating solutions have been studied: an electric heat-pump, a wood pellet condensing boiler and a wood pellet micro-cogeneration unit.

The three alternatives have been modeled using the building thermal simulation tool COMFIE, in order to evaluate their heating load, possibly cooling load and thermal comfort level. Environmental impact indicators have been evaluated for these alternatives applying the LCA tool EQUER, linked to the building simulation tool COMFIE and using life cycle inventories from the Swiss Ecoinvent data base.

INTRODUCTION

The « positive energy house » concept (PEH) is a concept of high-performance residential building, which combines energy saving and the recovery of energy from local renewable resources such as solar radiation, wind, biomass or heat from the environment. Energy can be saved by a high insulation level, the recovery of heat from extracted air, a high level of air tightness, and the use of efficient equipment – for instance applying the "Passive House" approach of the Passivhaus Institut of Darmstadt, Germany [1]. The recovery of energy from local renewable resources can provide a part or the whole building's heating load and of the hot water production, and can supply electricity to the grid or for local consumption.

Due to the relative newness of the PEH concept, its definition has not been clearly settled yet and several approaches remain possible [2]. In this paper, we assume that its objective is to achieve a positive *primary* energy balance for the building on a yearly basis (*local balance approach* in [2]). This means that, during a one-year period, a PEH recovers more renewable energy than the amount of primary energy it requires for its own operation.

Compared to standard house, a PEH generally requires more materials (thicker insulation, triple glazing windows, etc.) and more components (solar panels, etc.). Consequently its construction generally requires more energy (embodied energy) and induces increased impacts on the environment. Thus the environmental relevance of the PEH concept, which is often questioned, has to be studied.

METHOD

In order to contribute to answer this question, a life cycle assessment (LCA) has been used to evaluate the environmental impacts of a PEH. This method is now well established and can be applied to any kind of systems, and especially to the equipments of a building [3], to a building [4] or even to a settlement [5]. For a building, a LCA consists in analysing the fabrication of the components, construction, operation, maintenance, dismantling and waste treatment. For each phase, the various energy and material flows are assessed and then various impact indicators can be computed.

In this study, three different heating devices have been studied in order to evaluate their influence on the environmental assessment: a heat pump (HP), a wood pellet micro-CHP unit (CHP) and a wood pellet condensing boiler (CB).

In a first step, the annual heating load and the thermal comfort level in each thermal zone of the building have been computed using COMFIE, a dynamic, multizone, building thermal simulation tool developed by the CEP at MINES ParisTech [6].

In a second phase, the environmental impact indicators have been calculated for the three heating solutions using the software EQUER, dedicated to the LCA of buildings [4]. EQUER is based on the life cycle inventories of the Swiss Ecoinvent data base and can compute twelve different impacts [7] (Table 1). Case studies are being performed in the ENSLIC Building project.

Impact indicator	**Unit**	**Legend**
Cumulative Energy Demand	GJ	ENERGY
Water consumption	m^3	WATER
Abiotic Depletion Potential	kg Sb-eq	RESOURCE
Non-radioactive waste creation	t eq	WASTE
Radioactive waste creation	dm^3	RADWASTE
Global Warming Potential at 100 years (GWP_{100})	t CO_2-eq	GWP_{100}
Acidification Potential	kg SO_2-eq	ACIDIF.
Eutrophication Potential	kg PO_4^{3-}-eq	EUTROPH.
Damage caused by the ecotoxic emissions to ecosystems	PDF.m^2.yr	ECOTOX
Damage to human health	DALY	HUMHEALTH
Photochemical Oxidant Formation Potential (Smog)	kg C_2H_4-eq	O_3-SMOG
Odour	Mm^3	ODOUR

Table 1: List of the impact indicators computed by EQUER [5]

DESCRIPTION OF THE BUILDING UNDER STUDY

The building under study is a group of two attached houses built in 2007 in Picardy region, France (Figure1). These houses are the first “Passive-House” buildings in France [1, 8].

Figure 1: General view of the two houses (Arch.: En Act architecture, contractor: les Airelles)

Each house is two-storied, with an inhabitable area of 132 m^2, a garage, a terrace, a balcony and a garden. The internal structure is the same for both of them: a hall, an office, a living-room and a kitchen downstairs, and a sitting room, a bathroom and three bedrooms upstairs. Only the situation of the garage differs. These dwellings are designed for a family of four people.

Wood-frame external walls are insulated by cellulose (22 cm) and polystyrene (15 cm), the slab by polystyrene (20 cm) and the attic by cellulose (40 cm). Triple-glazed windows and insulated external doors provide good insulation and good air-tightness[1]. External venetian blinds provide solar protection during spring and summer. Thermal bridges are very low, supposed to be limited to 0,1 $W.m^{-1}.K^{-1}$ around the slab and the attic.

Both houses are equipped with a 30 m-long earth-to-air heat exchanger for summer cooling, with a heat recovery ventilation (average efficiency: 70%), with 5 m^2 of solar panels for solar water heating (solar fraction: 50%), and with a compact electric heat pump for the air heating and the water heating backup (annual coefficient of performance: 3).

SIMULATIONS

The real houses include no electricity production, but in the present case we assume that 76,8 m^2 of photovoltaic solar panels made of polycrystalline silicon are mounted on the roof (slope: 25°, azimuth angle: 35°E) so as to obtain a positive primary energy balance.

Three different heating solutions have been studied and compared:

- the above-mentioned electric compact heat-pump (HP),
- a wood pellet condensing boiler (CB) (average High Heating Value efficiency: 75%),
- a wood pellet Stirling engine micro-cogeneration unit (CHP), corresponding to the “Sunmachine® Pellet” pre-series version (electric power: 3 kW, thermal power: 5.5 kW).

[1] The houses fulfill the corresponding Passivhaus criterion : the air exchange rate is inferior to 0,6 $vol.h^{-1}$at 50 Pa.

The dynamical model used to compute the wood pellet consumption of the micro-CHP unit during a year has been developed by the authors and calibrated from experimental data [9].

The meteorological data used for the simulation correspond to the local climatic zone (oceanic climate). Ventilation, occupancy and internal heat gains are modeled by scenarios.

RESULTS

The total energy needs of the houses are very low due to the implemented energy saving solutions (Table 2). The heating needs are far inferior to the domestic hot water (DHW) production needs which represent nearly half of the total building energy needs.

Energy	**Use**	**kWh/yr**	**kWh/m^2/yr**	
Heat	Heating	2032	7.7	17.7%
	Domestic Hot Water Production	5255	19.9	45.9%
Electricity	Cooking, Lighting, other Appliances	2354	8.9	20.6%
	Ventilation	1807	6.8	15.8%
Total		*11448*	*43.4*	*100%*

Table 2: Computed energy needs of the two houses

The annual energy recovery from local renewable resources raises 6418 kWh for the PV electricity, 3227 kWh for the solar heat. The annual final energy consumption depends on the heating device (Table 3).

Heating device	**Consumption** *kWh/yr*			**Supply** *kWh/yr*	*kWh$_{PE}$/yr*
	Wood pellets	**Electricity** *heating*	**Electricity** *base*	**Electricity** *base*	**Net Primary Energy Prod.**
HP	0	677	4837	6418	+2805
CB	5413	0	4161	6418	+1160
CHP	9228	0	4870	7586	-1644
PE ratios *kWh$_{PE}$/kWh*	1.12	3.33	3.2	3.2	

Table 3: Computed energy consumption and supply of the two houses, and net primary energy production

The net primary energy indicator is the algebraic sum of the various energy flows expressed in primary energy (PE), using the primary energy conversion ratios given in Table 3 and considering supply as saved consumption. For both heat pump and wood pellet boiler solutions the building is a positive energy building, whereas the micro-CHP solution remains primary-energy-consuming, mainly due to the limited performance of the micro-CHP unit. Nonetheless, these three assessments correspond to very high level of performance (respectively +10.6, +4.4 and -6.2 kWh$_{PE}$/m^2/yr).

A simplified analysis, based on the indoor temperatures, shows that the thermal comfort in the houses is satisfactory most of the time during the year, and especially in the summer, whatever the heating solution.

The LCA of the houses considers the material, domestic water and energy flows during their life cycle (lifetime: 80 yr). The results for the above-mentioned 12 impact indicators and for the three heating solutions lead to the identification of 4 types of impact indicators (Figure 2).

The primary energy indicator depends on the efficiency of the energy chain; the WASTE indicator depends mainly on the materials implemented in the building and not on the chosen heating device; four indicators are increased by the electricity consumption (RADWASTE, WATER, RESOURCE, GWP_{100}), mainly due to the production processes of electricity; six indicators are increased by wood combustion (ACIDIF, EUTROPH, O_3-SMOG, HUMHEALTH, ECOTOX, ODOUR).

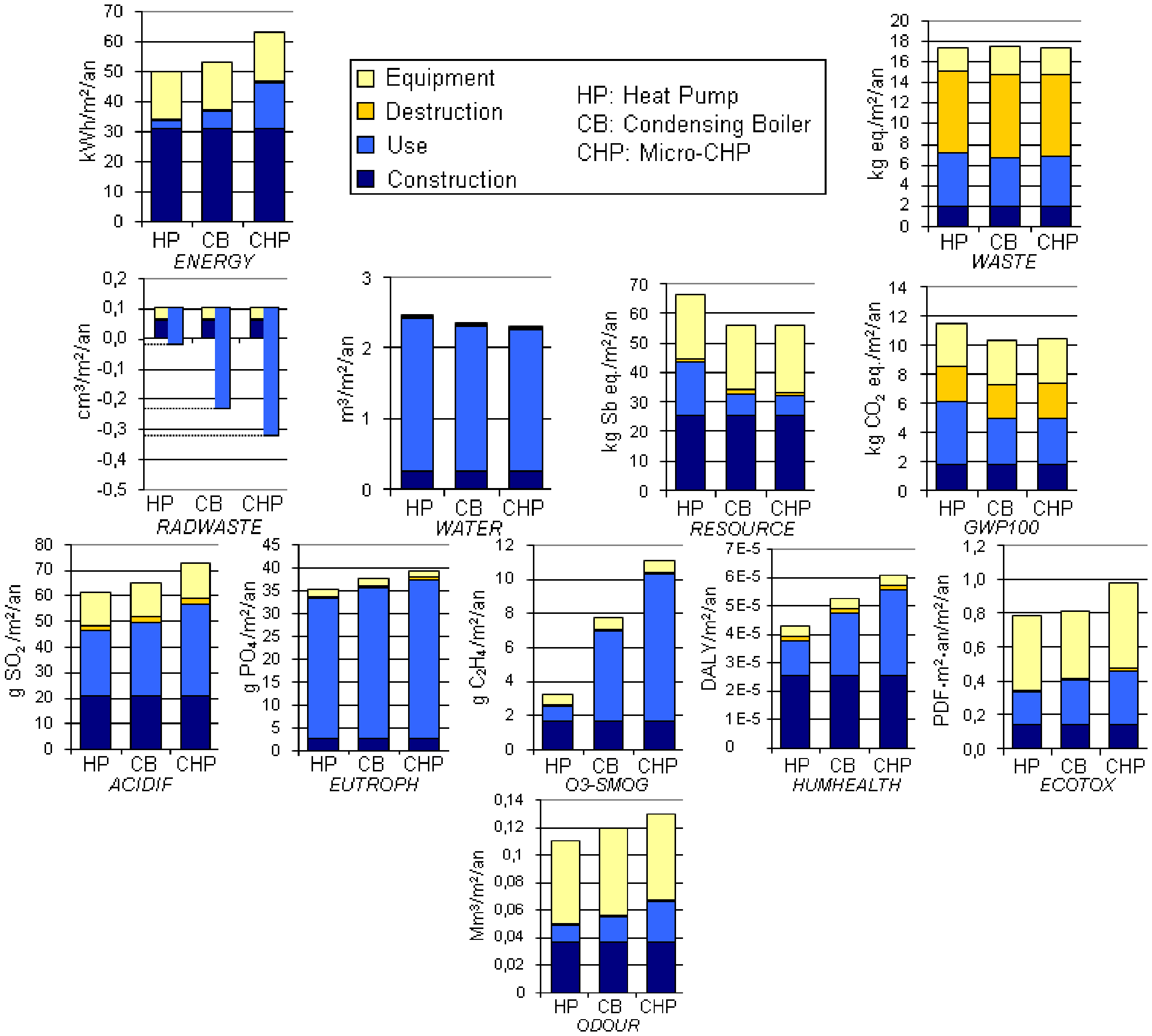

Figure 2: LCA detailed results for the two houses, for each indicator and for each phase

Discussion and Conclusion

The LCA has been applied to a positive energy building. The PEH studied here presents high energy and environmental performance, like a GWP limited to about 11 kg CO_2 eq./m^2/yr whatever the heating solution (the average value in France is about 37 kg CO_2 eq./m^2/yr [10]).

Nevertheless, in spite of a positive energy assessment, the majority of the environmental impacts remains positive during the operation phase. This is mainly due to the impacts of wood combustion or electricity production and to the domestic water consumption. Another important contribution to some impacts is induced by the equipments (solar panels, heating device, hot water tank etc.) which must be regularly renewed. The impacts of these equipments surely can be reduced, either by the improvement of their production process or by their recycling at end of life. This especially concerns PV panels which contribution to the performance of the PEH is major.

This study shows the influence of the heating device on the environmental impact of the PEH. In the French context – where about 75% of the electricity is generated by nuclear plants – none of the three solutions studied above seems optimal, but the PEH can contribute to reduce the radioactive waste production, especially if heat is not provided by a heat pump. The CB and CHP solutions reduce also the impacts on abiotic resources and greenhouse effect, but due to wood consumption, they affect the impacts linked to air and water chemical pollution. The improvement of the efficiency of the micro-CHP unit should also reduce these negative impacts.

ACKNOWLEDGEMENTS

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OPTIMIZING THE CONNECTABILITY OF EXISTING BUILDING TO THE "GENÈVE-LAC-NATIONS" DEEP LAKE WATER DIRECT COOLING NETWORK. REGULATION PRINCIPLES AND AUDIT METHOD.

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ABSTRACT

"Genève-Lac-Nation" is the name of the hydrothermal network which is currently under implementation in Geneva. This project is part of the TetraEner consortium and is financed by the European "Concerto" program. This water network will supply about 30 administrative buildings, by directly using deep lake cold water instead of cold machines to cool the buildings. It is designed to supply about 16.2 MW of cooling energy.

This energy will be transferred from the primary loop to the secondary loop through heat exchangers. However, most of the existing cooling installations are working at nominal temperatures of $T_{distribution}$=6°C and T_{return}=12°C. If the distribution regulation temperature remains unchanged, then only few of the required energy can be directly drawn from the lake, because the natural temperature of the lake is always above 6°C. To increase the cooling renewable supply part by the lake, the distribution temperature of the secondary loop has to be raised to 9°C, ideally to the available lake temperature. The return temperature should also be increased as high as possible.

These new regulation records will have strong implications on the performances. Therefore we have developed a specific auditing method, which proposes to simulate step by step the cooling cover ratio by the lake; the simulation tool takes into account the cooling demand of the building and the regulation parameters. On the basis of *in situ* measurements, the first part of this tool enables to determine the cooling power of the building as a function of external temperature; its second part enables to analyze the effect of an adaptation of control strategy when coupling with the lake, by simulating the cooling cover ratio by the lake and its profitability.

INTRODUCTION

GLN cooling concept and problematic

"Genève-Lac-Nation" or "GLN" is the name of the hydrothermal network which is currently constructed by the "Services Industriels de Genève" (SIG) in Geneva; it will be operative by June 2009. This project is partly financed by the European "Concerto" program, which focuses on optimizing the supply/demand balance through an improvement in the use of renewable energy sources.

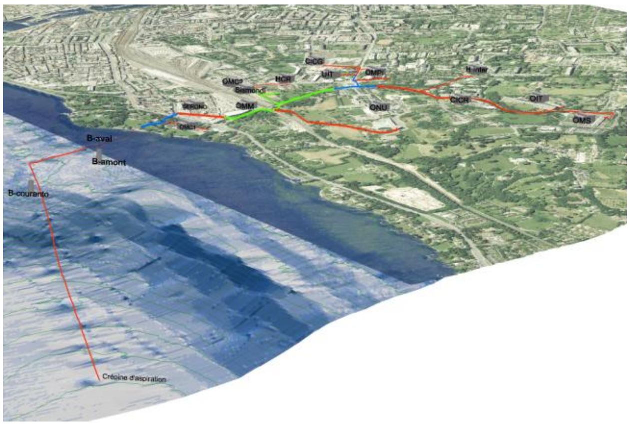

Figure 1: The GLN network and the planned connected buildings

This hydrothermal network will supply about 30 administrative buildings of various sizes (*figure 1*), by directly using deep lake cold water of Lake Léman (at about 37m depth) instead of cold machines to cool the buildings. Except some temperature peaks, this renewable resource remains below 9°C all along the hot period. The network is designed to supply about 16.2 MW of cooling energy. This energy will be transferred from the primary loop (lake cold water) to the secondary loop (cooling distribution network) through heat exchangers, which will be installed in each buildings. The existing installations of cooling distribution should *a priori* not be replaced, but conserved during the implementation phase for supply security.

In the GLN-network, the cold transfer from the lake network to the chilled loop of the building will be done through a main heat exchanger (*figure 2*). The SIG domain of responsibility will extend up to the output of the secondarie's pipes, and will of course include the flow and heat transfer counters for the invoicing. In fact, the SIG's flow-meter and heat counting will take place in the secondary building loop, with simultaneous recording of the return temperature level for invoicing (as the price of the kWh will be indexed on the return temperature level). The lake's loop management and regulation (valve opening) will require some information to be picked up from the building's central control system.

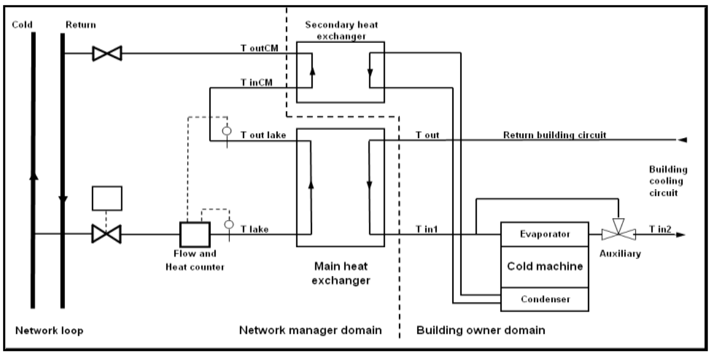

Figure 2: Connection between the cold network and a building, with a secondary heat exchanger

However, most of the existing cooling installations are working at nominal temperatures of $T_{distribution}$=6°C and T_{return}=12°C. If the distribution regulation temperature remains unchanged, then only a few of the required energy can be directly drawn from the lake, because the natural temperature of the lake is always above 6°C. First, to increase the cooling renewable supply part by the lake, the distribution temperature of the secondary loop has to be raised to 9°C, ideally to the available lake temperature; second, the return temperature should also be increased as high as possible. These new regulation records will have strong implications on the air conditioning installations performances. To promote an optimization of cooling supply, the network manager has settled a digressive tariff of the cooling kWh, according to the return temperature: it should incite the customer to also use the lake water in second time as the cooling source for the condenser instead of air cooling towers, during moments when the lake could not supply 100% of the cooling needs. Such a strategy sorely improves the global efficiency and the profitability of this cooling system.

METHOD

Development of a specific audit method

The GLN network concept aims to deliver cool water for a direct use in the existing cooling installations of the buildings, avoiding as far as possible the need to use the existing cooling machines, which should ideally only be activated as a back up, when the available renewable energy is not sufficient.

This involves constraints on the operating temperature levels, which are usually not a problem in the traditional cooling installations. The deliverable energy is closely related to the operating temperature levels in the building installations, with respect to the delivered lake water temperature, which is an "environmental" factor which cannot be adjusted. Before construction, the network manager needs to acquire a good knowledge of the potential energy to be distributed, which involves a specific analysis of the buildings. This is necessary on the one hand for determining the location and size of the pipes to be installed, and on the other hand for establishing the energy prices.

Before taking the decision to sign a GLN medium-term cooling supply contract, the building owners need to be specifically informed about the global service price, the possible improvements to the building regulation concept, the effects of alternative control strategies, and the profitability of being/not being connected to the network (in term of air-conditioning installations different costs).

Nowadays no specific audit methodology exists to analyse the connection of existing buildings to a Deep Lake Water Direct Cooling (DLWDC network). Therefore we have developed a specific “medium size” auditing method (about 2-3 working weeks), which proposes:

- Rules for gathering pertinent information about the building, including analysis and optimization of the building envelope and cooling needs, cooling installations, air-conditioned distribution,
- Methods for the acquisition and analysis of specific data about the cooling system operation and end-user service.

Using this restricted set of data, the method provides an information technology tool for the evaluation and the optimization of the operation with sight on the connexion to the network. This tool gives advices to improve the control strategy, and calculates the energy transferred, the flow rate required from the network, and the general costs according to the evolving energy tariffs.

This method includes a simple core Excel tool, which proposes to simulate step by step the cooling cover ratio by the lake; this simulation tool takes into account the cooling demand of the building and the regulation parameters. On the basis of *in situ* measurements, the first part of this tool enables to determine the cooling power of the building as a function of external temperature, by focusing on the study of the "connectivity" of the buildings to the network.

This should evaluate the ability of the air-conditioning installations to increase the chilled loop operating temperatures to values which are as high as possible. The second part of the tool enables to analyse the effect of an adaptation of control strategy when coupling with the lake, by simulating the cooling cover ratio by the lake and its profitability.

This method has been established on the basis of the analysis of two concerned buildings. The HCR building has been studied in detail, gathering a maximum of information. This allowed for the identification of the pertinent information required for such an audit. The second object was the UN building. Our approach for analysing it was less detailed. It should be understood as a test of the applicability of the method.

RESULTS

1. Determination of the cooling energy signature

The first step of this simple core Excel tool is to estimate the yearly cooling energy consumption. This is quite easy using the parameterized energetic signature – determined by *in situ* measurements – and a meteorological data set for the whole year (consisting essentially of external temperatures). The signature may include a constant component (data center, internal loads), and a linear component which is determined by the cooling threshold temperature and the maximum cooling demand which has been measured.

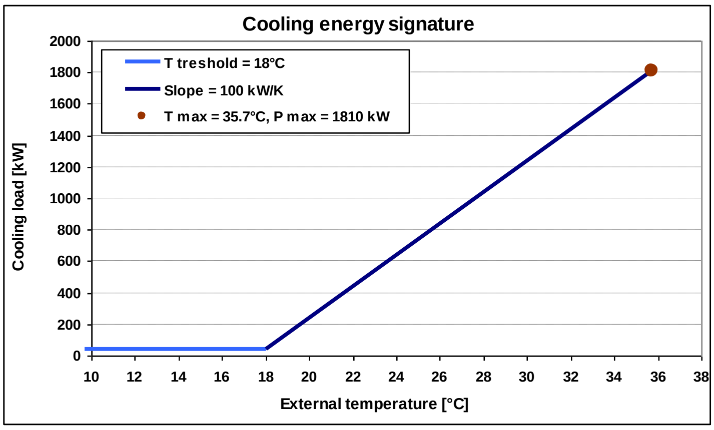

Figure 3: Model of the cooling energy demand of a building based on measurements (data by hour)

2. Optimization of regulation strategy with/without lake feeding

The regulation of the chilled loop can be optimized without a necessary feeding by the lake:
- First, simple modulations of temperature levels ($\boldsymbol{T_{in}}$ and $\boldsymbol{T_{out}}$) and flow rate, both in function of cooling loads has an influence on the quantity of energy consumption and costs,
- Second, the regulation of the chilled loop can be optimized with taking into account the lake feeding, which adds an additional constraint: the temperature at the output of the exchanger $\boldsymbol{T_{in}}$ will be governed by the lake flow input temperature $\boldsymbol{T_{lake}}$, with an additional temperature due to the exchanger efficiency. If the cooling demand is important and the $\boldsymbol{T_{lake}}$ is greater than corresponding needed $\boldsymbol{T_{in}}$, then the lake itself is not sufficient for ensuring the required cooling energy, and the spare cooling machine has to supply the complement energy (*figure 4, right*),
- Third, the control strategy can take into account a modulation of the flow rate: it involves a greater decrease of the flow rate as in the proportional mode (*figure 4, left*). The decrease of the slope may be as big as possible, as long as it can supply the power demand in any

conditions of partial load. This will drastically increase T_{out}. Besides meeting the lake requirements, this strategy with minimum flow rate is the best regarding the pump consumption.

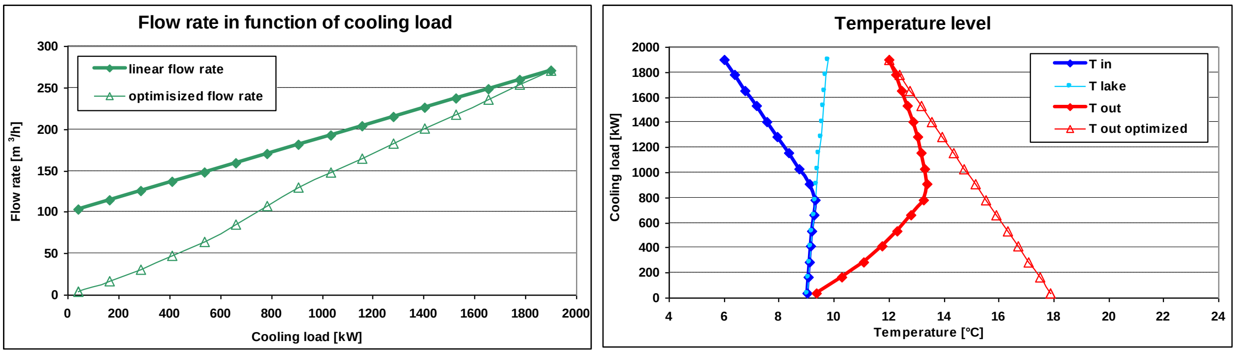

Figure 4. Chilled Loop flow rate (left) and operating temperatures (right)

In summary, for the control strategy, essentially 3 parameters have to be defined: the return temperature at nominal conditions, the nominal flow rate decrease and the threshold temperature for proportional cooling operation.

3. Results and Scenarios: output of the simulation Excel tool

This sheet shows two graphs with power demand, and corresponding water needs for all defined scenarios (*figure 5*): the left graph illustrates the proportion of cooling demand which is feeded by the lake; the right graph illustrates the corresponding lake water volume and the level of return temperature as a function of cooling load steps.

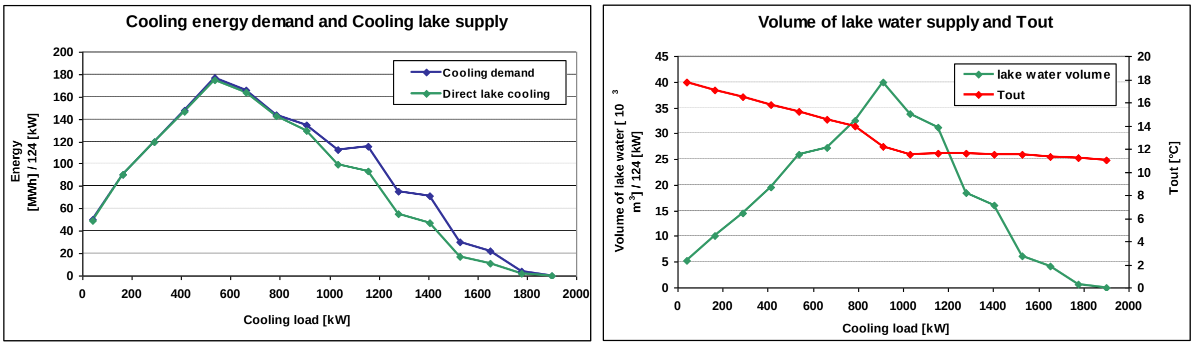

Figure 5. Cooling supply by the lake (left) and corresponding volumes by increasing cooling demand steps (right)

This sheet also gives the balance of cooling energy which is supplied by the lake and determinant indication on the linked costs (*figure 5*). The tool lastly contains a sheet which gathers in a single table all parameters and the main results of different scenarios: it enables an overview of the effects of different parameters and optimisations which have been studied.

Lake						
Energy	**1248**	**MWh**	Cooling energy supplied by the lake			
% lake	**94**	**%**	Energy percentage of lake supply in comparison with the building demand			
Volume	**548**	**m³**	Lake water supply			
Average flow rate	**89.87**	**%**	Percentage of the utilized flow rate, in comparison with concession flow rate			
Equiv. P souscrite	**891**	**heures/an**	Operation time equivalent to nominal cooling power			
GLN cooling indicative costs						
Total cost	**227'912**	**CHF/year**	Total cost for cooling energy which is supplied by the lake			
details :	**76'000**	**CHF/year**	Connexion cost (constant part)	connexion cost	40	CHF/kW
	151'912	**CHF/an**	Consumption cost of lake energy supply (variable part)	energy price	10.5	ct/kWh
				degressive	-0.5	ct/kWh/K
Cost/kWh	**18.3**	**ct/kWh**	Cost of kWh which is supplied by the lake	above Tout =	14	°C
details:	**6.1**	**ct/kWh**	Connexion cost (constant part)			
	12.2	**ct/kWh**	Consumption cost of lake energy supply (variable part)			

Figure 5. Example of output data which could be obtained and stocked by the Excel tool

DISCUSSIONS

This method has been established on the basis of the analysis of two concerned buildings. The HCR building has been studied in detail, gathering a maximum of information. This allowed for the identification of the pertinent information required for such an audit. The second object was the UN building. Our approach for analysing it was less detailed. It should be understood as a test of the applicability of the method.

Specific problems are linked to the direct connexion, especially regarding the operating temperatures. The transferable energy, as well as the flow rate required from the network, are very dependent on the operating temperature of the chilled loop. The possibilities of increasing the operating temperatures in the air-conditioning installations are a very important aspect the present analysis, especially under partial loads. Operating at higher temperatures when the cooling demand is moderate (most of the time in central Europe climates) would lead to an increased COP of the production machines, a decrease of thermal losses in the distributing pipes, possibly less condensation problems, and significant saving of pumping energy when using increased ΔT, i.e. lower flow rates.

With the DLWDC connexion, the distribution (input) temperature is determined by the Lake conditions. The output temperature of each device circuit may be adjusted by diminishing the flow rate down to a limit ensuring the satisfaction of the cooling service. The remaining problem is during the short periods of lake temperature peaks (some hours). This may be overcome by the back-up cooling machine in the existing installations, but the question should be solved - perhaps by a risk acceptation - in new installations without back-up.

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LONG-TERM HEAT STORAGE WITH NAOH

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ABSTRACT

To reach high solar energy fractions for building heat supply, several seasonal thermal storage techniques have been developed and tested so far. Besides ground storage techniques, thermo-chemical techniques with high heat storage capacity and virtually no heat losses in the storage state are most promising. The paper deals with closed sorption systems and focuses on the concept with sodium hydroxide (NaOH) - water as the working pair. In an experimental single-stage prototype set up, heat charge and discharge processes of the storage under low pressure conditions were analysed and verified.

The storage capacity is limited by the temperature levels of the produced heat and by the solidification of the NaOH lye. Simulation results for a prototype with double-stage heat exchanger show that for charging the storage, solar heat can be supplied at 100°C, and that, compared to conventional water storage, the system volume related heat capacity could be increased by a factor of 6 for low temperature space heating (40°C) and by a factor of 3 for domestic hot water supply (65°C).

The laboratory prototype set up is currently extended with a double-stage heat exchanger. Future systems shall be built in one integral vacuum container, containing solution tanks, heat exchangers, piping and pumps.

INTRODUCTION

The aim of the 2000 Watt society is the reduction of the fossil fuel consumption per person in Switzerland by a factor 9 until 2150 to 2200 [1]. This goal can only be reached with an increased use of renewable energy sources. In the last years, passive houses have been developed [2]. They only require 30% of the heating energy demand compared to houses which meet the Swiss standard SIA 380/1. This offers the possibility to cover the small residual energy demand for heating and domestic hot water by solar heat. So far, the use of solar energy has been limited by the semi-annual time shift between maximum gain and maximum heat demand. To overcome this limitation, various approaches of seasonal storage are explored. Basically, three main technologies can be distinguished: (i) large scale thermal energy storage (water, soil, and aquifer) [3], (ii) phase change material (PCM) based storage [4], and (iii) thermo- chemical storage [5].

With the first two storage techniques, heat is stored by a temperature change of a material with a high specific heat capacity per volume. For seasonal storage, extraordinary insulation of the vessel is required. With thermo-chemical storage techniques, heat is stored by separation of substances. To retrieve the heat, the substances have to be recombined. While ground storage (soil, aquifer) is mostly applied for larger solar plants and PCM storage is mostly suitable for low temperature heat sources, thermo-chemical storage is most promising for building integrated storage tanks. In the field of thermo-chemical storage, a promising method for low temperature storage is closed sorption. This concept is based on sorption materials which, for heat output, absorb/adsorb the vapour of a solute (mostly water) and thus release the enthalpy of ab/adsorption.

Sorption Heat Storage

Thermo-chemical storage is an indirect way to store heat. The heat is not stored directly as sensible (i) or latent (ii) heat but by way of a physico-chemical process. Thermo-chemical storage systems can be classified by design (open/closed systems), by the reaction type (adsorption/ absorption), and by the number of phase changes. A detailed overview can be found in [5].

The working principle of closed sorption storage is illustrated in Figures 1 and 2. During the charging phase, heat is needed to evaporate the working fluid. In closed systems, the working fluid (mostly water) is condensed and stored in a separate vessel. The thereby obtained evaporation enthalpy is released to the environment. As long as a recombination of the agents can be prevented, no heat losses occur. In the reverse process (heating mode), low temperature heat is taken from the environment to evaporate the working fluid. The vapour is absorbed by the sorbent, also releasing the evaporation enthalpy. The produced heat can be used for space heating or domestic hot water. This reverse process is running, until a status is reached, where the sorbent does no longer absorb. Closed storage systems typically run under vacuum conditions (meaning: air free environment) to speed up vapour transport and to minimise heat losses by convection.

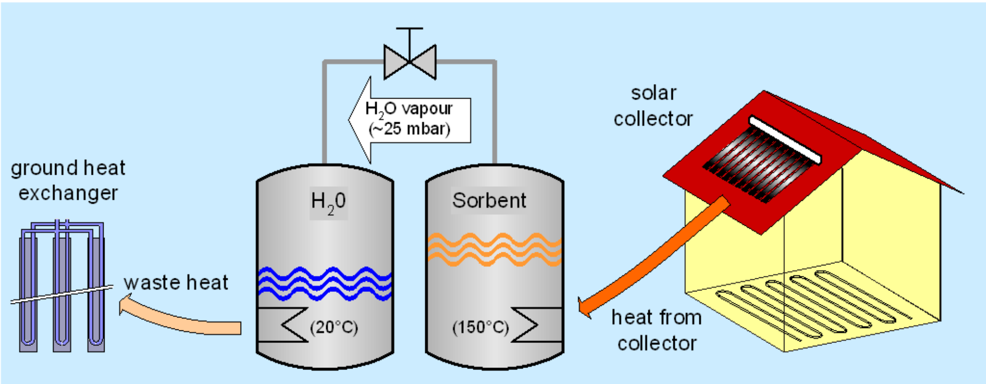

Figure 1: Charging mode. Sorbent is heated up to evaporate the working fluid.

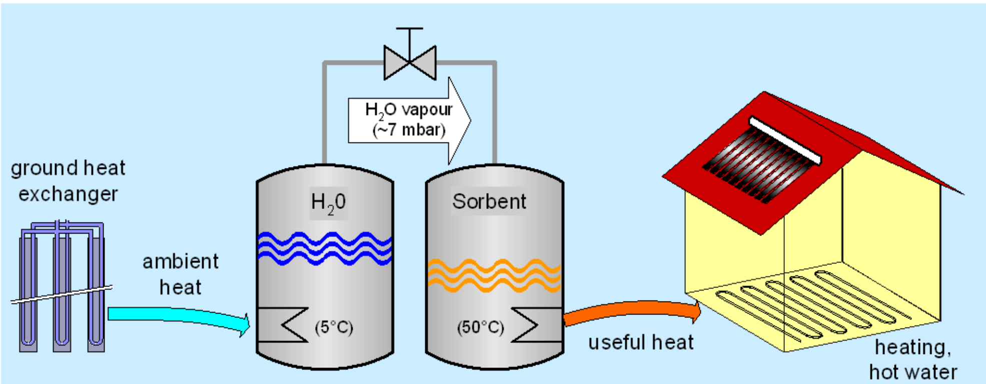

Figure 2: Heating mode. Vapour is absorbed by the sorbent.

Several combinations of sorbent and working fluid, called working pairs, are possible. An optimal working pair complies with the requirements and criteria listed below [5]. However, there is no working pair known, which complies with all criteria. Therefore, the material selection has to be optimized. Works on the identification of suitable materials for closed sorption storage are still in progress [6].

- The sorbent grants high uptake (kg sorbate/kg sorbent) of working fluid. If water is the sorbate (working fluid), the sorbent has a high selectivity for water.
- The working pair shows high thermal energy density at operating temperature.
- Charging is possible by heat at relatively low temperature.
- For solar heat use, low regeneration time is needed (requires either a small saturation gradient in thick sorbent layers or thin sorbent layers, where the gradient is no criterion).
- To keep the heat exchanger small, high heat conduction in the sorbate and high heat transfer to the heat exchanger are required.
- To inhibit corrosion, the materials of the working pair have to be chemically stable.
- The materials have to be easy to handle and non poisonous.
- An economically viable solution can only be realized with low cost material (low price per kWh heat energy stored and delivered).

This paper describes a project where sodium hydroxide (NaOH) - commonly known as caustic soda, soda lye, or sodium hydrate - has been selected as working pair, considering the following advantages (+) and disadvantages (-):

+ Theoretically, NaOH has a high uptake of water and therefore a high storage density.
+ Temperature levels for both charging and discharging match with the respective levels of the (solar) heat source and the demand side.
+ The NaOH lye is readily available, commercially employed, and available at low price.
+ The liquid NaOH lye forms thin films on the heat exchanger, and thus offers high heat transfer coefficients and short regeneration times.
+ NaOH is chemically stable.
- NaOH is caustic; measures to prevent unintended skin contacts must be taken.
- NaOH is corrosive.
- NaOH crystallizes at high concentration, which has to be considered in the handling.

DESIGN OF THE SODIUM HYDROXIDE STORAGE

In contrast to the general description in Figures 1 and 2 where the storage works in a batch mode, the NaOH storage shall work continuously. The main functionalities of that system are transforming a heat flux to a mass flow (and vice versa) and storing the resulting products. To reach that goal, the transforming function and the storing function are separated (Figure 3). To charge the storage, weak soda lye is pumped from a tank to the heat and mass exchanger area, where it is concentrated. The vapour produced is condensed. The products, water and concentrated soda lye, are pumped to separate tanks and stored again. The storage is fully charged, if the concentration of the soda lye reaches about 75%. Higher concentrations lead to crystallisation.

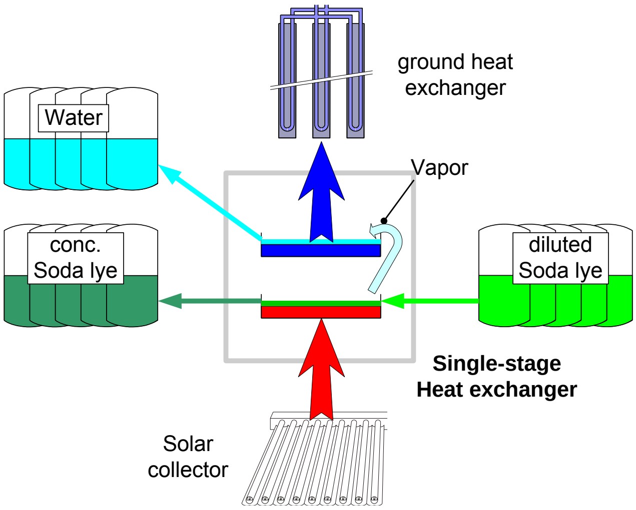

Figure 3: Charging mode. Weak sodium hydroxide is pumped to the heat exchanger and concentrated. Water and concentrated soda lye are stored separately.

To discharge the storage (Figure 4), water and concentrated soda lye are pumped from the corresponding tanks to the first heat exchanger. There, low temperature heat is produced either for heating or for evaporating water in the second heat exchanger. With a second stage, higher temperatures can be reached for the production of domestic hot water. Additionally, the usable concentration range for the sodium lye is higher, which results in a higher heat capacity of the storage. A detailed description of the working principle of the second stage can be found in [7].

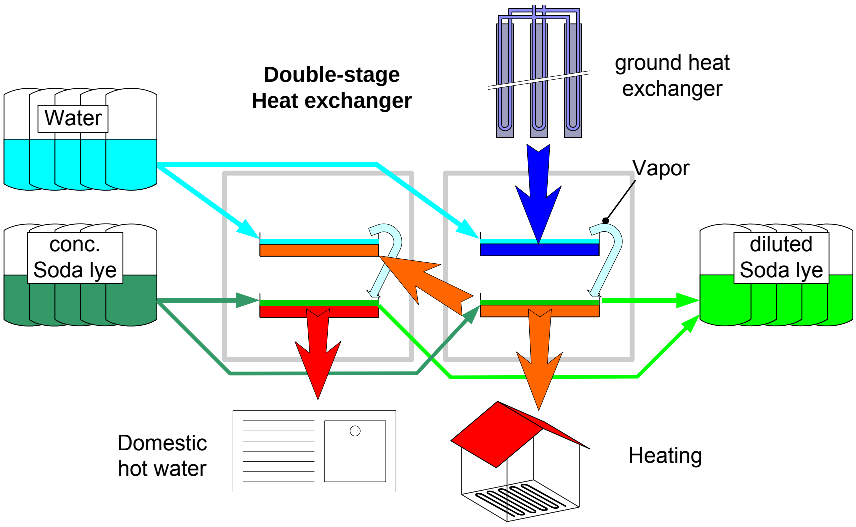

Figure 4: Discharging mode. The produced heat of the first stage is used for heating and for evaporating water in the second stage. High temperature heat produced in the second stage is used for domestic hot water.

PROTOTYPE TEST PLANT

A laboratory test plant has been set up at Empa. It consists of three storage tanks, a process unit with integrated heat exchangers (single stage), dosing pumps, connections to cold and hot water supply, and a domestic hot water tank. The storage tanks with a volume of ca. 200 litres each are used to store water and solutions at different concentrations. In the high concentration solution tank, a heating unit is installed to allow for liquefying the solution if required. To prevent corrosion, all metallic parts consist of stainless steel. The low temperature heat source is formed by Empa's chilled water campus grid. Hot water is supplied from an instantaneous water heater. The domestic hot water tank is used for intermediate storage of the produced hot water. Inside the process unit, all absorption and desorption processes take place. The system is designed for gravity driven flow; therefore the dish shaped heat exchangers are staggered in a cascade (Figure 5, left side). A radiation protection is installed to minimize heat losses between the hot and cold heat exchangers. In order to prevent crystallisation, heating strips are attached to the pipes beneath the insulation, and a double bottom is installed in the process unit, allowing for heating with hot water from the heat source.

STORAGE PERFORMANCE

The process was modelled by a simplified static model, the storage density estimated, and the application potential analysed [8]. The energy density was basically calculated using the mean enthalpy of absorption per weight at specific temperatures. To be on the safe side for the performance prediction, several factors were conservatively assumed. Calculations were made for a single family home, of about 120 m² living space, and complying with the Passive House standard [2]. As a result, a NaOH storage unit of approximately 7m³ is required for 100% solar fraction. The total volume of the storage unit, including NaOH tanks, condensed water tanks, and heat exchangers is considered. In general, for a hot water tap temperature of 65°C, the heat storage density is roughly 3 times higher compared to traditional hot water storage, and about 6 times higher for a tap temperature of 40°C for low temperature space heating.

The losses of a sorption storage system are indicated by an efficiency number ε.

$$\varepsilon_{tot} = \frac{Q_{Heat.in} + Q_{Auxiliary}}{Q_{Heat.out}} \tag{1}$$

Theoretically good values of ε are situated in the range of 0.6 – 0.8. Currently, the laboratory prototype reaches values in the range of about 0.45 – 0.5. These rather low values are due to the non-optimised first version heat exchanger. This heat exchanger suffers from high convection and radiation losses (Figure 5, left side).

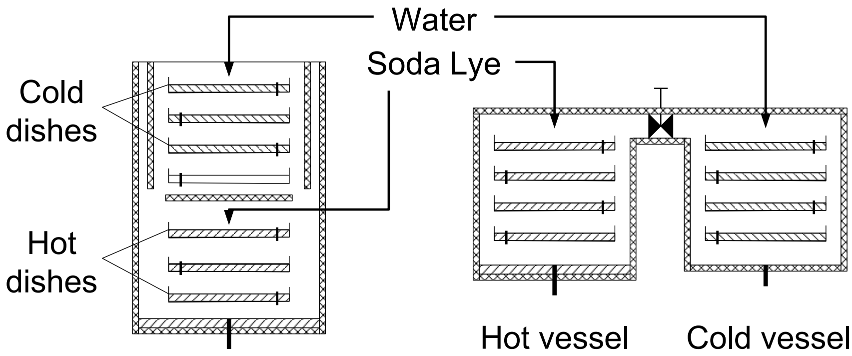

Figure 5: Left side: First version heat exchanger (still used as the first stage). Right side: Improved heat exchanger (used as the second stage).

CONCLUSIONS AND OUTLOOK

A NaOH – water based process for long term storage of solar heat has been analyzed. The process has been demonstrated in a prototype plant with individually vacuumed storage tanks and solution/water vapour heat exchangers unit. The results show that, compared to conventional water storages, the system volume (tanks and heat exchangers) related heat capacity could be increased up to a factor of 6 for low temperature space heating with 40°C supply temperature. For domestic hot water supply at about 65 °C this factor is reduced to about 3. Currently, the system is upgraded to a double-stage system with an improved heat exchanger (Figure 5, right side). A second stage in the heat exchanger allows for lower solar heat input temperatures during charging (about 100°C) and for higher tap water temperatures or for operating with lower solutions concentrations during discharging. With that extension, the behaviour and performance of the whole storage shall be tested. In parallel, building and system simulations using TRNSYS shall show how the storage and the additional components (solar collectors, earth heat exchangers, buffer stores etc.) have to be dimensioned to reach 100% solar fraction.

In future, the system will be designed as one integral vacuum container, in which the whole storage system is placed, comprising multiple solution tanks, two process units (because of the double-stage system), and the necessary piping and pumps. Such, the vacuum container has not to sustain the highly corrosive environment of the NaOH lye and may be of conventional carbon steel. As the solution tanks are fully placed in vacuum they do not experience a high pressure difference and can be made of polypropylene. This will contribute to a cost effective system.

ACKNOWLEDGEMENTS

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PASSIVE AND ACTIVE SOLUTIONS FOR A NET ZERO ENERGY OFFICE

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ABSTRACT

This work shows the concept development for an office tower in Bolzano, Italy. The main goal of the building owner was to assure high comfort level while reducing overall fossil fuel consumption using heat and power from a biomass-fired cogeneration plant and integrating renewable power from photovoltaic. Eurac's role was to facilitate the design process providing simulation results in order to enhance the awareness of the designing team for energy efficiency solutions. Step-by-step technical meetings have led to a steady improvement of the building performances: parametric analyses have been carried out focusing on glazing and shading features for a double skin full-glass façade, for the maximization of natural night ventilation, and implementation of an absorption chiller. The implemented approach has allowed reaching a good interaction among the actors of the design process and has led to a very high-energy building. Simulations show a good comfort level in all rooms. The future, planned monitoring will be a tool for verification of the building behavior under real conditions and its management optimization.

INTRODUCTION

Zero energy buildings are not a new concept, but addressing the limitations of autonomous buildings, while still achieving “zero”, leads to utility-connected solutions that optimize energy generation, distribution and storage. This “net zero” approach still incorporates on-site renewable energy, but the focus is on achieving an annual balance of energy supply and demand. Finally it has to be chose the system boundary, whether the construction embodied energy is to be computed or not, how to calculate primary energy factors, whether the energy consumption produced by the building such as transport has to be considered [1]. Also the European Parliament, by recasting the Energy Performance of Buildings Directive (EPBD) from 2002, voted for “zero energy buildings”: from 2019 all new buildings in the EU will have to produce more renewable energy on-site than they consume. Nevertheless, a Europe-wide harmonized model is needed. In this context the project presented here would represent an example where very strong architectural marks (shape, transparency, spaces organization, etc.) are well balanced by constructive and technological choices, pushing the building towards net zero energy.

SITUATION AND METHODOLOGY

The planning of Hafner headquarters in Bolzano, Italy, was already in an advanced stage when Eurac Research was asked to explore the feasibility of a high efficient or possibly net-zero-energy building and to monitor the building beyond commissioning in order to validate the calculated results. The building (Figure 1) is situated in an urban/commercial area amid the Italian Alps. Despite the geographical position, the city is located in a large valley at only 270 meters above sea level with hot summers and sunny and not too severe winters. Thermally, the building is divided in two main zones: a block of 4 stories with underground parking, and a 10-story triangular tower. The bottom block has a compact, rectangular shape, mainly massive external walls and a total floor area of 3614 m^2; it includes storage rooms, an exhibition area connected to the hall, a conference room, several offices and 4 residential units. The tower, with a total area of 2305 m^2, is planned with a double-skin full-glass façade (DSF). All stories are used as offices. Architectonically and energetically important is a photovoltaic “sail” built obliquely on the south side, which provides permanent shading and electricity production. CO_2-neutral energy is further provided by an in-house cogeneration plant fired by biomass. The high ratio of glass in the walls leads to lower average insulation values compared with opaque constructions. Further, the DSF is known to easily cause overheating [2] in the summer months. The building and DSF modelling has been performed with DesignBuilder [3], a user-friendly graphic interface linked to the simulation engine EnergyPlus [4] that consents the in-depth analysis of lighting and thermal effects of solar radiation on transparent surfaces. The model includes all usual hard and soft parameters. The simulation results encompass hourly data on comfort conditions in single building zones (temperature, humidity, lighting) as well as integral energy consumption data. Furthermore, the PV power production has been calculated dynamically with PV-Sol [5].

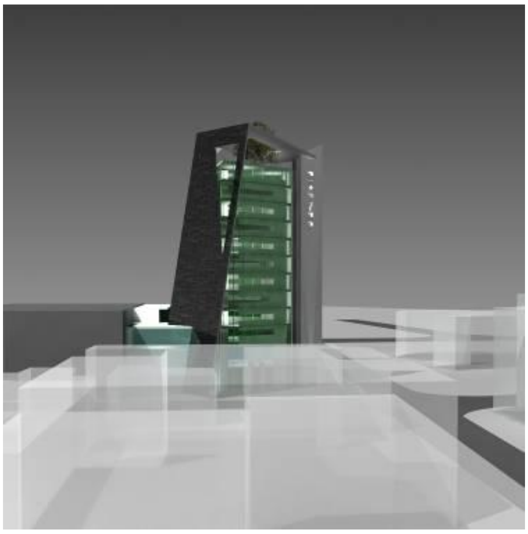

Figure 1: Model of Hafner Head-quarters, Bolzano, Italy.

DOUBLE SKIN FAÇADE

The modelling and analysis has been planned for three objectives, i.e. understanding the DSF performance with respective cooling loads given to the conditioned space depending on: i) geometric characteristics of the openings in the external façade for natural ventilation and height of the inner space between each fire section (3 or 5 stories); ii) light and energy values of the inner façade and positioning of the shading devices; iii) light and energy values of the outer façade with and without shading devices. The simulation strategy was centred on the analysis of two weeks in August with high cooling peaks. All the most relevant input parameters for simulations are reported in Table 1.

The assessment of the different options was carried out comparing the percentage load changes of a reference case with possible alternatives. A summary of the results is presented in Table 2. The simulations are focused on offices on the southwest façade, most exposed to direct solar radiation. The first set of simulations shows the influence of slots between the outer panes and the presence of major horizontal apertures at the bottom and top of the multi-story sections. The best performance in terms of lower over-heating and correlated loads is given as expected by the façade with large apertures, whereas the impact of the slots seems to be minor. The temperature range remains in all cases above 40 ˚C, i.e. 8 K above ambient temperature. The second simulation set investigated the influence of low-emissivity and selective glass in combination with mobile shading positioned either close to the external or to the internal skin. The low-e panes with a g-value of 0.6 cause a higher energy transmission into the conditioned space, compared to selective panes with g = 0.4. The positioning of the mobile shading does not contribute noteworthily to the indoor climate. Lastly, the parametric study was applied to the external skin, by means of panes having different U-values.

As expected panes with low g-value achieve the best overall result. However, also a clear glass coupled with vertical slats achieves results very similar to the best case. Large openings of 10-20 cm at the bottom and the top of multi-stories sections seem to improve substantially the air exchange in the DSF with a corresponding lower overheating.

	Geometry			Internal skin			External skin			Shadings	
	Stores	s [1]	H [2]	U g skin	g	LT	U g skin	g	LT	Angle[3]	D[4]
Objective	*[store]*	*[cm]*	*[cm]*	*[W/m²K]*	*[-]*	*[-]*	*[W/m²K]*	*[-]*	*[-]*	*[°]*	*[cm]*
Simulation	3	0	0	1.1	0.38	0.66	5.95	0.78	0.87	45	1.5
Simulation	3	3	3	"	"	"	"	"	"	"	"
Simulation	3	3	10	"	"	"	"	"	"	"	"
Simulation	5	3	10	"	"	"	"	"	"	"	"
Objective											
Simulation	5	3	10	1.158	0.406	0.715	5.95	0.78	0.87	45	5
Simulation	"	"	"	1.158	0.406	0.715	"	"	"	"	70
Simulation	"	"	"	1.227	0.62	0.75	"	"	"	"	5
Simulation	"	"	"	1.227	0.62	0.75	"	"	"	"	70
Simulation	5	3	20	1.158	0.406	0.715	"	"	"	"	5
Objective											
Simulation	5	3	10	1.227	0.62	0.75	5.95	0.714	0.859	45	5
Simulation	"	"	"	"	"	"	5.95	0.714	0.859	85	5
Simulation	"	"	"	"	"	"	5.61	0.54	0.63	No	No
Simulation	"	"	"	"	"	"	5.61	0.54	0.63	45	5

Table 1: Input parameters and variables for each DSF design solution analysed. 1: Distance between external skin panes. 2: Height of the hole at the top and bottom of the stores block. 3: Angle respect horizontal plane. 4: Shading distance from external skin.

		Office facing			DSF facing south-west		
		ΔPcool[5]	ΔEcool[6]	Trad max[7]	Top max[8]	Trad max	Tair max[9]
Objective 1		*[%]*	*[%]*	*[°C]*	*[°C]*	*[°C]*	*[°C]*
	Simulation 1	20.6	33.6	30.8	45.6	50.7	41.8
Reference case	*Simulation 2*	0.0	0.0	29.1	42.2	48.0	37.1
	Simulation 3	-2.6	-2.4	29.0	41.0	46.8	35.4
Best case	*Simulation 4*	-6.6	-7.8	28.8	40.3	46.4	34.9
Objective 2							
Reference case	*Simulation 5*	0.0	0.0	28.7	40.4	44.5	36.6
	Simulation 6	0.1	-0.3	28.6	40.4	44.2	36.8
	Simulation 7	10.2	10.8	29.3	40.3	44.2	36.5
	Simulation 8	9.9	10.4	29.3	40.2	44.1	36.8
Best case	*Simulation 9*	-1.1	-1.2	28.6	40.1	44.3	36.2
Objective 3							
	Simulation 10	8.2	9.9	29.3	40.3	44.2	36.5
Reference case	*Simulation 11*	0.0	0.0	28.5	38.9	41.5	36.2
	Simulation 12	18.0	17.8	30.0	43.4	50.6	36.9
Best case	*Simulation 13*	-2.9	-3.9	28.6	40.6	43.9	37.3

Table 2: Impact of different double skin façade options on the cooling load in the conditioned space. 5: Delta cooling peak power. 6: Delta cooling energy for cooling season. 7: Maximum radiant temperature. 8: Maximum operative temperature. 9: Maximum air temperature.

A selective pane with low g-value on the inner skin reduces the radiation into the conditioned space with consequent cooling load reduction; stronger overheating of the DSF air space was not observed. A selective pane with low g-value on the external skin induces the most benefit on the cooling load reduction through a minimum DSF overheating. However, a similar effect was calculated for the mobile shading slats in vertical position (85˚) instead of the usual 45˚.

ENERGY DEMAND

Baseline building

The energy demand of a standard version of the building has been assessed in order to create a baseline for the impact assessment of energy-efficient measures. For this simulation the internal loads have been set at usual numbers such as 12 W/m^2 for the lighting with on/off control and threshold at 400 Lux, average computer loads of 100 W each, automatic shading (slats at 45˚) for solar radiation values higher than 300 W/m^2. The HVAC schedule follows occupancy with corresponding operation hours for energy supply and ventilation units. The heat and cold distribution is handled by radiant floors with dehumidification carried out by post-cooling and reheat coil in the air ducts. A heat recovery ventilation unit was included with 75 % efficiency. The summer indoor air temperature was set at 26 ˚C; the air change based on a hygienic rate of 40 m^3/(h pers) and a high occupancy level of 0.1 pers/m^2 was set at ACH=1.25 (in compliance with UNI 10339). Figure 2 shows the monthly behaviour related to the energy demand for heating, cooling and electric loads. Heating and cooling are supposed to be covered by biomass-produced heat – for cooling in combination with an absorption chiller – whereas the electric loads include lighting, plug loads and parasitic consumption of pumps and fans. As expected the heating load is extremely low (2.3 kWh/m^2) due to high internal gains, especially solar and equipment (Figure 2a). Differently behaves the cooling (total average 31 kWh/m^2, but 62 kWh/m^2 in the tower) with high summer peaks. The DSF, responsible for the overheating outside of the internal skin, contributes to this outcome with ca. 15 %. The overall electric consumption sums up to 46.8 kWh/m^2 with equipment and fans playing a major role: 27 kWh/m^2 and 11.4 kWh/m^2, respectively. Summarizing the results, 15.6 MWh/a is the demand for heating and 214.7 MWh/a is the cooling need. The electric need amounts to 322.9 MWh/a.

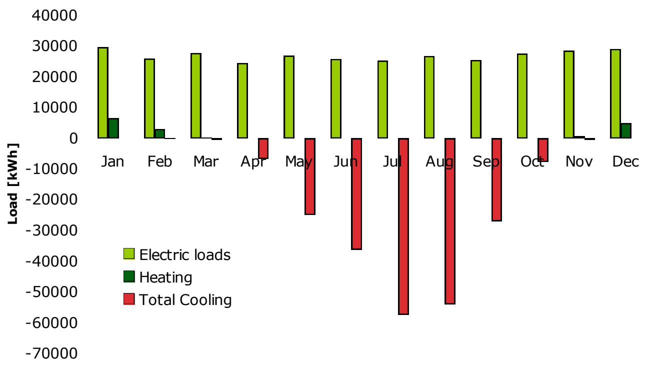

Figure 2: Monthly energy demand for heating, cooling and electricity.

The design peak powers for the basement are 506 kW for heating and 122 kW for cooling, whereas for the tower (10 floors) heating and cooling peak powers are 244 kW and 138 kW, respectively.

High-efficiency building

The high-efficiency case was reached acting mainly on the internal electrical gains and using night ventilation as a mean for passive cooling, whereas the HVAC system with corresponding schedules and the building envelope have remained unchanged. The lighting was switched to high-efficiency fluorescent bulbs with 3 W/m^2 controlled by continuous dimmers. All office equipment was chosen with mobile technology, thus decreasing the specific load to 5 W/m^2. In figure 3b the reduced loads are compared to the original ones. In order to boost natural ventilation at night, vents have been opened in the offices external walls of the tower and between the stairways and adjacent offices at each story. A major opening in the stairways roof was designed to permit the transit of the warm exhaust air. This design produced in the simulations a mean air change rate ACH of 6, which in turn decreased substantially the temperature of the thermal mass in the building. Figure 4 shows the new monthly load characteristics. As overall result heating increased to 6.7 kWh/m^2 due to lower internal gains but cooling decreased by half to 16.5 kWh/m^2. The overall electric load was also substantially cut to 25.6 kWh/m^2.

ENERGY SUPPLY WITH RENEWABLE

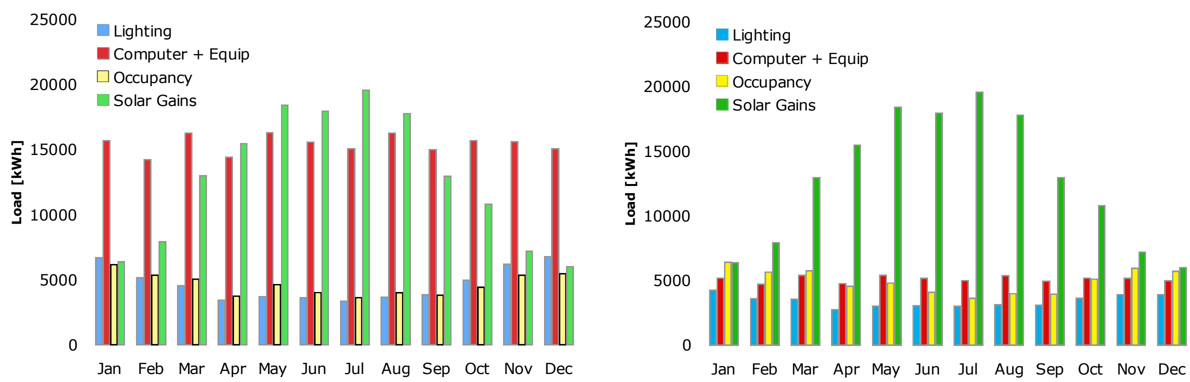

Figure 3: Monthly energy load by int. and solar gains. A) baseline; B) high-efficiency.

Photovoltaic sail

On the south side the PV-sail ranger for the whole height of the building, for a total area of 367.7 m^2. The sail is sloped to 78˚ with respect to the horizontal. The sail will be plastered with photovoltaic Suntech Power (STP180S-24/AC) mono-crystal modules with a planned installed capacity of 51.8 kWp. The annual yield has been estimated at 45690 kWh. This amount would cover 26 % of the total electric load, with the remaining to be covered by the bio-mass driven cogeneration plant.

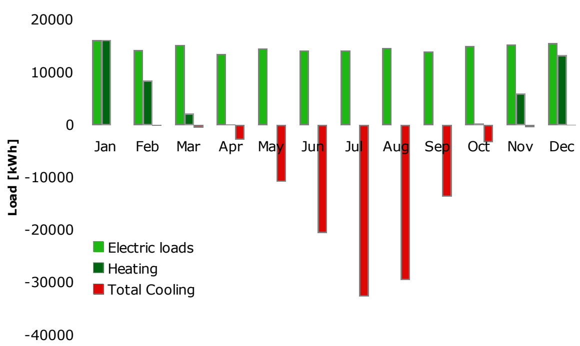

Figure 4: Monthly energy demand for heating, cooling and electricity. High-efficiency case.

Cogeneration plant

Hafner headquarters is embodied in a building complex including a biomass-fired cogeneration pilot plant of 6 MW thermal capacity. The plant is scheduled to run for 8000 h/a. Water at 90 ˚C from the turbine is put at building's disposal via a plate heat exchanger. During operation the thermal capacity of the cogeneration plant can easily cover the entire demand for heating and electric power. Moreover, a 300 kW hot water driven absorption chiller is planned to meet the cooling demand. However, 9 % of the time (760 h/a) remains to be covered by a different source. Since the plant operation time is not known and cannot be foreseen, the downtime was assumed to happen evenly through the year, thus leading to a statistical 91 % of energy coverage. Table 2 gives an insight of the energy flows and coverage. Starting from the load covered by the cogeneration plant, a thermal load of 4.6 MWh/a for space heating remains to be covered by a furnace, which accordingly to PWI 12655 [6] on the real use of energy in buildings leads to a electricity equivalent of 3.1 MWh/a. The cooling load share covered by a gas-fired absorption chiller causes 10.8 MWh/a primary energy equivalent. The power consumption to be covered by the grid amounts to 15.9 MWh/a. The total electricity from conventional sources sums up to 29.7 MWh/a. In a net-zero-energy optic, exactly this quantity must be replaces by renewable sources. The PV sail with its projected yield of 45.7 MWh/a sets Hafner Headquarters on the safe side towards plus-energy buildings.

	Building demand	Cogen coverage	Conventional energy consumption	Electric energy equivalent
Heating	46.4	42.3	4.6	3.1
Cooling	114.1	103.8	16.3	10.8
Power	176.4	160.5	15.9	15.9
Required PV power production				**29.7**

Note: all values in MWH/a

Burner efficiency	*90%*
Chiller COP	*0.7*

Table 2: Load covered by cogeneration plant and electricity equivalent to be produced by PV.

CONCLUSION

A new building has been planned for commercial use in Bolzano, Italy as headquarters for Hafner AG, a leading company in the cogeneration business. The scientific work has investigated first the building double skin façade (DSF) by means of dynamic simulations. Large openings of 10-20 cm in the external skin at the bottom and the top of 5-story sections seem to improve substantially the air exchange in the DSF with a corresponding lower overheating; selective panes with low energy transmission (g-value) on the inner skin reduce the radiation into the conditioned space without a substantial overheating of the DSF air space; selective panes with low g-value on the external skin induce the most benefit on the cooling load reduction through a minimum DSF overheating. Further, a baseline and a high-efficiency scenario have been set up for the building. By means of mobile technology for electric equipment, continuous lighting dimmers and massive use of night ventilation the electric loads could be decreased by 45 % and the cooling loads by 47 %. The overall primary energy consumption – with loads covered conventionally – would amount to 111 kWh/m^2. A biomass-fired experimental cogeneration plant in the building provides 91 % of the heat and power necessary with the remaining 29.7 MWh/a covered by a large PV sail architectonically integrated in the building façade. The sail is projected for 45.7 MWh/a, thus making the building possibly plus-energy.

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GIS-BASED ASSESSMENT OF SOLAR IRRADIANCE ON THE URBAN FABRIC AND POTENTIAL FOR ACTIVE SOLAR TECHNOLOGY

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ABSTRACT

A general understanding of the solar admittance and solar gains incident on the urban fabric is very useful to assess the potential implementation of renewable energies at the scale of the city. The authors propose a tool that uses Light Detection and Ranging (LIDAR) data to automatically derive this information in a fast way with no need to refer to the construction of complex models of the urban layout/geometry. Very few applications have been implemented in order to process LIDAR data for the environmental analysis and to get an understanding about the performance of the urban form. Yet, the increasing interest in the quantification of energy-based indicators at the scale of the city, strongly suggests the integration of 3-D GIS and urban studies in order to provide useful applications for the urban planning.

Aim of the work is to establish a conceptual method and tools to calculate yearly input of irradiation on roofs of buildings so as to estimate the suitable areas eligible for the production of energy from the sun through solar panels (PV and thermal). The proposed process investigates digital urban models integrating cross-disciplinary competences, like remote sensing, GIS, image processing and urban and environmental studies.

The process for structuring the proposed methodology is based on four major steps:

(1) the construction of the 2.5-D urban surface model;

(2) the calculation of roof surface areas taking into account the slope and the pre-selection of suitable roofs for PV and thermal panels considering the minimum area requirement.

(3) the calculation of outputs (solar irradiation on building roofs, electrical and thermal energy) through the image processing of urban models;

(4) the visualizations of results through communicative maps.

Case study for application is made in a district (58 buildings) of Geneva to be refurbished.

INTRODUCTION

Numerous authors are convinced that cities play a leading role in controlling sustainability and redefining more efficient cities in terms of energy and environmental performance [1]. Anyway, a comprehensive and reliable toolkit for sustainable urban design is lacking among professionals. The calculation of solar radiation gives us some clues about the energy-performance of the urban fabric concerning the different contributions of vertical and sloped surfaces. Hence, some critical questions in urban design and planning arise: can we build denser cities without decreasing the potential for passive solar architecture? Which is the incidence of beam versus diffuse solar irradiance contributions in typical urban textures?

The investigation of solar radiation in architecture is not new and there are already several tools that calculate radiation performance of buildings very accurately. A lot of them are based on Computer Aided-Design in the architectural domain and consist in simulating solar access: RADIANCE lighting simulation model [2], SOLENE [3] and other works [4, 5]. However, Batty et al. [6] stress the need to couple such CAD tools with 3D GIS so as to include data processing and spatial analysis and to provide automated analysis on urban area. Pioneers in the use of image processing techniques to analyse environmental indicators of digital urban models was a group of researchers at the University of Cambridge [7].

Our work proposes a conceptual and methodological framework that formalises the introduction of solar irradiance analysis into 3D building models in a consistent way. The aim of the work is to establish a conceptual method and tools to calculate hourly input of irradiation on roof buildings so as to estimate the suitable areas of roofs eligible for the production of energy from the sun through solar collectors (PV and thermal). The proposed process investigates digital urban models integrating cross-disciplinary competences, like remote sensing, GIS, image processing and urban and environmental studies.

METHOD

Synoptic view of the process

The process for structuring the proposed methodology is based on four steps: (1) the construction of the 2.5-D urban surface model, (2) the calculation of roof section surface areas taking into account slope and the pre-selection of suitable roofs for PV and thermal panels, (3) the calculation of outputs (solar irradiation on building roofs, electrical and thermal energy) through the image processing of urban models, (4) the visualizations of results.

The construction of the 2.5D digital urban surface model (2.5-DUSM)

A 2.5D digital urban surface model is built from a 2D vector map of roof sections and raw LIDAR data (elevation). This urban model is only composed by terrain and buildings heights information (DTM + nDSM). The interpolation of a digital terrain model (DTM) is made by classifying the LIDAR points, whereas the building height (also defined as normalized DSM of buildings) is taken to be the difference between the terrain elevation and the building elevation. For more details on such operations the reader can refer to [8]. In the last version of the tool presented in this paper, the DSM, in addition of building elevation, also includes the modelling of trees by considering different echoes of LIDAR.

Surface roof requirement analysis

For PV technology, roof surface areas must at least be equal to 20m² to meet the requirement of minimum installed power capacity (2kW) for cost-effectiveness. For thermal technology, the minimum area depends on the users requirements. But we consider that below an area of 4 m², any installation would be unrealistic. The calculation of inclined roof surface area should consider slope (classic trigonometric formulae); slope is obtained by transferring heights information from LIDAR to each section. For flat roofs, additional slope is provided to panels to increase their efficiency, which results in decreasing the part of the roof area being used.

Image processing tools for calculating irradiation, electrical and thermal energy produced

The 2.5-D urban model was applied for implementing specific tools for calculating, with MatLab scripts, the hourly solar irradiance intercepted by urban roofs.

Two types of input data are required for running the tool: first, geographical data that inform the geographical coordinates of the case-study area, the height above sea level and the physical extension and second, the statistical hourly irradiance values which are based on METENORM® (statistical data of a typical year for the Geneva location).

The technique used is based on the image processing of the 2.5-D urban surface model that is interpreted as raster images. These images result from the transformation of all the information attributes needed for the irradiation calculation into masks: height values, slope, orientation, roof prints with area >20m² (PV) or 4m² (thermal), building labels. Numerical data of solar radiation is thus collected pixel by pixel (0.5 m * 0.5 m) on the roofs and stored in synthetic tables containing the list of the identified roof sections.

Solar geometry formulae allow deriving the beam and the diffuse components of hourly radiations for every orientation and inclination of surface starting from the previous mentioned inputs. The shadow casting routine first introduced by Ratti and Richens [7] is applied to the input images or masks at a specific day of year and hour of day and is used to detect which pixels on roofs are in shadow (cast from buildings or trees in the surrounding environment) and which collect direct sunlight [9]. Another procedure is applied for the calculation of the sky view factor on the model that evaluates the reduction of the sky visibility from the roof point of view due to obstacles in the surrounding environment [10].

Hence, when we are able to determine for every pixel its shadowing condition, its SVF, its orientation, and its inclination, we can assign the global incident solar radiation calculated in W or J /m² for various times scales (hour, aggregation to month, year). From the irradiation value we can then calculate the electrical and thermal energy production.

The **electrical energy produced** [kWh] is obtained by multiplying the global radiation incident on a given roof section by the installed power of a given PV panel and a performance ratio. If we basically consider an installed power of 120 [kWp/kW/m²], which corresponds to an average value among the common technologies of poly- and mono-crystalline and a PR of 75%, we obtain an electrical production equivalent to 9% of the global irradiation.

For the calculation of **thermal production for heating and DHW** the formulae used in the software EnerCAD were implemented in the Matlab scripts. The formulae result from a simulation model that computes the energy production of typical (flat-plate) collectors from meteorological data [11]. The model is based on daily Input/Output functions. The formulae differ depending on the type of use (heating or DHW) and the type of collector (glazed or unglazed). For the heating production, the main parameters in addition of the irradiation are: the supply temperature, inside/outside temperature, the surface area of the panels to be installed. The calculation of energy production for DHW depends on the number of users and total heated area of the building (available in GIS databases), on building energy requirement and surface area/resident available in common norms.

RESULTS

The analysis aims to reveal the potential to solar admittance on the case-study area. Figure 1 shows the shadowmap calculated for each hour; Figure 2 shows the sky view factor analysis result. The outputs of the irradiance analysis are displayed as maps with irradiance values represented on the roofs (Figure 3).

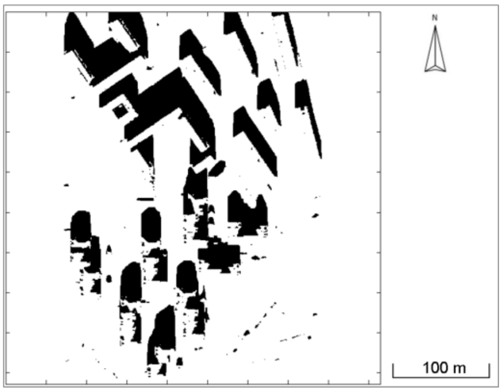

Figure 1: Shadowmap to recognize roof pixels under beam radiation (15th Jan. 12am)

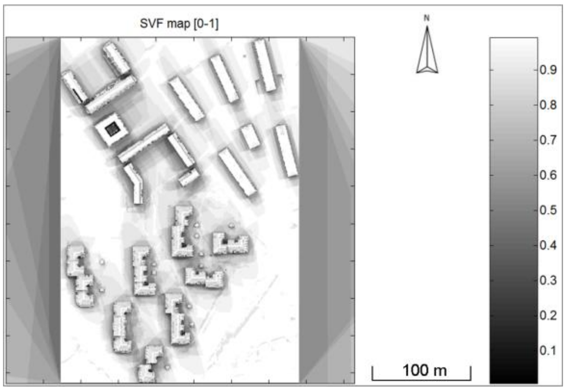

Figure 2: The sky view factor. The average SVF on the roofs is 0,83

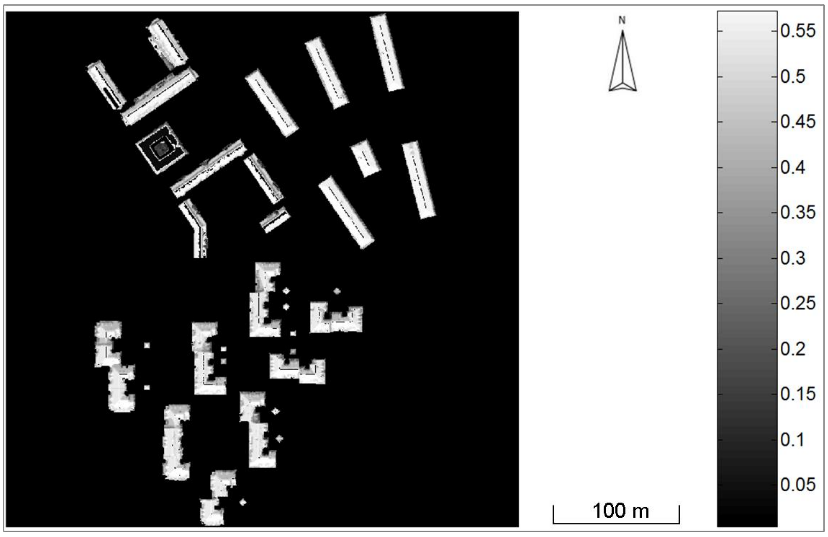

Figure 3: Solar radiation collected on roofs at 12am on the the 15th of January (MJ/m²)

It is also interesting to calculate the total collected solar energy in the district for each month as in the following histogram (Figure 4). Such aggregated values would be a basis for the comparison with the performance from other districts or urban fabrics having different types of morphology (high vs. low density, old vs. new districts, etc.).

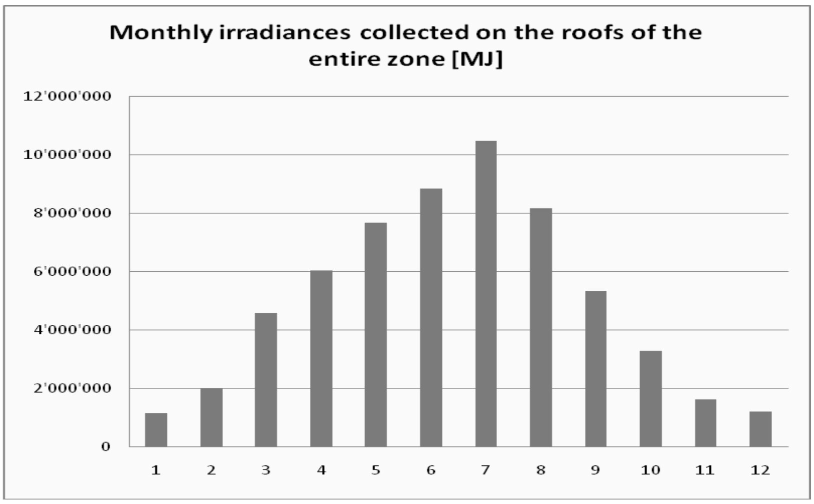

Figure 4: Monthly irradiances (MJ) values collected on roofs on the analysed district.

User requirements concerning the utility and usability of 3-D urban models for communication and visualization purposes are very important to consider. In our case, the potential user would be interested in assessing which roofs' sections would be suitable or not for solar panels installation. Grid pixel representation is not really appropriate for this purpose. Therefore, values are aggregated on each roofs' section to highlight in a synthetic representation which are suitable surfaces for installing solar collectors (Figure 5).

Figure 6 gives the results of the calculation of the thermal energy production for heating during a winter month (February).

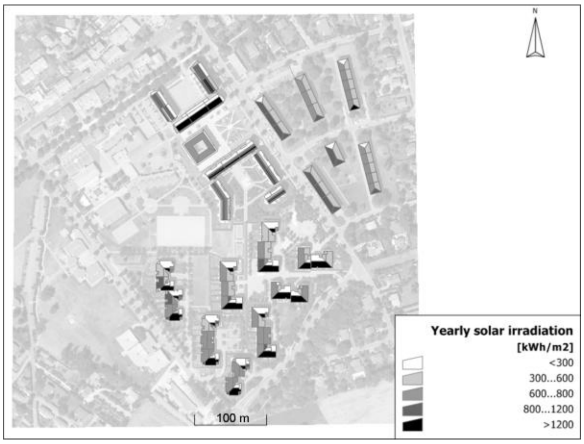

Figure 5: Annual solar irradiance values for the first pilot zone

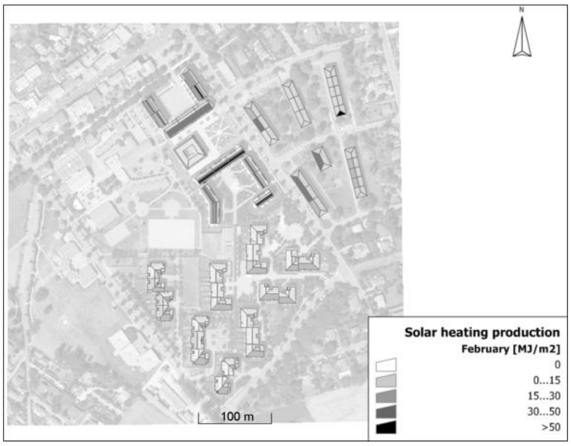

Figure 6: Monthly energy production for heating with glazed collectors

DISCUSSION

In this paper a complete methodology from the extraction of LIDAR data to the automated analysis of solar admittance over urban models and the visualization of results was introduced. The aim was to provide an educated estimation during the first stages of studies at the urban scale. In comparison to other software our methodology uses LIDAR data as input. Many cities do not have expensive 3D models, but LIDAR data are easy available and becoming cheaper; this type of data gives very rich information, is fast to process with the methodology here presented, and easily exportable to other tools (ex. RADIANCE) when it is matter of calculating solar admittance at building scale more accurately.

Applications of this methodology in urban design and planning are very promising. As the tool enables to calculate irradiation on a whole city, it could contribute to add a new data layer on building solar potential in the spatial information system (e.g.: SITG Geneva).

Such a database of solar admittances could be useful for various actors and purposes. In terms of energy urban planning, a municipality or energy company could be interested in identifying which are suitable roof-buildings for installing centralized or decentralized PV modules which would supply a part of a given region. They could program interventions and define specific incentives allowing to take into account the real potential energy production strategies of the urban fabric more precisely. Similarly, state-owned companies or building owners would certainly be interested in knowing which of their buildings are suitable to be equipped and to assess their value according to their energetic potentials.

In our case study we limit the analysis to the physical built environment, but we could extend the investigation to assess the impact of new buildings in the city or refurbished buildings. This technique could also be used to improve design schemes based on an evaluation of quantitative indicators before and after changes are introduced. In the case of a refurbishment of a block of buildings or a district, this tool could help to see if solar technology (in particular thermal) could be a good alternative of renewable energy supply depending on the users' requirements.

ACKNOWLEDGEMENTS

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MAXIMUM POWER POINT TRACKING UNDER REALISTIC OPERATING CONDITIONS

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ABSTRACT

The process of tracking the Maximum Power Point (MPP), known as MPPT, becomes problematic under realistic operating conditions due to the potential for there to be more than one local maxima.

A very detailed physics based model has been developed for a PV module (in this application a PV roof tile) using the Orcad platform for PSpice. This model is unusual in that it properly represents partial module shading and cell temperature variation. The PV roof tile, based on polycrystalline silicon cells, comprises 18 series-connected cells. In the model, each cell is represented by a standard two-diode sub-model, for which different levels of radiation and cell temperature can be simulated to obtain a realistic overall I-V characteristic for the module. The model can be extended to model any reasonable number of PV roof tiles wired in series and parallel to form a roof array.

The IV characteristics calculated in this way using PSpice will be validated using an outdoor PV roof test system located at the University of Strathclyde, Glasgow.

NOMENCLATURE

STC: standard test conditions
V_{0c}: open circuit voltage
V_T: thermal voltage
Isc: short circuit current
I_0: dark saturation current
E_g: energy gap E_{g0}: 1.17 eV
α, β: constant
T: temperature in Kelvin
B: constant independent of the temperature
k: Boltzmann's constant
$I_{sc\lambda,\ scE(B)\lambda}$: spectral short circuit current/wavelength, for emitter (base)
R_s: series resistor
R_{sh}: shunt resistor
n: diode ideality factor

INTRODUCTION

Photovoltaic (PV) technology is increasingly widespread as a result of the desire for clean and sustainable electricity, but system efficiencies remain too low for a number of reasons. The performance of a PV system depends on weather conditions but not all parts of a PV array are affected equally. It is known that different levels of irradiation and temperature across an array can result in a high reduction of performance due to increased mismatch losses.

The performance parameters of PV modules are optimized normally at STC (1000W/m2 of irradiance, 25°C cell temperature, air mass 1.5 global spectrum) but real operating conditions are generally far from these standard conditions [1].

For this reason it's important develop a model able to accurately represent all these losses so as to better understand the behaviour of real systems operating under real weather condition.

Predicting the performance under real conditions is also relevant for improving the efficiency of the converter and in particular the design of the MPPT algorithm.

PARAMETERS

In brief, the I-V characteristic of a PV cell, module or array describes its performance and gives information about the maximum power that can be potentially converted by the inverter. For a module, this I-V characteristic is the result of the individual response of each cell under its specific temperature and irradiance conditions, with proper consideration of the detail of their electrical connection, including any bypass diodes should they be used.

As well know, Voc decreases with temperature increasing because:

$$V_{oc} = V_T \ln\left(-\frac{I_{sc}}{I_0}\right) \quad (1)$$

where

$$I_0 = CT^3 \exp\left(-\frac{E_g}{kT}\right) \quad (2) \qquad [2]$$

and

$$E_g(T) = E_{g0} - \frac{\alpha T^2}{\beta + T} \quad (3)$$

In real operating conditions the cell temperature can reach as high as 80°C, reducing the value of open circuit voltage of the module and so the total power from the array.

The short-circuit current is due to the generation and collection of light-generated charge carriers. For an ideal solar cell with negligible resistive loss mechanisms, the short-circuit current and the light-generated current are identical. The short-circuit current is the largest current which may be drawn from the solar cell [3].

and can be calculated from the total amount of current generated by the base and the emitter when illuminated by a light source of a given spectral distribution.

$$I_{sc} = \int_0^{\infty} I_{sc\lambda} d\lambda = \int \left(I_{scE\lambda} + I_{scB\lambda}\right) d\lambda \quad (4)$$

It is clear that any shadow falling on a cell will cause a reduction of the short circuit current (and the power as well). If, in a module, one or more cells are shaded, the power from the unshaded cells is to an extent dissipated across the shaded cell and the overall current is limited primarily by the shaded cell. This energy dissipation causes so called hot-spots and can produce irreversible damage to the module when a large number of series connected cells causes a large reverse bias across the shaded cell, leading to large dissipation of power.

The short circuit current is also affected by the temperature: it increases slightly with temperature due to the decreasing of the energy gap that allows lower energy photons have enough energy to create electrons-holes pairs.

The overall short circuit current of a module can be affected also by intrinsic mismatch, caused by the interconnection of solar cells which do not have identical properties or due to other reasons, not connected to irradiance or operating temperature, experience different conditions from one another.

In non ideal solar cell, other factors must be considered: the losses due to the movement of current through the emitter and base of the solar cell, to the contact resistance between the metal contact and the silicon and to the resistance of the top and rear metal contacts themselves, all potentially increased due to manufacturing defects.

The recombination at the space charge region of solar cell explains non-homic current paths in parallel with the intrinsic solar cell; this is relevant to cell operation under conditions of low voltage bias [4].

OUTLINE OF MODULE MODELLING

In this paper an electrical model to take into account all the losses above described is proposed. Such a model is necessary to undertake research aimed at improving performance of PV systems through being able to predict real I(V) characteristics and thus helping to better understand the behaviour of the maximum power point.

With the one-diode model several effects are not taken into account that may affect the solar cell response. Consequently, in this work all the effects described in the paragraph above are taken into consideration by using the two-diode model.

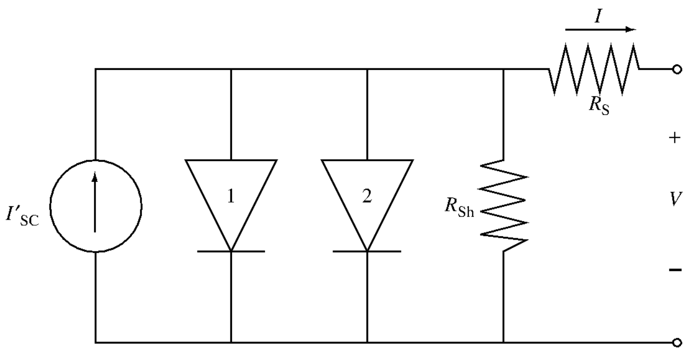

Figure 1: two diode model

The 2-diode model reproduces all the relevant losses. As is conventional, the series resistor Rs represents the accumulated series losses following the complete path of the current generated as far as the points of external connection. The current passes through the resistive semiconductor material (base and emitter) then also the resistance of the metal grid, the contacts and current collecting bus also contribute to the total series resistive losses.

A number of shunt resistive losses are identified, such as representing localized shorts at the emitter layer and perimeter shunts along cell borders.

Recombination is represented by the second diode with an ideality factor equal to two.Ideal diode has an ideality factor equal to one, but solar cell as no ideal behaviour so n1 can be calculated [5] and in that case is 1.036.

Now the relationship between current and voltage is:

$$I = I'_{sc} - I_{01}\left(\exp^{\left(\frac{V+IR_s}{V_T n_1}\right)} - 1\right) - I_{02}\left(\exp^{\left(\frac{V+IR_s}{V_T n_2}\right)} - 1\right) - \frac{V+IR_s}{R_{sh}} \quad (5)$$

A model of polycrystalline (roof tile) module was build up from connecting 18 solar cells, each represented by an individual 2-diode model.

In Spice, the current generator is controlled by using two series connected voltage sources where 2 parameters have to be specified: the value of the amplitude and the area of the device.

The amplitude of both DC sources represents the value of density of photocurrent (A/mm^2) generated by the cell simulating in the (4) the spectrum of the sun measured from the outdoor experiment. The DC sources control a voltage source, in this second device (the voltage source voltage controlled) the area of the cell can be specify. In this way two different values of radiation can be simulated in a single cell (ie the cell has an area of 156.25 mm2, we can, for instance, simulate half area of the cell under 1000W/m2 and the rest area under shadow with 163 W/m2 – see the figure 2). This 2 DC voltage source are connected in series and the output voltage controls the current source that represents the photocurrent generated by the sun in response at the sun's spectrum. In this way the module can be simulated also in case of partial shadow with particular shape.

To represent the dependence from the temperature each diode will have its own saturation current value to be able to simulate different value of temperature in a module using (2) and (3). The value of series resistance and the shunt resistance can be extrapolated from the measurement. All the cells are connected in series and follow the data sheet for the module with just one bypass diode for the module.

Some simulations were run and the result are showed in the picture below

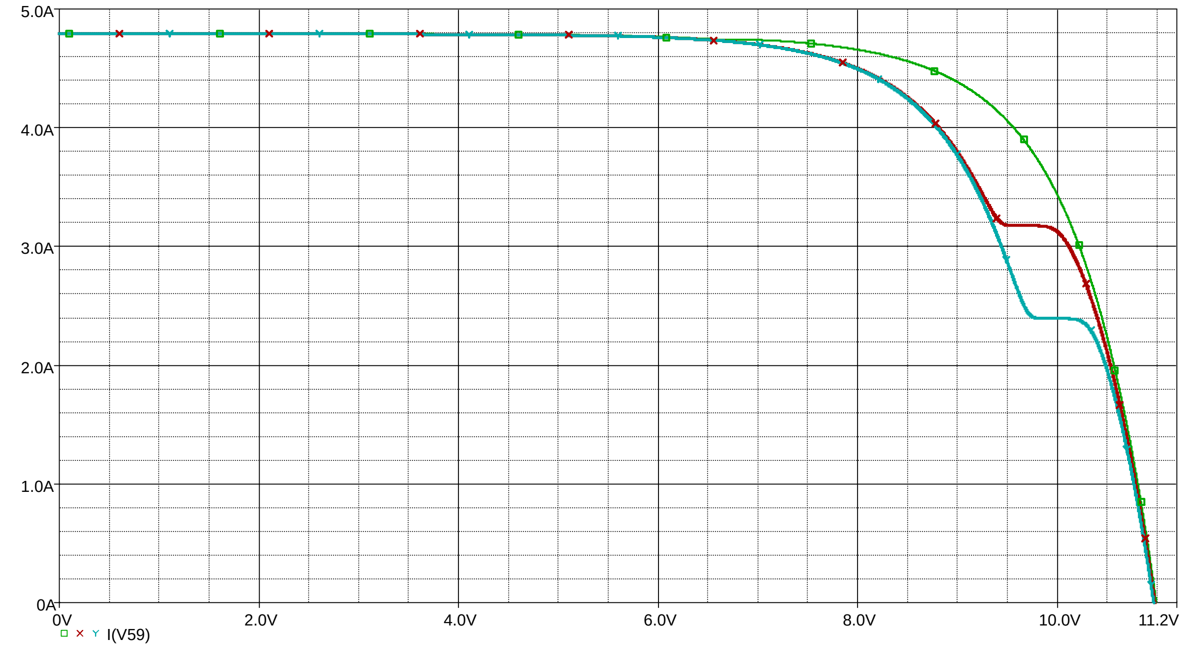

Figure 2: module simulated in different condition. Green line (square): total area of the module receives 1000 W/m^2; Red line (x): all the module receives 1000W/m2 but one cell for half of its own area has 1000 W/m^2, the other half just 163 W/m^2; Violet line (diamond): all the module receives 1000W/m^2 but one cell for half of its own area has 1000 W/m^2, the other half just 0 W/m^2

EXPERIMENT

On the roof of the James Weir Building at Strathclyde University, Glasgow, the test PV system has been installed. The PV array comprises eight series connected polycrystalline modules from Solar century (C21-P40), roof mounted at an angle of 40°, with integrated 'thru-flow' ventilation. At STC the capacity of the array is 320 Watts.

Weather conditions are monitored continuously using a data logger mounted close to the array. The data logger monitors solar irradiance (direct and diffuse), the back surface temperature of the tiles, ambient temperature. Module voltage and current monitoring is undertaken and controlled using a Kepco power supply.

The solar data is measured using a pyranometer (CM 11) to measure the global radiation on the horizontal plane; from a pyranometer with shadow ring (CM 11) to measure the diffuse radiation; and a spectroradiometer, MS 700, mounted with the same angle to the horizontal as the roof in order to measure the solar radiation as a function of wavelength (i.e. the solar spectrum).

Tile temperatures are measured using K-type thermocouples, stuck to the backside of each tile. For the ambient temperature measurement, the thermocouple is protected by a radiation shield.

Due to technical problems with the Kepco power supply, the instrument now is programmed with an analogue signal from the data logger able to generate an analogue sawtooth from -10 Volt to 10 Volt.

The power supply will be used to validate the model of the module, it is connected to the module and works like a voltage source reading the current, both values are recorded by the data logger [6].

Figure 3: experimental outdoor testing

CONCLUSION

Real operating conditions involve changing irradiance and temperature and also often partial shading of the array. There is also likely to be some temperature variation across the array, and some differences in the intrinsic quality and efficiency of individual cells and modules.
These effects combine to give a degree of mismatch between the cells and modules within the array that is time varying.
In this paper a model for the photovoltaic module under real operating conditions was proposed. Every cell has its own temperature, useful to simulate hot-spot problem, and also different values of radiation can be set in the area of each cell. In this way real operating conditions can be simulated.
Unfortunately, due to technical problem, in this paper any experimental data is presented.

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ECONOMICAL ASPECT AND ENVIRONMENTAL IMPACT OF RENEWABLE TRIGENERATION IN URBAN AREAS SCHARNHAUSER PARK CASE STUDY

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ABSTRACT

In this study, a biomass powered tri-generation system integrated in an urban area is described and both its economical aspect and environmental impact are assessed.

Scharnhauser Park (Germany) is a modern urban settlement in which low-consumption buildings and renewable technologies are demonstrated. Through EU-funded research projects CITYNET and POLYCITY [1, 2], a significant part of on-site energy flows is measured and monitored. The core of the energy supply system is an 8 MW_{th} wood-fired ORC co-generation plant. The residual heat from the electricity generation process amounts to 30 GWh/a and is fed into a 13 km long district heating network. The plant is operated in heat-driven mode and its power can be adapted flexibly to the demand of the urban quarter. Additionally, more than 40 kWp of photovoltaic equipment have been installed in the area.

Finally, a decentral 105 kW absorption chiller has been connected to the district heating in order to provide cooling to a 3 500 m² office building.

ENERGY SYSTEM DESCRIPTION

Urban area

Scharnhauser Park (Germany, 48.72°N - 9.27°E) is a modern urban settlement in which low-consumption buildings and renewable technologies are demonstrated. The site offers opportunities of public spaces, 40 000 m² of industrial area, 90 000 m² of mixed commercial area as well as a wide range of housing types for more than 7 000 inhabitants.

Biomass ORC power plant

The core of the energy supply system is an 8 MW_{th} wood-fired ORC co-generation plant.

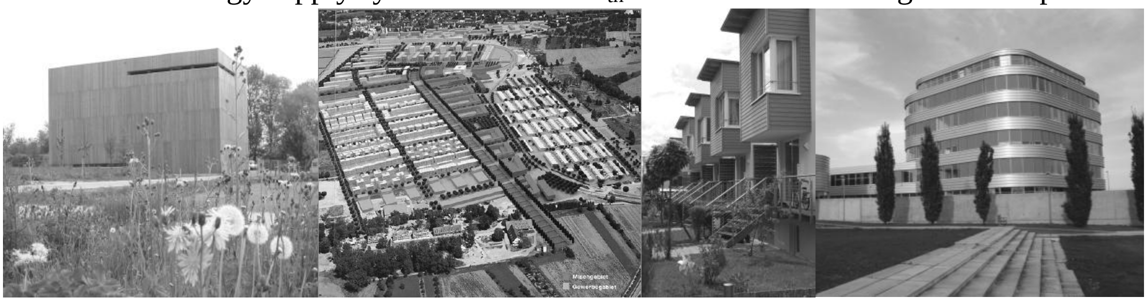

Figure 1- Scharnhauser Park – CHP / Aerial view / dwellings / Elektror office building

Component	Physical quantity	Value	Unit
Biomass furnace	heat transfer rate	8 000	[kW]
Wood storage	capacity	1 400	[m³]
Fuel consumption	design point volume flow	200	[m³/d]
Power ORC	heat transfer rate (input)	6 356	[kW]
	heat transfer rate (output)	5 300	[kW]
	electric output	1 000	[kVA]
Feed pump	electric input	61	[kW]
Vacuum pump	electric input	5	[kW]
Auxiliary power furnace	electric input	25	[kWh(el)/MWh(th)]
Annual wood comsumption	annual mass flow	43 000	[tonnes/a]
Fossil fuel saving		38 000	[MWh/a]
CO2 reduction		7 000	[tonnes/a]

Table 1 - Biomass cogeneration plant specifications [2]

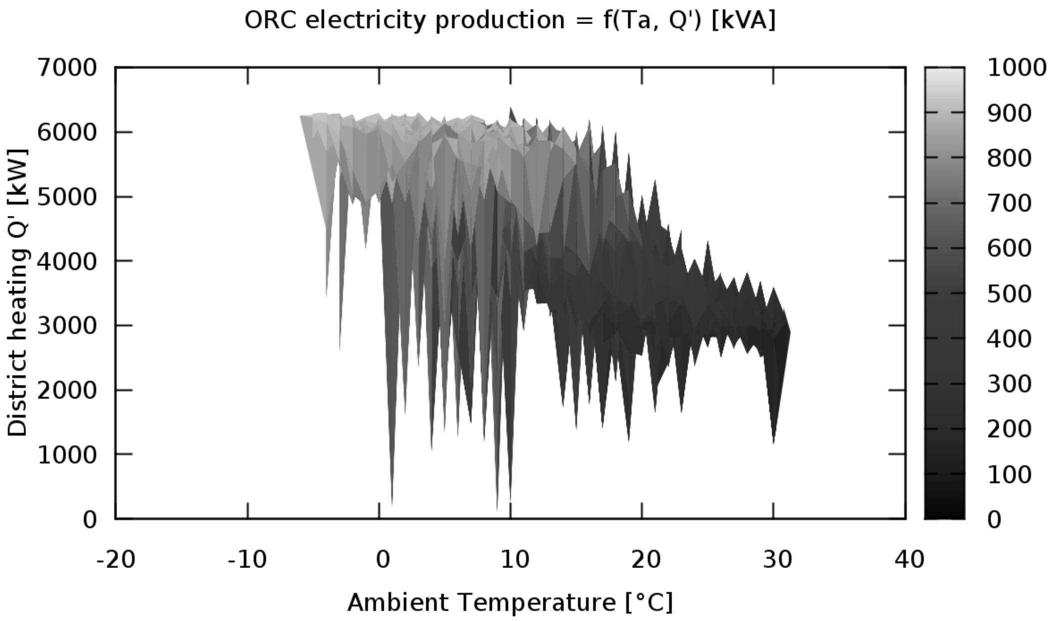

Figure 2- ORC electricity production vs ambient temperature T_a and district heating heat transfer rate $\dot{Q}$ – 8760 hourly values of 2008

The carpet plot is ill-shaped because T_a and $\dot{Q}$ are not independent variables: the heat-driven power plant only delivers its full power when requested, i.e. when outside temperatures are low and heat demand is sufficient. This graph clearly shows that the ORC process only reaches its maximal power in winter cases, when more than 5 MW heat are delivered to the district heating network.

One suggested way to improve electricity production in summer cases is to connect decentral absorption chillers to the district heating system.

District heating network

The residual heat from the electricity generation process amounts to 30 GWh/a and is fed to the 13 km long district heating network.

District heating network	Physical quantity	Value	Unit
Annual heat transfer	heat transfer	29.5	[GWh/a]
Maximum heat transfer rate	heat transfer rate	16	[MW]
Design supply temperature	water temperature	85	[°C]
Design return temperature	water temperature	55	[°C]
Average mass flow	mass flow	103	[m³/h]
Maximum mass flow	mass flow	460	[m³/h]
Supply pipes total length	length	13	[km]

Table 2 – Design parameters of district heating network

The plant is operated in heat-driven mode and its power can be adapted flexibly to the demand of the urban quarter.

Photovoltaic modules

More than 40 kW_p of crystalline silicon photovoltaic modules has been installed in the area.

Generator type	Energy yield [kWh/kWp.a]	Method	Reference
Facade	639	(measured)	[internal]
Horizontal	810	(simulated)	[4] [5]
Tilted (30°)	910	(simulated)	[4] [5]

Table 3 – PV-generator energy yield

Absorption cooling machine (ACM)

A decentral 105 kW absorption chiller has been connected to the district heating in order to provide cooling to a 3 500 m^2 office building.

Yazaki WFC-SC 30	Physical quantity	Value	Unit
Nominal power	thermal power	105	[kW]
Coefficient of performance	ratio	0.65	[-]
Generator level	temperature	78.0→73.7	[°C]
Heat sink level	temperature	27.0→30.6	[°C]
Evaporator sink level	temperature	15.0→9.0	[°C]

Table 4 – Absorption chiller specifications

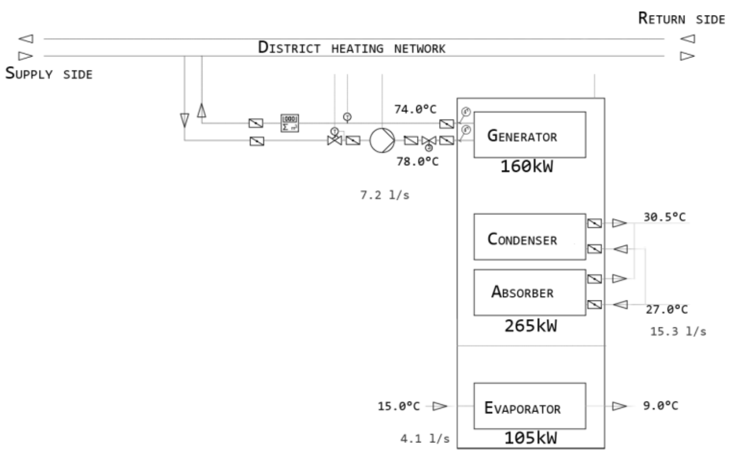

Figure 3 - Yazaki WFC-SC 30 connected to the district heating network

ANALYSES

Primary energy analysis

COP based comparisons of thermal-driven and vapour-compression chillers (CCM) are not satisfying, since they do not take into account that these systems use energy of different qualities. Studies should take either exergy or primary energy requirements under consideration in order to reflect the associated environmental impact.

In (1) and (2), the required amount of primary energy to provide 1 MWh of cooling with both systems is calculated.

$$\left.\begin{aligned} COP_{el} &= 3 \\ \eta_{el} &= 0.38 \\ PEF &= \frac{1}{\eta_{el} \cdot COP_{el}} \end{aligned}\right\} \Rightarrow PEF_{ccm} \approx 0.88 \frac{MW_{pe}}{MW_{cooling}} \qquad (1)$$

0.88 MWh of primary energy is required in order to provide 1 MWh of cooling with a vapour-compression chiller, when driven by German electricity grid [6].

$$\left.\begin{aligned} COP_{el} &= 7 \\ COP_{th} &= 0.65 \\ \eta_{tot}^{(CHP)} &= 0.88 \\ \eta_{el}^{(CHP)} &= 0.16 \\ \eta_{el}^{(PP)} &= 0.38 \\ PEF &= \frac{1}{\eta_{el} \cdot COP_{tot}} \\ \frac{1}{COP_{tot}} &= \frac{1}{COP_{th} \cdot x} + \frac{1}{COP_{el}} \\ x &= \frac{\eta_{tot}^{(CHP)} - \eta_{el}^{(CHP)}}{\eta_{el}^{(PP)} - \eta_{el}^{(CHP)}} \end{aligned}\right\} \Rightarrow PEF_{acm} \approx 1.61 \frac{MW_{pe}}{MW_{cooling}} \qquad (2)$$

These calculations are based on Directive 2004/8/EC [7], being slightly modified to take the electricity consumption of the auxiliary pumps and cooling tower into account.

In the case of Scharnhauser Park 1.61 MWh of primary energy are required in order to provide 1 MWh of cooling with an ACM connected to the district heating network. This represents approximately 84% more than shown in (1). The parameter that varies the most from one energy system to the other is $\eta_{el}^{(CHP)}$. All other parameters being equal, the same primary energy requirements for ACM and CCM will be achieved with an $\eta_{el}^{(CHP)}$ of 30%, while state of the art combined-cycle CHPs can reach 60%.

CO_2 savings

Even though the heat driven chiller requires more primary energy than the conventional one, its energy input derives from a biomass furnace with a much lower carbon footprint than the average German power plants: a life cycle analysis has shown that the biomass CHP releases 5 times less CO_2 (110 g/kWh vs 550 g/kWh) [8].

Therefore, producing one MWh of cooling will release approximately 60% less CO_2 with an ACM than with a CCM.

Cooling costs

Costs	Capital [€/kW]	Extra [€/kW]	Maintenance [€/kW.a]
Absorption	420	830	30
Compression	220	108	37

Table 5- Costs related to absorption and compression chillers

Energy costs		
electricity	150	€/MWh
heat	20	€/MWh
water	1.8	€/m³

Table 6 - Energy costs

This raw data sum up to cooling costs of 145 €/MWh for the ACM, and 92 €/MWh for the CCM. The European Union funded 35% of the capital costs, which led to cooling costs of 120 €/MWh for the heat-driven alternative.

Heat demand

After refurbishment, the specific heat demand of the area has been lowered by 30% in comparison to German standards [9].

U value [W/m².K]	Residential			Offices		
	Standard	SHP*	Savings [%]	Standard	SHP*	Savings [%]
Facade/Wall	0.45	0.3	33	0.45	0.17 - 0.26	53
Roof	0.25 - 0.3	0.23 - 0.31	2	0.3	0.1 - 0.21	48
Ground/Floor	0.4 - 0.5	0.26 - 0.36	29	0.45	0.16 - 0.38	50
Windows	1.6 - 2.3	1.2	25	1.6 - 2.3	1.2 - 1.24	24

*SHP Scharnhauser Park

Table 7- Heat transfer coefficients of buildings envelopes [10]

CONCLUSIONS

More than 80% of the heat demand is delivered by renewable energy sources, while 50% of the electricity demand is covered by the combination of PV systems and ORC power plant.

The thermal driven chiller is planned to ensure CO_2 emissions savings of ~60% in comparison to conventional compression chillers, at a cost of 120 €/MWh (compared to 90 €/MWh with CCMs).

Under the following conditions, economic break-even can be achieved:

– Electricity price should be significantly higher than heat price (ratio>10)

– Auxiliary consumption must be kept at a minimum.

- System must be used its nominal power as often as possible. Additional thermal storage on the chilled side (either as a water tank or activated parts of the building) allows to shave the demand peak, therefore reducing the required design cooling power. A compromise must be achieved between increased capital costs due to thermal storage and reduced capital costs due to smaller design power.
- Most importantly, a low cost heat-sink should be available: the heat transfer rate ratio between heat rejection and cooling is approximately 2.5. The heat sink therefore has a significant influence on both cooling cost and primary energy requirements.

Biomass powered tri-generation in urban area is a promising technology and an efficient way to reduce primary energy requirements as well as CO_2 emissions. High electricity prices, the availability of a low cost heat-sink, very careful design and a good integration into the energy system are needed in order for this technology to achieve economic break-through without incentives.

ACRONYMS

ACM	: Absorption cooling machine, heat-driven chiller
$\eta_{el}^{(CHP)}$	: Electrical efficiency of a cogeneration plant
EU	: European Union
CCM	: Compression cooling machine, vapour-compression chiller
CHP	: Combined heat and power, cogeneration plant
COP	: Coefficient of performance
ORC	: Organic Rankine Cycle

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DEVELOPMENT OF A HIGH PERFORMANCES PV-THERMAL FLAT PLATE COLLECTOR

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ABSTRACT

Recent increased interest in the development of highly energy-efficient buildings is strongly related to the world-wide efforts to reduce greenhouse gas emissions and energy costs. One of the principal goals is to develop the Building Integration of Photovoltaic (PV) components (BIPV). Integration of PV components may submit them to a higher heating risk in comparison with non integrated configuration. Electrical performances of PV modules decrease with increasing operating cell temperature (effects are usually in the range of -0.5%.K^{-1} to -0.2%.K^{-1} for the different PV-cell technologies). Therefore, this leads to a decrease of their electrical efficiency if there is no specific solution or component design. In this context, the design of hybrid collectors as Photovoltaic-Thermal (PV-T) system can offer a solution to control (or support) satisfying operating conditions for electrical conversion and to recover a part of collected energy usually wasted. Indeed PV cells operate as a thermal absorber. If they are cooled by water (or air) circulation a part of the collected thermal energy can be recovered for domestic hot water or space heating.

Facing this complex hybrid solar concept, the global aim of our study is to develop a very efficient PV-T flat plate collector. Focusing on heat transfer between PV cells and fluid and also optical properties of materials, a first small collector has been built and tested. Results of those tests are presented in this paper and have been compared to one of a mature PV-T covered and water based product existing on the market. Grounded on these first steps, different ways of optimization of the designed PV-T collector are presented.

INTRODUCTION

A photovoltaic-thermal collector is a hybrid collector in which PV-cells are integrated in the absorber plate of a thermal collector and are cooled by water (or air) circulation. Many configurations of PV-T collectors have been developed during last years and differ to each other according to the nature of the cooling fluid (water [1,2], air [3] or bi-fluid [4]) and to the type of absorber (flat plate [1], concentrator [2] or bi-facial [5] for example).

In a previous paper [6], yearly system simulations have been carried out using test results on existing PV-T collectors. Based on these results, it has been decided to focus our work on single glazed flat plate PV-T collectors based on water circulation. In this collector concept, Silicon crystalline PV cells operate as a thermal absorber. The presence of an additional glass cover reduces to some extent the optical performance of the PV module but increases strongly the thermal performances of the collector, leading to a better overall energy conversion in comparison to an unglazed collector.

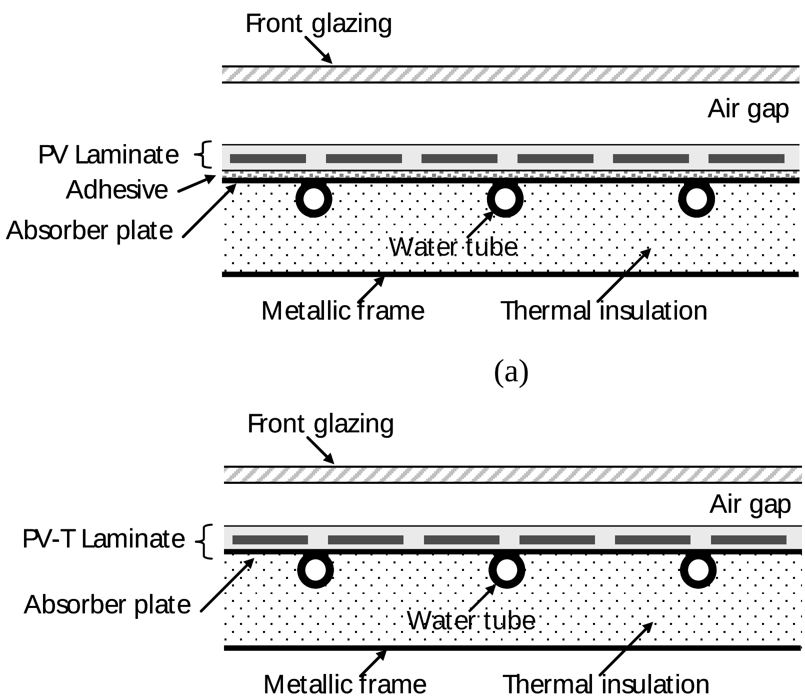
As reported by Zondag in his review on flat-plate PV-T collectors [7], one key point for the development of PV-T collectors concerns the heat transfer between PV cells and fluid. In fact, higher heat transfer results in a smaller temperature gradient and therefore in a lower PV-cell temperature. That is the reason why a good thermal contact between PV cells and absorber plate increases both thermal and electrical efficiency.

METHOD

A standard PV module is made up of different layers (highly transparent front glazing, encapsulant material, PV cells, and a back sheet) which are laminated together.

The most basic approach to manufacture a flat-plate PV-T collector is to glue such a standard PV module to the absorber of a commercial thermal collector (see Figure 1a). However, this method has some drawbacks: The glue increases the thermal resistance and, even worse - when air enclosures in the glue layer are significant, the thermal resistance between the PV laminate and the absorber may become too large for good thermal performance. Large reflection losses can be also observed due to the white Tedlar® layer used at the back side of standard crystalline PV module.

A more advanced technique which we are following is to laminate the transparent front glazing, encapsulant material, PV cells and an absorber together in one step as presented in the Figure 1b (whole package lamination).



(b)

Figure 1: Flat plate PV-T collector. (a) Gluing of pre-laminated PV module on metal absorber. (b) Direct lamination of PV module component on a metal absorber

The aim of the 'whole package lamination' is to minimise the thermal resistance between the PV-cells and the metal absorber. In fact, instead of three different layers (encapsulant, Tedlar® and adhesive) normally used in the case of the gluing method, only one is necessary in the case of the whole package lamination. The heat transfer coefficient between PV cells and metal absorber is given by the equation 1 in the case of gluing and by the equation 2 in the case of direct lamination:

$$h_{PV-abs} = \left(\frac{e_{EVA}}{\lambda_{EVA}} + \frac{e_{Tedlar}}{\lambda_{Tedlar}} + \frac{e_{Glue}}{\lambda_{Glue}} \right)^{-1} \tag{1}$$

$$h_{PV-abs} = \left(\frac{e_{EVA}}{\lambda_{EVA}} \right)^{-1} \tag{2}$$

where e_i is the thickness and λ_i the thermal conductivity of materials. According to the parameters of EVA [8] (e_{EVA}=500µm, λ_{EVA}=0,35 W/mK), the heat transfer coefficient between PV cells and absorber obtained for whole package lamination is 700 W/m²K. De Vries reported in his PhD thesis that the heat transfer coefficient between PV cells and absorber may be much lower than in reality, due to possible enclosing of air bubbles into the glue layer. He determined a value of 45 W/m².K [9].

A high thermal resistance has an impact on the value of the collector efficiency factor F'**,** as presented in the equation 3 [10]:

$$F' = \frac{1/U_L}{W\left(\frac{1}{U_L\left(D + (W - D)F\right)} + \frac{1}{W.h_{PV-Abs}} + \frac{1}{\pi D_i h_f} \right)} \tag{3}$$

where U_L is the thermal losses coefficient of the collector, W the distance between two tubes, D the diameter of a tube, F the collector factor and h_f the heat transfer coefficient from tube to fluid. The collector efficiency factor F´ is related to the thermal efficiency of a collector through the formula given by the equation (4):

$$\eta_{Th} = F'\left(\tau\alpha - U_L . \frac{(T_m - T_{amb})}{G} \right) \tag{4}$$

where τ is the top glazing transmission, α the PV-T plate absorption, T_m the mean temperature, T_{amb} the ambient temperature, G the incoming radiation per m² and F' the collector efficiency factor.

Using the following parameters for PV-T collector (U_L=6,5 W/m².K, W=0,1m, D=0,01m), the collector efficiency factor has been calculated for both techniques. Results are presented in the Table 1.

	Absorber	**Absorber thickness**	**F´ coefficient**
Gluing of PV panel	Cu	0,2 mm	0,89
Direct lamination	Cu	0,2 mm	0,90
	Cu	0,5 mm	0,92

Table 1: Properties of three absorber types and corresponding collector efficiency factors for both concepts.

According to the calculation, the direct lamination of PV module components onto a metal absorber results in a higher collector efficiency factor. In this case, a good thermal-contact between the thermal absorber and the PV module can be achieved and therefore both the electrical efficiency and the thermal efficiency can be raised as mentioned by Van Helden [8].

EXPERIMENT

A metal absorber , PV encapsulant materials, Multi-Si PV cells and transparent cover have been laminated together in a vacuum laminator using standard PV lamination conditions in order to obtain a first functional PV-T laminate The ratio between the solar cell active area and the whole thermal absorber surface (packing factor) is about 0,5 only in this first small experimental PVT-collector. The dimensions of the thermal absorber are 64,5 cm x 48,5 cm.

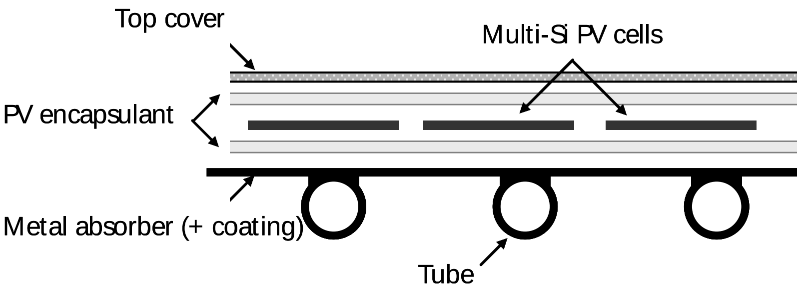


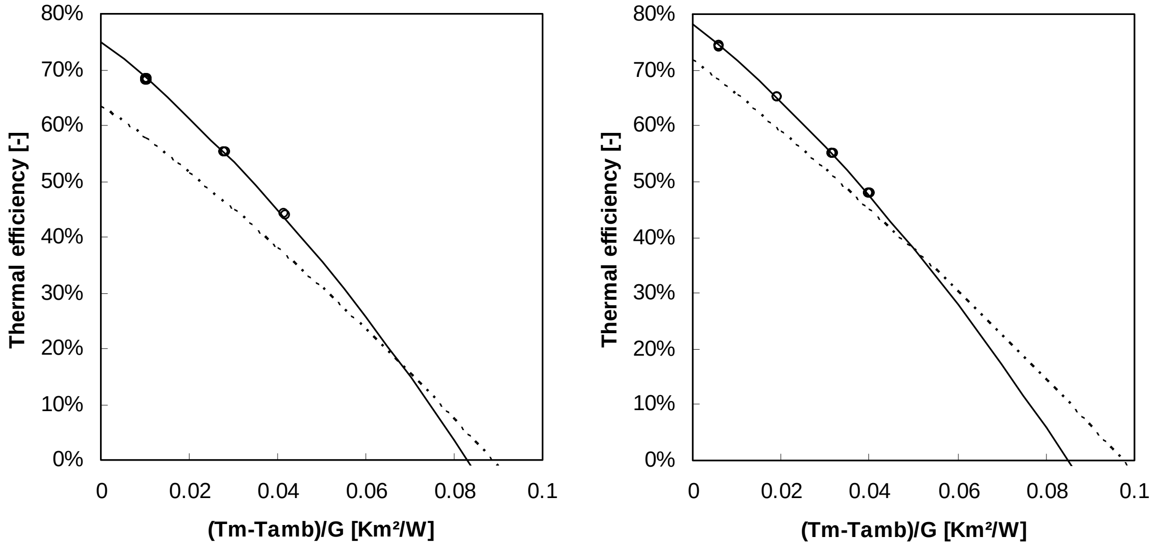
Figure 2: Lamination of PV components on metal absorber.

No delamination between PV encapsulant and metal absorber has been observed after the lamination in the limited tests carried out with this experimental absorber. The electrical function of the PV-T laminate has been tested. Nominal efficiency related to the total area is lower than for a comparable standard PV module, mostly due the lower packing factor of the experimental PV-T laminate.

RESULTS

In order to investigate this first experimental PV-T laminate from a thermal point of view, a small single glazed PV-T collector has been built using the PV-T laminate as presented in the Fig 1b. The outer dimensions of the experimental collector are 74,5 cm x 58,5 cm x 12 cm. The front glass used is Anti Reflexion coated and has a transmission factor of 0,93. The thermal insulation on the back of the absorber is 6 cm thick.

Thermal and electrical measurements on this small PV-T collector were carried out in the indoor testing facility with solar simulator according to EN12975 [11]. The thermal efficiency curve has been measured at PV maximum power point condition (see Fig. 3a) and in PV open-circuit mode (see Fig. 3b). Results of the tests are compared to a commercially available, single glazed water PV-T collector which was also measured at Fraunhofer ISE [6].



(a) *(b)*

Figure 3: Thermal efficiency curve (a) with PV extraction (Maximum Power Point) ; (b) without PV extraction (open-circuit). Dashed line: commercially available sheet and tube PV-T collector, dots: measurements point for small laminated experimental PV-T collector, full line : corresponding polynomial fit.

In both cases, the thermal efficiency of the experimental collector is higher than for the commercially available collector. These results are thus quite promising for further developments of the PV-T collector already started. At this stage, it does not make sense and it is not justified to keep on making more detailed comparison of the two collectors. One has to kept in mind that our first hybrid collector is very small and that the different components (type of solar cells, size, front glazing, collector casing, back insulation) of the two collectors are too different. Our main conclusion is that we are able to handle the lamination process to an extent that we can continue our experimental development work.

CONCLUSION

The development of PV-Thermal collector may become an important issue in the context of building integration of photovoltaic components (BIPV) and high energy efficient buildings. In a PV-T collector the part of incoming radiation usually wasted into heat can be used, leading to a better overall efficiency of solar energy.

The global aim of our study concerns the development of a high performance PV-Thermal flat plate collector based on water circulation. Focusing on the heat transfer between the PV cells and the fluid, a first small experimental collector has been built using the concept of whole package lamination in order to obtain a better collector efficiency factor F´.

Electrical and thermal tests have been made at Fraunhofer ISE on this first small experimental collector and compared to an existing commercial PV-T collector. Regarding the overall efficiency, test results show that our first collector has better performances than the existing product. To summarize, the investigations show that the direct lamination of PV module components onto a metal absorber may provide better thermal and electrical results than the gluing method.

Further optimizations concerning the electrical insulation, PV encapsulant material and PV cells may increase the performance and will be implemented in our next prototype.

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EVALUATION OF STANDARD SOLAR COMBI PLUS SYSTEMS FOR SMALL SCALE APPLICATIONS

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ABSTRACT

Small sorption chillers are available on the market for the installation in solar assisted domestic hot water and space heating plants. Their use in office and residential buildings could potentially lead to a significant mitigation of the primary energy consumption and therefore of the CO_2 production for air conditioning. However, the economical sustainability of this technology shows significant hurdles due to the costs of the investment and of the plant's design. The latter could be reduced if standard system configurations were considered for installation, as it actually happens in the case of ordinary domestic hot water plants.

The presented work concerns with the analysis of the methods and the results elaborated within the IEE programme SolarCombi+ project. The aim of this project is to take small scale sorption chillers and identify and promote standardised systems for combined solar water, space heating and cooling production up to cooling loads of 20kW. Accelerating and smoothing the market entry of those systems, the project contributes to achieving energy policy goals of the EU and supports the diffusion of a technology where a group of European enterprises has a favourable starting point for international leadership.

INTRODUCTION

The air conditioning market both for heating and cooling is expanding rapidly in Europe as a result of increasing comfort expectations; almost 49% of the total energy consumption in Europe is employed for buildings' heating and cooling [1]. About 90TWh of electrical energy are used for summer air conditioning in EU15, the biggest markets being Spain (33TWh), Italy (27TWh) and France (10TWh) [2]. For this reason much effort in the EU energy policy [3] is devoted to the implementation of renewable energies for the management of the buildings' thermal loads [4].

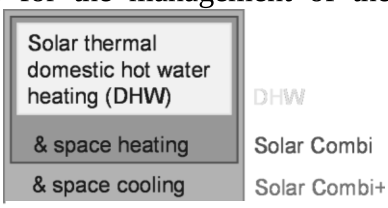

Figure 1 – Solar combi+ system explanatory scheme.

Already today, solar thermal energy for domestic hot water (DHW) preparation and for space heating is a developed technology with a high penetration rate in some countries, as Germany and Austria. Solar driven sorption chillers were up to now only manufactured in the high power range (>100

kW_{cold}). Today, machines with rated power between 5 and $30kW_{cold}$ are available to be included in solar combi+ systems (see Figure 1) for small applications, which make up for the major part of heating and a constantly growing part of cooling demand. Costs of the investment and lack of experience of designers and installers are the most important barriers for a broad diffusion of solar combi+ applications. The assessment of standard system configurations might reduce considerably the design effort for single applications and is the basis for the development of package solutions possibly manufactured at a large scale level.

The presented paper concerns with the analysis of the methods and the results elaborated, within the IEE programme SolarCombi+ project, in the process of evaluation of standard solar combi+ configurations. Aim of the process is the definition of a reduced number of system configurations, which can be promoted and applied similarly to the standardized systems for domestic hot water production, which work reasonably well in common applications and are independent of the specific products considered.

METHOD

The study started from an extensive campaign of numerical simulations carried out in TRNSYS on a basic plant configuration detected through market and technical analysis. Each industrial partner of the consortium opted for one of the two plant layouts represented in Figure 2, which suites best the working features of its chiller.

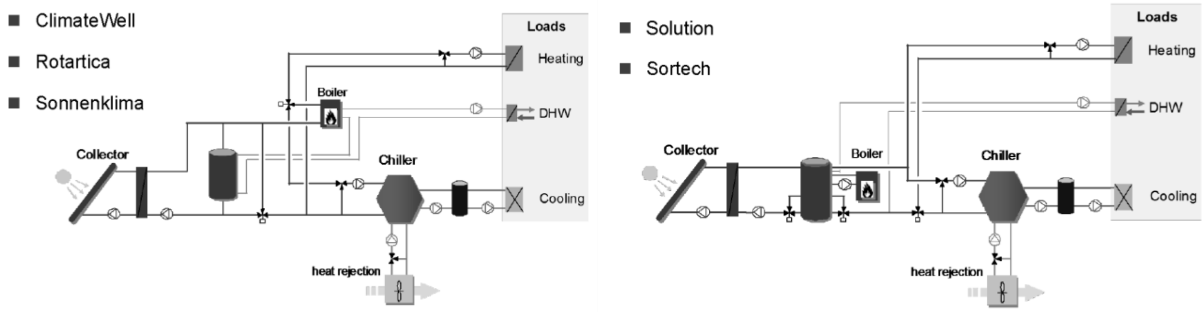

Figure 2 – Solar combi+ layouts selected by the industrial partners.

Within the basic systems, a number of parameters were varied; so called “fixed”, “semi-fixed” and “free” parameters were identified and a range of values was selected for each one. As fixed parameters of the analysis were taken:

- Geographical location of the solar combi+ plant
- Building in which the solar combi+ plant is installed
- Chiller brand.

Three locations were chosen, representative of different climatic areas between the south and mid Europe, with fairly different needs in terms of heating and cooling demands [5, 6]; in particular the climatic conditions in Naples (south Italy), Toulouse (south France) and Strasbourg were considered. Three small scale applications with different specific heating and cooling requirements were also selected: one office and two residential buildings (see Table 1). The size of the building was adapted to the Reference Power of the specific chiller Power (power delivered at the rated generator temperature and condenser/evaporator temperatures given by the heat rejection/distribution technologies) to allow a fair comparison of the chillers’ performance.

Simulations were performed for each of the five commercial chillers studied. The three parameters above were named fixed since they cannot be settled by the manufacturer/designer. On the contrary technology related figures might be negotiated to some extent. Within this category were considered:

- Collectors' type (flat plate and evacuated tube collectors)
- Heat rejection system's type (wet cooling tower, dry air cooler and hybrid cooler)
- Chilled/Warm water distribution system (fan coils and chilled ceiling).

Fan coils were simulated with regard to all the applications, while chilled ceilings were only considered in case of residential building.

	Office		Avg. consumption residential		Low consumption residential	
	Heating (kWh/m2/y)	Cooling (kWh/m2/y)	Heating (kWh/m2/y)	Cooling (kWh/m2/y)	Heating (kWh/m2/y)	Cooling (kWh/m2/y)
Strasbourg	69	34	-	-	-	-
Toulouse	34	50	46	6	25	6
Naples	9	81	21	18	9	18

Table 1 – Thermal loads relative to office application, average and low energy consumption residential buildings. Thermal loads for given application change as a function of the climatic conditions

Finally, collectors' area and warm water storage volume were considered as free parameters of the analysis. Even in this case however, constraints were decided related to economical and technical performance of the solar combi+ system:

- Collectors' area between 2 and 5 $m^2/kW_{Ref.\ Pow.\ cold}$
- Warm water storage volume between 25 and 75 $l/m^2_{collectors'\ area}$

The collectors area was scaled with regard to the Reference of the single chiller. A large number of performance, environmental and economical figures were evaluated for about 2500 simulations. Among those, four were evaluated as the most interesting for the assessment of the standard system configurations:

- Total solar fraction
- Total electrical efficiency
- Primary energy saved per year
- Primary energy saved per year and per collectors' area

The first two are technical parameters. The total solar fraction accounts for the fraction of the total DHW, heating and cooling needs covered through the solar energy utilization. The total electric efficiency is the average ratio of the total thermal loads (for heating, cooling and domestic hot water) and the electrical consumption of the system (comprising chiller and solar circuits pumps, heat rejection system fans, etc). The primary energy saved is an environmental figure comparing energy needs of the conventional and the renewable solution, while the last two join techno-economical aspects to environmental ones. The primary energy saved per collectors' area accounts for the expense, in terms of system size, of the environmental benefit.

Each of the four parameters mentioned above was used to detect a "best" system layout: for each set of fixed parameters, the system configurations that maximize/minimize the given figure were determined in terms of semi-fixed and free parameters. A set of "good" solutions that allow for system environmental-technical performance close to the best was also established: the two solutions closest to the best for each set of fixed parameters were taken. This was done since the best environmental-technical solution might not be the most effective from the point of view of marketing-cost aspects.

RESULTS

Table 2 shows results of the simulations run with regard to a low energy consumption residential building placed in Naples and setup with chilled ceilings. Naples was selected for the discussion as the most severe environment in terms of cooling needs, due to its high summer temperatures and latent loads induced by the proximity of the sea. The table allows comparing the system performance if semi-fixed parameters are exchanged: flat plate (FP) and evacuated tubes (ET) collectors, wet cooling tower (WCT) and hybrid cooler (HC, dry air cooler + sprinkled water) are taken into consideration. Representative average values for the chillers investigated are presented. More data than the ones relative to the standard configurations selected (the three performing best) are reported to show the potential improvements achievable through well-designed systems.

	Coll. type	H.R. type	Coll. area [m2/kW]	Storage Vol. [l/m2]	TOT. Solar Fraction [%]	Electrical Efficiency [-]	Relative PE Saved [%]	Specific PE Saved [(kWh/year)/m2]	Specific CO_2 Saved [(kg/year)/m2]
1	ET	WCT	4.27	50	70	20.3	38	168	65
	ET	WCT	4.27	75	73	20.2	45	196	72
	ET	WCT	5.00	25	67	20.7	34	136	51
	ET	WCT	5.00	50	76	20.4	49	184	65
	ET	WCT	5.00	75	80	20.3	56	209	71
2	FP	WCT	4.27	50	64	20.1	29	128	46
	FP	WCT	4.27	75	68	20.0	36	157	46
	FP	WCT	5.00	25	61	20.3	23	86	54
	FP	WCT	5.00	50	70	20.0	39	146	54
	FP	WCT	5.00	75	75	20.1	47	175	54
3	ET	HC	4.27	50	68	20.2	35	153	38
	ET	HC	4.27	75	71	20.0	39	175	36
	ET	HC	5.00	25	68	20.6	35	127	41
	ET	HC	5.00	50	71	20.4	38	147	41
	ET	HC	5.00	75	77	20.3	50	192	43

Table 2 – Solar combi+ systems performance related to a low energy consumption residential building placed in Naples. Chilled ceilings used.

Once the collectors' area and the heat rejection system are set, the effect of changing collectors' type, from ET to FP (dataset 1 and 2), is a slight decrease of the solar energy utilization ability of the system (solar fraction decreases of around 5-10%). A much larger cut is noticed in terms of primary energy saved; reductions between 15 and 30% are obtained, depending on the warm water storage size. This is mostly due to the lower water temperatures that might be reached with the flat plates technology and that affect both summer (chilling) and winter system performance. Moreover, the storage size becomes more and more important as far as the collectors' return temperature drops.

Comparing the heat rejection systems (datasets 1 and 3), the effect of using a technology that is less effective than the wet cooling tower is a decrease of the performance of the entire plant. The drop of primary energy saved (6-8%) is not so significant as in the case of the solar collectors change; the trend is due on one side to the lower chillers overall performance when coupled with this kind of heat exchanger and on the other side to an higher electrical energy consumption for driving its fans.

Table 3 reports the results for the same chiller and application (Naples, low energy consuming residential building); in this case, the building is setup with fan coils as a distribution system for the chilled and heating water. Again a reduction of performance with regard to the first set of data shown in Table 2 is noticed (compare dataset 1 and 4), with a large effect mostly on the primary energy saved: decreases between 40-50% are reported on average. In general chilled ceilings are better suited since higher distribution temperatures (13-18°C) are employed and higher thermal inertia is obtained with respect to fan coil systems. On the other side, in some cases (e.g. refurbished buildings) fan coils are the only useful way for distributing heating and cooling.

	Coll. type	H.R. type	Coll. area [m2/kW]	Storage Vol. [l/m2]	TOT. Solar Fraction [%]	Electrical Efficiency	Relative PE Saved [%]	Specific PE Saved [(kWh/year)/m2]
4	ET	WCT	4.27	50	63	14.6	13	37
	ET	WCT	4.27	75	68	14.9	22	37
	ET	WCT	5.00	25	65	15.1	18	42
	ET	WCT	5.00	50	69	15.0	22	44
	ET	WCT	5.00	75	75	15.0	35	44

Table 3 - Solar combi+ systems performance related to a low energy consumption residential building placed in Naples. Fan coils used.

The last column of Table 2 and Table 3 represents the saved CO_2 per collectors' area: CO2 savings between 36 and 72 kg/year/m^2. In absolute terms, the CO_2 emissions avoided range between 2 and 4 tons/year in all studied cases. If one bears in mind that the residential building considered could be used by a 4 people family (0.5 to 1 tons CO_2 spared each), and that in a typical European city every inhabitant is responsible for around 8 to 10 tons of CO_2 emitted per year (transport and economical activities are considered in this figure), it can be noticed that the large scale diffusion of solar combi+ systems would lead to a significant reduction of the CO_2 emissions and therefore of the primary energy used. If only heating, cooling and DHW needs are regarded, primary energy savings between about 30 and 60% are reported in case of well-designed solar combi+ systems.

The comparison of the four datasets shows that the chilled ceiling, wet cooling tower and evacuated tubes collectors configuration allows the solar combi+ system to perform best from a purely technical and environmental point of view. This outcome is applicable to all chillers investigated, leading to a "best" standard system configuration, chiller independent. The simulations for the office application show the same result even when fan coils are considered for the distribution (wet cooling tower and evacuated tubes should be preferred).

Moreover, the best solutions are obtained when the biggest collectors area and storage volume are used. A change of the trend would be obtained for bigger system size (collectors' area larger than 7m^2/kW); nevertheless, the highest collectors areas were not investigated since they are not suitable for small applications.

When the solutions close to the best are regarded (i.e. the "good" ones), the effect of both exchanging technologies and varying components size is not clearly chiller and application independent. This aspect and cost issues – raw investment costs are considered together with cost of primary energy saved when planning a system - leave a certain freedom to the manufacturers when designing a standard system configuration. For example, in the case reported, the best technical solution is also the best economical one, if only the cost per saved primary energy is regarded. However, solutions that provide somewhat lower overall effectiveness (e.g. systems setup with a dry cooler or flat plats) might result also in significantly lower system costs.

CONCLUSIONS

The above discussion shows that standard configurations for solar combi+ systems might be determined, mostly chiller independent, which can be promoted and applied similarly to the standard systems for DHW with reasonably good results in typical/average cases.

The technologies and sizes of the components to be selected are clearly stated from a environmental-technical point of view. However, considerations about investment and costs per primary energy saved might lead to standard configurations that differ to some extent from the ones showed before.

Although well designed solar driven solar combi+ systems allow major reductions of primary energy usage and CO2 emissions, their cost is still significantly higher than the one of traditional air conditioning systems. The gap could be easily bridged through national funding schemes for the duration of the market startup phase and consequently to economy of scale.

ACKNOWLEDGEMENTS

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SIMULATION OF THE THERMAL INTERACTION BETWEEN A BUILDING INTEGRATED PHOTOVOLTAIC COLLECTOR AND AN AIR-SOURCE HEAT PUMP

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ABSTRACT

The number of buildings simultaneously equipped with air-source heat pumps and photovoltaic collectors is constantly increasing. Nevertheless, both systems are installed independently, and their thermal interaction is not taken into account. In addition to electricity, the photovoltaic collector produces heat which can be used to increase the temperature of the source of the heat pump, thus improving its COP (Coefficient Of Performance). Inversely, the fluid cooled by the external unit of the heat pump can be used to lower the operating temperature of the photovoltaic collector, improving its electrical efficiency.

This paper presents the methodology employed to simulate this kind of system and gives some results. The two systems (heat pump and photovoltaic collector) have been modelled and implemented in a thermal simulation tool of buildings. The resulting software enables to take into account the thermal interaction between each physical object (heat pump, PV collector and building) in a dynamic way. Simulations are run for the whole year and with a time step of one hour.

The aim of this development is to evaluate the increase of efficiency of the combined system installed in a building compared to the case where both systems are installed independently. The simulation tool is applied on a case study : a single family house with a living area of 135 m² and recently renovated. The south oriented roof gives enough space to install a 30 m² photovoltaic collector. The external unit of the heat pump is installed in the attic just beneath the PV collector, which preheats the incoming air. The results illustrate how the thermal interaction between both systems can be taken into account.

INTRODUCTION

The number of buildings simultaneously equipped with air heat pumps and photovoltaic collectors has been increasing. Nevertheless, both systems are installed independently, and their thermal interaction is not taken into account. In addition to electricity, the photovoltaic collector produces heat which can be used to increase the temperature of the source of the heat pump, thus improving its COP (Coefficient Of Performance). Inversely, the fluid cooled by the external unit of the heat pump can be used to lower the operating temperature of the photovoltaic collector, improving its electrical efficiency. This concept was investigated by [1] who designed systems in which the air heated by the PV collector is used as an air source for the heat pump. Other authors, as for instance [2], studied photovoltaic solar assisted heat pumps. The aforementioned researches gave interesting results, but didn’t show the annual performance of the whole system integrated into the building.

The aim of the paper is to present how the thermal interaction between a Photovoltaic – Thermal (PV-T) collector and an air-source heat pump integrated into a building can be modelled and the annual performance of the whole system integrated into a building calculated. The model of the heat pump and the PV-T collector will be presented first. The coupling and integration into a building simulation tool is also explained. The resulting simulation tool is finally applied on a case study.

MODELLING

Heat Pump model

The heat pump model, whose heat balance is illustrated in figure 1-a, is based on a steady-state empirical model and considers full load and part load conditions [3]. A first set of equations is used to calculate the full load performance, for non rated conditions. The empirical model uses parameters which are deduced from manufacturer data.

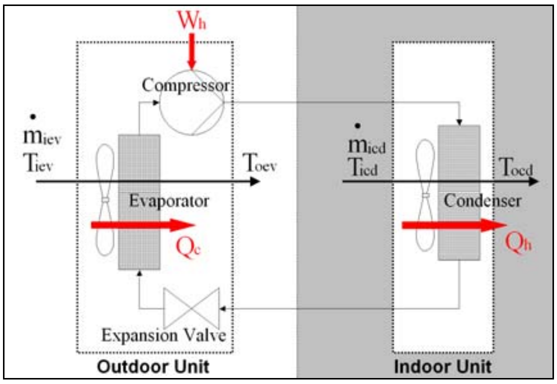


Figure 1-a
Heat pump energy balance

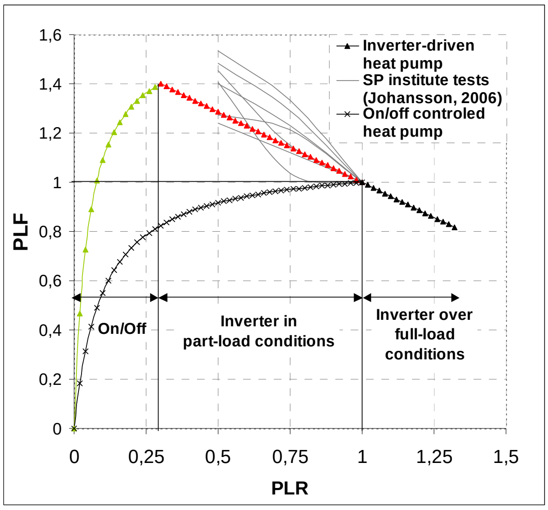


Figure 1-b
PLF versus PLR

The results calculated in full load conditions are then corrected to take into account the part load conditions, as illustrated in figure 1-b. The part load factor (PLF) is the ratio between the real COP (coefficient of performance) and the COP calculated for full load conditions. This PLF is function of the part load ratio (PLR), defined as the ratio between the heating load of the building and the heating capacity of the heat pump at full load conditions. The reader can find more details in [3], but we see in figure 1-b that, for part load conditions (PLR < 1), the PLF is higher for *inverter-driven* heat pumps than for *on-off* heat pumps. Moreover, for inverter-driven heat pumps, the fan speed varies according to the part load ratio. Performance degradation due to frost formation is also accounted for.

Photovoltaic-thermal model

The production of electricity by photovoltaic modules is calculated with the 1-diode model, assuming the collector is grid-connected. The electrical efficiency is function of the junction temperature, which is equivalent to the operating temperature of the photovoltaic cells (and assumed to be uniform over the whole PV collector). This junction temperature depends on the type of integration of the PV collector, and is given by a PV-T model, developed by [4].

The PV-T model is able to represent many different types of integration of the PV collector in the building envelope : integration without thermal interaction with the building envelope (PV collector installed on a flat roof for instance) ; integration without air gap (PV collector directly integrated into the wall, and placed against an insulation for instance); and integration with a ventilated air gap (see figure 2).

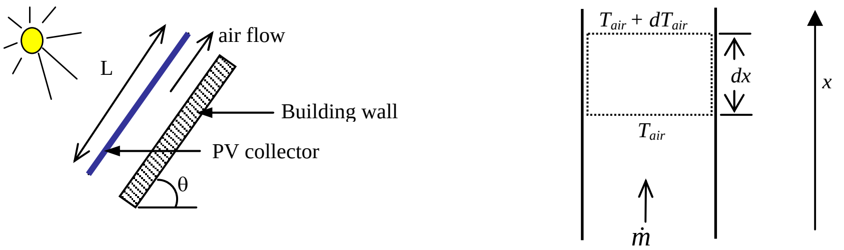


Figure 2 – PV-T model illustration

In the case with a ventilated air gap, a model has been developed to calculate the thermal efficiency of the PV-T collector. This model assumes steady-state conditions (the thermal mass of the PV collector is neglected) and a one-dimensional conduction heat transfer perpendicular to the collector surface. The bulk air temperature varies according to the direction parallel to the air flow, and the mean outlet air temperature $T_{air,out}$ is calculated according to the mean inlet air temperature $T_{air,in}$. The heat transfer rate q is deduced, $\dot{m}$ being the mass air flow rate and Cp the specific heat of the air:

$$q = \dot{m} Cp \left(T_{air,out} - T_{air,in} \right)$$

In case of natural ventilation, several studies concerning the air flow in an air gap heated by a PV collector have been carried out (see [5] for instance). A rather simple method avoiding to use CFD (Computational Fluid Dynamics) type calculations allows to predict the air mass flow rate : a one-dimensional loop analysis in which the buoyancy forces are balanced by the pressure drops due to friction yields a third order polynomial equation. The calculation of the mass air flow rate $\dot{m}$ and q are inter-dependant and the solution is solved by using the Newton method.

COUPLING AND INTEGRATION INTO A BUILDING SIMULATION TOOL

The thermal simulation tool of multi-zone buildings named COMFIE allows heating and cooling loads as well as temperature profiles in different zones to be evaluated. It is based on a finite volume method, reduced after modal analysis [6]. The program has been developed using an object oriented approach, allowing modules to be linked to the core of the program. These modules can represent building integrated photovoltaic systems or heat pumps for instance.

During the simulation process, parameters are exchanged at each time step (typically 1 hour) between objects and/or the core of the program (see figure 3). For example, the outlet air temperature of the PV-T collector is injected as an input in the Heat Pump. As the fan speed of the external unit of the heat pump varies according to the heat load (for inverter driven heat pumps), the Heat Pump module gives as output the external unit air flow rate. In some cases, this output can be used by the PV-T collector module for the heat balance.

Moreover, both models (PV-T and Heat Pump) interact at each time step with the building model. For instance, the heat balance of the PV-T collector is function of the temperature of the adjacent building zones, and the heat balance of the building can depend on the air flow rate of the external unit of the heat pump (if for instance the external unit is placed in the attic of a house).

If more complex interactions are to be simulated, iterative algorithms are employed at each time step. This would be the case for instance if, in addition to inject the air heated by the PV -T collector into the external unit of the heat pump, the system inject the air cooled by the external unit into the PV-T collector.

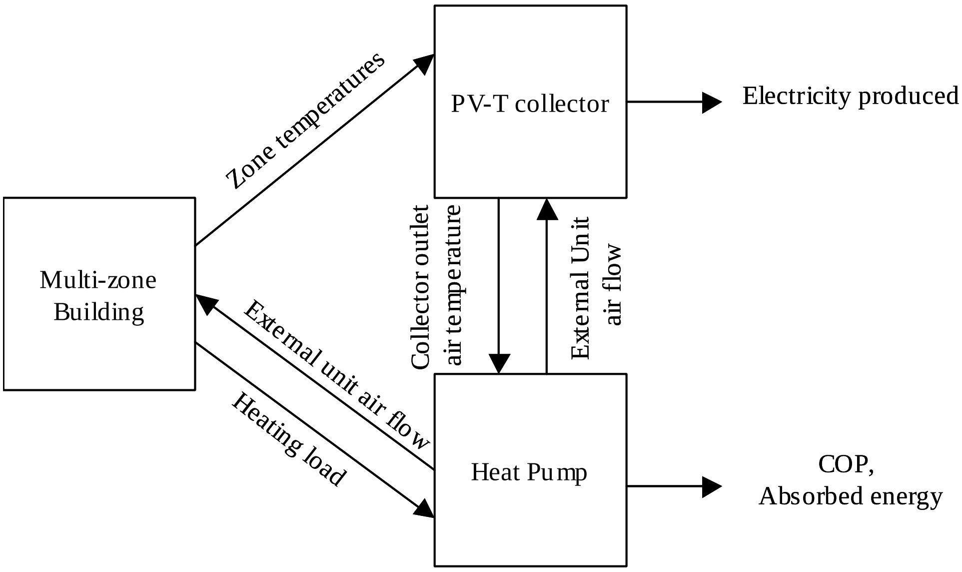


Figure 3 – Coupling of the different modules

The hourly output of the resulting simulation tool are the electricity produced by the PV collector, the absorbed energy and the COP of the heat pump. Theses results, once integrated over one year, will give the efficiency of the whole system. Other variables (hourly mean temperatures for instance) can also help to assess its performance.

CASE STUDY

Description

The building is a single family house with a useful area of 135 m², and occupied by 4 inhabitants (see figure 4-a). This house was built in the seventies, and was recently fully retrofitted and well insulated. For instance, the pitched-roof wall is insulated with 18 cm of mineral wool. All windows are double glazed with low emissivity glass. A sunspace facing south has been added with low emissivity double-glazing. An efficient heat recovery system lowers the heat losses by ventilation. With this characteristics, the heating load is 40 kWh/m² if the house is located in Trappes (north of France)

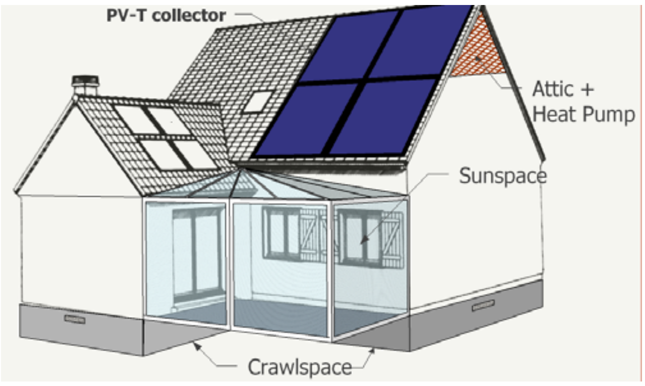
The PV collector is made of 30 m² mc-Si (mono-cristalline silicon), with a total peak power of 4280 kWp. The collector is placed on the south oriented roof, with an inclination of 45°. An air gap of 10 cm is placed behind the PV collector to recover the heat produced. An inverter with a nominal power of 3850 kW is installed to convert direct current into alternative current.

The heat pump has a rated heating capacity of 4 kW, a rated COP of 3.46, and provides energy for heating only. The compressor is inverter driven and, and it is also assumed that the fan speed of the exterior unit varies according to the part load ratio of the heat pump (see above).

Two different configurations are studied. In the first case, the PV-T collector is naturally ventilated, and the external unit is placed outside the building. This is the reference case, without thermal interaction.

In the second case, the external unit is placed in the attic (which is insulated with 4 cm mineral wool), as illustrated in figure 4-b. During the heating season, the air heated by the PV-T collector is injected in the attic. This air is blown by an additional fan (with a constant speed in our case, and assuming a consumption of 0.1 W/(m^3/h)) if it is warmer than the air in the attic. If the air flow rate required by the external unit is higher than the air flow induced by the additional fan, the remaining air flow comes from outside (see figure 4-b). In other words, the air coming on the external unit is the air in the attic, which is a mix between the air coming from the PV-T collector and the outside air. During the summer, the PV-T collector is naturally ventilated as in case 1.

[2]



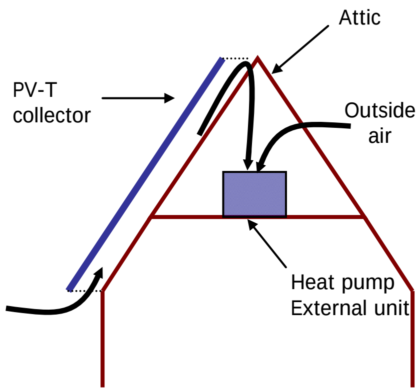


Figure 4-a – The studied house

Figure 4-b –Heat pump in the attic (case2)

Results

The table 1 below gives the results for the two cases described above (with and without thermal coupling), and with Trappes for the meteorological location (north of France). In the second case, the air flow coming from the PV-T collector varies from 0 to 2000 m^3/ hour.

Heat pump air source	**Outside air**	**Attic (PV-T collector + Outside air)**			
Air flow rate (m3 / h)	-	0	500	1000	2000
COP (Heat pump only)	3.06	3.12	3.18	3.4	3.67
COP (Heat pump + back up resistances)	2.91	2.94	3	3.21	3.54
COP (Heat pump + back up resistances + additional fan)	2.91	2.94	2.77	2.71	2.51
Building heating load (kWh)	6420	6420	6394	6351	6327
E_{pv} (gross, collector output - kWh)	4299	4113	4157	4170	4173

Table 1: Annual results for the two cases described in the previous paragraph (reference case and heat pump in the attic with air preheated by the PV-T collector)

We see that the annual COP of the heat pump slightly increases when the external unit is placed in the attic (3.12 against 3.06 for the reference case). Moreover, the COP increases according the air flow passing through the PV-T collector : the COP is 3.67 for a air flow rate of 2000 m^3/h, giving an increase of 20 % compared to the reference case. But the COP including also the back up resistance and the consumption of the additional fan decreases significantly (- 14 % compared to the reference case, the main part coming from the consumption of the additional fan).

The electricity produced by the PV collector (gross production, PV collector output) is lower in the second case than in the reference case. We have for instance 4113 kWh in the second case with no air circulation compared to 4299 kWh in the reference case, or approximately a 4 % loss. In the second case, during the heating season, the air flow is constant and fixed by the additional fan. The fan is off if the temperature of the air in the PV-T collector is lower than in the attic, and in this case the PV collector is not ventilated, compared to the reference case where the PV collector is always naturally ventilated. Nevertheless, we see that the electrical efficiency of the PV collector rises when the air flow rate increases.

CONCLUSION AND PERSPECTIVE

This paper demonstrates how it is possible to model an air source heat pump coupled with a PV-T collector, and to simulate the global system integrated into the building envelope.

According to the case study, the COP of the heat pump increases if a PV-T collector injects warm air in the attic, where the external unit of the heat pump is placed. But the consumption of the additional fan required to blow the air in the attic lowers the COP of the system. Moreover, the electrical efficiency of the PV collector decreases slightly, but better control strategies are expected to be developed to increase the global efficiency of the system.

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INTEGRATION OF RENEWABLES TO COVER COOLING LOAD OF BUILDING. FEASIBILITY AND APPLICATION

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ABSTRACT

The paper reports on the calculation of hourly cooling loads of a building in the climate conditions of Latvia with the aim to estimate and survey existing solar cooling technologies and their limitations, and also to consider possible application in Latvia. The hourly cooling load of a building is used to evaluate the reasonable fraction of the needed primary energy to be replaced by solar energy and to assess the collector area required to achieve the fixed primary energy savings. Analyses of research and results of simulation of solar thermal systems in climate conditions of Latvia allowed using this data for solar cooling applications. For energy calculation, a solar fraction 50% was assumed for solar absorption and adsorption cooling technologies. Analyses showed that solar cooling could be an attractive solution to increase the use of renewable energy and diminish the use of electricity for cooling applications.

INTRODUCTION

Buildings are responsible for about 40% of the global primary energy consumption. Despite the fact that for much of Europe's increases in cooling energy demand due to global warming will be outweighed by reductions in the need for heating energy [1] there is still a need for investigation. In most European areas both cooling and heating are needed, as well as in Latvia. Therefore, the capacity of solar-assisted air-conditioning systems which fulfil both requirements is a key element for techno-economic feasibility [2]. Solar cooling has a strong potential for significant primary energy savings [3]. Other assessments claim that around 120-150 systems are operational in Europe with a capacity over 12 MW_{th} and collector area of 36 000 m^2 giving 3 m^2/kW of cooling capacity mainly used in buildings but some by industry such as for wine cooling [4]. Nowadays solar energy is one of the promising resources not only for heating of buildings, but also for cooling. Solar fractions therefore need to be higher than about 50% to start saving primary energy [8]. A typical solar cooling system includes three main sub-systems: (1) Cooling load of building, characterized by the required cold energy, temperature and power, e.g. the cooling system. (2) The thermally driven cooling system (thermally driven water chiller or refrigeration cycle, open sorptive cooling cycle etc.). (3) Heat source: the solar collector system as the essential driving heat source and additional heat source, for example, pellet or woodchip boiler, to cover the necessary heat load when solar energy is not enough. All these three sub-systems are coupled to each other by heat fluxes at different temperature levels and other thermal engineering parameters and solutions.

For each MWh of cooling energy demand, between 1.6 and 6.2 m^2 collector aperture area are required for the cooling installation. The total system costs for commercially available solar cooling systems are between 180 and 270 EURO MWh^{-1} (for a more moderate climate with low cooling energy demand 680 EURO MWh^{-1}) again depending on the cooling load file and the chosen control strategy [8]. The total potential cooling demand in Europe (EU-32), if 100% of all useful space would be air conditioned, is estimated to an annual 1400 TWh_c [9]. There is no investigation of a solar cooling application for the climate conditions of Latvia.

SCOPE AND METHODOLOGY OF THE WORK

The paper analyses the feasibility of integrating renewable energy (practically solar energy) to cover the cooling load of a building in the climate conditions of Latvia. The goals are to calculate the hourly cooling load when the internal temperature of building exceeds 24 °C. The analyses consist of several main successive stages: (1) Estimation of hourly cooling load and internal temperature rate for a reference building in climatic conditions of Latvia using a developed calculation model; (2) Survey about existing solar cooling technologies and limitations, with regard to possible application in Latvia; (3) A reasonable fraction of the needed primary energy to be replaced by solar energy; (4) Evaluation of the collector area required to achieve the fixed primary energy savings.

COOLING LOAD AND INTERNAL TEMPERATURE OF BUILDING

Calculation method of building cooling load

A developed model for building hourly cooling load calculation in Latvia based on the European Standard EN 15255:2007 „Thermal performance of buildings – Sensible room cooling load calculation – General criteria and validation procedures" (has a status of Latvian Standard) is used in the paper to define the hourly cooling loads and demand of building. For weather data are used hourly values of air temperature, and solar radiation (global, direct and diffuse) for the whole year. The hourly cooling power is calculated to define the operation time of the cooling system.

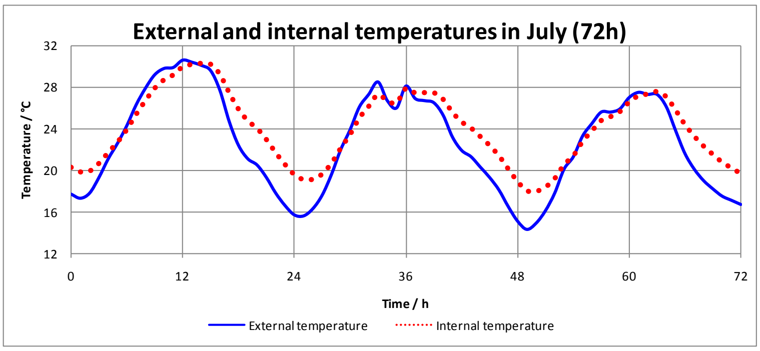

Figure 1: Dynamics of external and calculated internal temperature of building

The used reference building is a real and typical three-storey residential building in Latvia (Figure 1) built in the end of 1960s. Basic data of the reference building: length 24.5 m, width 10.5 m and height 9 m. Windows area (glazed area) from total wall surface: 19%, approx. 120 m^2. Heating or cooling area (living area) is 257 m^2. All the main materials and thermal parameters of reference building are given in Table 1. The air exchange rate is 0.545 h^{-1}. Specific heat losses via enclosed constructions of building are 1072.2 W/K, but total specific heat losses of building included ventilation, doors, roof, walls and windows are 1509.8 W/K. Some output of calculation model is shown in Figure 2. There is a time lag between external and internal temperature due thermal inertia and effect of thermal mass of building components.

Analyses of the recommended design value of the maximum indoor temperature of building for cooling (practically summer season) have shown that the average temperature is basically 25 °C in European Union [5].There are no limitations and regulations about maximum internal temperature for the cooling season in Latvia, there exist only limitations for the heating season. In this paper for cooling season it is assumed to be 24 °C. An analysis of the primary energy heat input requires a complete model of the building load with a time resolution of at least 1 h [8]. Developed hourly cooling load calculation model allows evaluating and analysis of partial loads as required for system design, operation and control.

SOLAR COOLING TECHNOLOGIES AND SYSTEMS

The main advantage of solar cooling is the fact that there is a simultaneousness of solar radiation and cooling load of the building. There are several main technologies using solar thermal energy for cooling. Leading technology is the absorption technology.

Absorption technology

There are single-effect and double-effect absorption technologies where the refrigerant is water and the sorbent is lithium bromide. Also there is a single-effect technology where the refrigerant is ammonia and the sorbent is water, but as ammonia is not an environmentally friendly solution this type is not analysed. Cooling medium is water, cooling temperature is 6 – 20 °C, necessary heating temperature is in range 75 – 100 °C (single-effect) and 80 – 160 °C (double-effect). Cooling capacity range per one unit available on the market is 5 – 20500 kW (single-effect) and 5 – 1000 kW (double-effect). The main parameter of technology – coefficient of performance (called COP) – is in range 0.6 – 0.7 (single-effect) and 1.1 – 1.4 (double-effect) [3,6,8,9].

Adsorption technology

For this type of technology water is a refrigerant and sorbent is silica gel. Cooling medium is water, but cooling temperature range is 6 – 20 °C. Delivered heat temperature range is 55 – 100 °C, but cooling capacity range for one unit available on the market is 5 – 350 kW. COP is 0.6 – 0.7[3,6,8].

Desiccant technology

For sorbent silica gel or lithium chloride is used, but the cooling medium is air. The reachable cooling temperature is 16 – 20 °C. Necessary heating temperature range is 55 – 100 °C. Cooling capacity range per unit available on the market is 6 – 300 kW, but COP 0.5 – 1.0 [3,6,8,9]. This type will not be analysed because of technical issues and availability in the market of Latvia because small capacity systems (less than 20 kW) are not commercially available.

HEAT SOURCE

There are different basic types of solar thermal collectors: flat plate, evacuated tube or concentrating. Feasible for all buildings are flat plate or evacuated tube collectors. The required collector area per square metre of conditioned floor area varies significantly with the latitude. This makes solar-assisted air-conditioning systems less viable compared to conventional cooling systems if typical Central Europe climate conditions are considered. Therefore the possible economic feasibility of solar cooling systems seems in general to be limited to Southern Europe regions. Use of evacuated tube collectors in place of flat plate collectors, as low temperature driving heat source, allows a noticeable increase in the annual system performance [2,8]. The experimentally observed efficiency of the collectors for desiccant cooling conditions varies between 60% and 70% [7]. For climate conditions of

Latvia it is possible to use flat plate or evacuated tube collectors, also concentrate collectors have potential, but as yet there is no example and practice experience to operate them in Latvia.

Additional heat source is necessary to cover the required thermal energy for cooling units because solar collector systems can cover only part of this energy for technical (area for collectors, architectural and esthetical aspects etc.) and physical (solar radiation, climate etc.) reasons.

RESULTS

The developed calculation model of cooling load was used to determine the cooling load profile and find out the internal temperature. This calculation is used to set down hourly cooling power and operation time for cooling systems. The model allows finding out the accurate time period when cooling is necessary and internal temperature exceeds a set temperature, e.g. 25 °C, and thus evaluates the dynamics of cooling load.

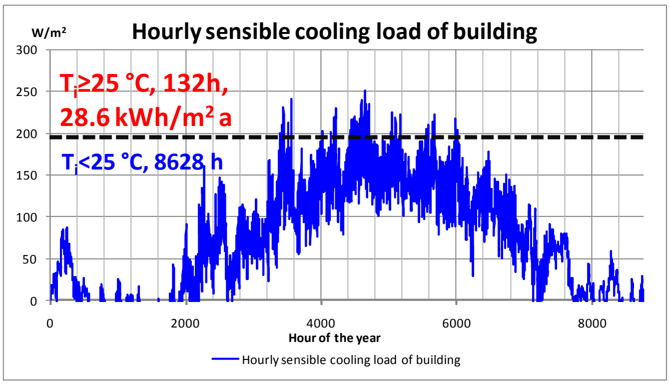

Figure 2: Calculated hourly sensible cooling load of building for whole year and cooling load for cooling season (internal temperature of building is equal or increase 25 °C).

Internal temperature is greater or equal to the set temperature of 24 °C about 200 hours in calculation year (cooling season is about from star of May to middle of September). Operation time for the cooling system is approximately 200h. Maximum cooling power is 247 W/m2 or 63,5 kW. The specific cooling demand is 28,4 kWh/m^2 a (Figure 2 and 3).

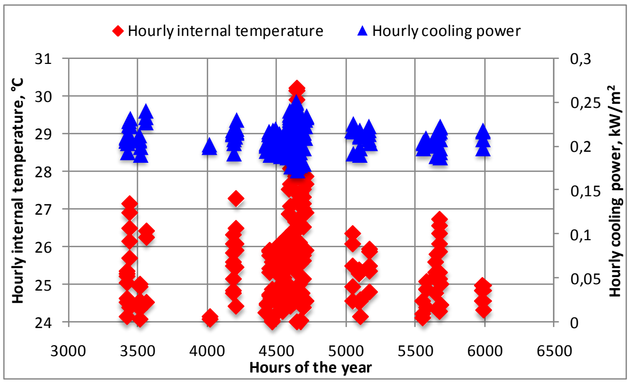

Figure 3: Hourly internal temperature of building and hourly cooling power for whole cooling season (internal temperature of building is equal or increase 24 °C).

Cooling load is calculated also for moments when hourly internal temperatures of a building exceed 25 °C (approximately from end of May till beginning of September). Operation time for a cooling system is approximately 135 h; the~~,~~ total heat that should be removed from the building for a whole year (cooling energy demand) to prevent that the internal temperature of the building exceeds 25 °C is 28,6 kWh/m^{2}a.

For the often used single effect machines, the ratio of cold production to input heat (COP) is in the range of 0.5–0.8, while electrically driven compression chillers today work at COPs around 3.0 or higher. Solar fractions therefore need to be higher than about 50% to start saving primary energy [8].

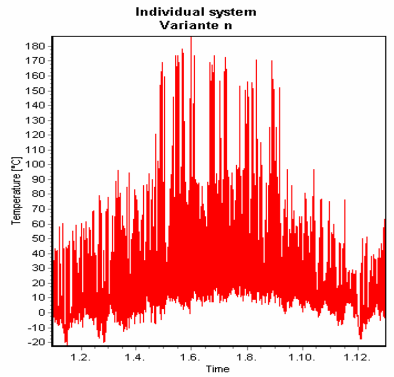

Figure 4: Temperature of glycol in the centre of solar collector (absorber area: 7,4 m2) [10].

Based on previous investigations and simulations on solar energy systems and their application in Latvia, the average solar energy output from 1 m^2 of flat plate solar collector in the climate conditions of Latvia is about 400 kWh/m^2 per annum [9]. An analysis of the potential fluid temperature from the solar collector (see Figure 4) is very significant in so far as it is important to reach a maximum solar fraction and obtain the temperature necessary as driving heat for the cooling system.

Solar cooling absorption technology

An appraisal of heat output and temperature from a solar collector loop (Figure 4.) has shown that it is possible to provide necessary heat and temperature for absorption technology input, both single-effect and double-effect. For an annual cooling energy demand of nearly 7298.8 kWh and an average COP of 0.7 (single-effect) the system requires about 104266.8 kWh of heating energy. To achieve a solar fraction of 50% for the given cooling profile, a collector area of 13 m^2 is required. For an average COP of 1.3 (double-effect) the system requires about 5614.5 kWh of heating energy. To achieve a solar fraction of 50% for the given cooling profile, a collector area of 7 m^2 is required. But it is necessary to take in consideration that double-effect absorption technology requires a higher driving heat temperature rate, which is 80 – 160 °C.

Solar cooling adsorption technology

Appraisal of heat output and temperature from a solar collector loop (Figure V.) simulation in climate conditions of Latvia has shown that it is possible to provide necessary heat and temperature for adsorption technology. For annual cooling energy demand of nearly 7298.8 kWh an average COP of 0.6 the system requires about 12164.7 kWh of heating energy. To achieve a solar fraction of 50% for the given cooling profile, a collector area of 15 m^2 is required.

CONCLUSIONS AND DISCUSSIONS

In the work, feasibility and performance of solar cooling technologies in climate conditions of Latvia were analysed. Hourly cooling loads of a building were calculated to obtain the partial load and cooling power taking into account the external surface heat balance, conduction through the building envelope, the effect of the thermal mass and thermal inertia of the structure. Calculation showed that cooling is necessary also in North-East Europe although not as much as in hot countries in South Europe. The investigation of existing solar cooling technologies was made to establish the main operation parameters and conditions of such technologies. Analyses showed that solar cooling could be an attractive solution to increase use of renewable energy and diminish use of electricity. The main limitation factors for solar cooling in the climatic conditions of Latvia are solar irradiation, external temperature and efficiency of each solar cooling system sub-system. The work shows that further research is necessary to make dynamic simulations to determine the suitable solar thermal systems size and get maximum solar fraction of total energy requirements not only for thermal application but also for cooling application.

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ENERGY EFFICIENCY STRATEGIES FOR URBAN QUARTERS

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ABSTRACT

In the total German end-energy balance heat accounts for 59% and is therefore the most important form of energy in Germany [1]. Consequently the building sector plays a key role in the definition of local climate protection concepts. With the vast majority of the German population living in urban or semi-urban areas a context specific approach seems appropriate to assess the energy demand on the scale of an urban quarter substituting the sector specific by a spatial definition of the system boundary.

The paper argues that the full potential of energy efficiency on the scale of an urban quarter can only be exploited by bringing together urban form and adapted energy concepts in the energy assessment.

Investigating the complex interrelations between renovation and energy supply system a need is identified to go beyond the assessment of single buildings of the same use in order to analyse the integration of energy efficient renovation measures, efficient supply systems and to discover existing synergies. Also the potential that lies within the cascading or coupled usability of energy pointed out in the progress report on heat supply of the German Federal Environment Agency1 shall be assessed.

First steps towards an energy assessment method on the scale of urban quarters integrating different uses and supply systems will be described building on the methods of the urban energy assessment and the simulation of individual buildings.

INTRODUCTION

Today nearly 90 percent of the German population lives in cities [2] the ratio thus even exceeds the European average of 75 percent. At the same time heat accounts for 59 percent of the total German end-energy balance [1]. The discussion on energy efficiency strategies in urban quarters therefore is one of the keys to achieve the national goals of increased energy efficiency and the reduction of green house gas emissions. Local climate protection strategies [see 3, 4, 5] even though they encompass a wider range of sectors usually address the building sector as a key component. The focus is often put on individual buildings both public and private neglecting that also the "[u]rban design, including the clustering of buildings and mixing of different building types within a given area greatly affect the opportunities for and cost of district heating and cooling systems" [6] and as a consequence the efficiency of energy supply systems. It is assumed that the scale of analysis of energy efficiency strategies largely influences the choice of measures or technical solutions applied. Consequently an enlarged system boundary holds possible benefits in order to increase the energy efficiency and enable a sustainable development of urban areas. The demand for an integrated planning approach therefore also questions the scale of individual buildings as the scale at which urban decision makers should take action.

It is in this framework that a methodology for an energy balance at the scale of urban quarters is discussed. This paper will describe the implications that are expected from an enlarged scale in the energy assessment.

METHOD

In order to provide guidance in the planning process of energy efficient urban redevelopment projects the objective is to develop a methodology that describes the energy balance of urban quarters building on an integrated assessment of energy efficiency measures and efficient supply systems. An energy balance is in this context understood as an assessment of the heating or cooling demand and the energy demand that has to be provided to the system. The energy balance shall be described in a level of precision that allows for the investigation of expected synergies in mixed use quarters. Reflecting the spatial definition of the system boundary chosen the method to describe the energy balance is seen as an integration of approaches currently available on different scales. Therefore elements of a bottom-up approach will be included to classify individual buildings or zones. On the other hand elements of a top-down approach will have to be included to describe the characteristics of the urban quarter as well as the specific setting within the larger urban context that could be referred to as embeddedness [7].

The scale has been addressed as an important factor in the assessment. It is assumed that in order to define a near optimal system boundary an additive approach could be chosen linking the model to the urban reality (Figure 1). It is expected that the complexity of the model will rise with the number of buildings (i.e. the size of the area) therefore their number should be limited to a minimum without loosing the potential scale effects. The increase in the number of actors and interest groups involved could eventually prove as another limiting factor. As a result the scale of the system boundary of the energy balance should be large enough to allow for different technical solutions to be included in such an assessment but should on the other hand be as small as possible to limit its complexity. In connection with the need to localise heat sinks and sources within the quarter a stepwise calculation of subsystems is suggested to identify efficiency potentials and to allow for the definition of individual characteristics on different scales. Figure 1 illustrates the additive proceeding with the calculation of subsystems referring to scales of planning processes.

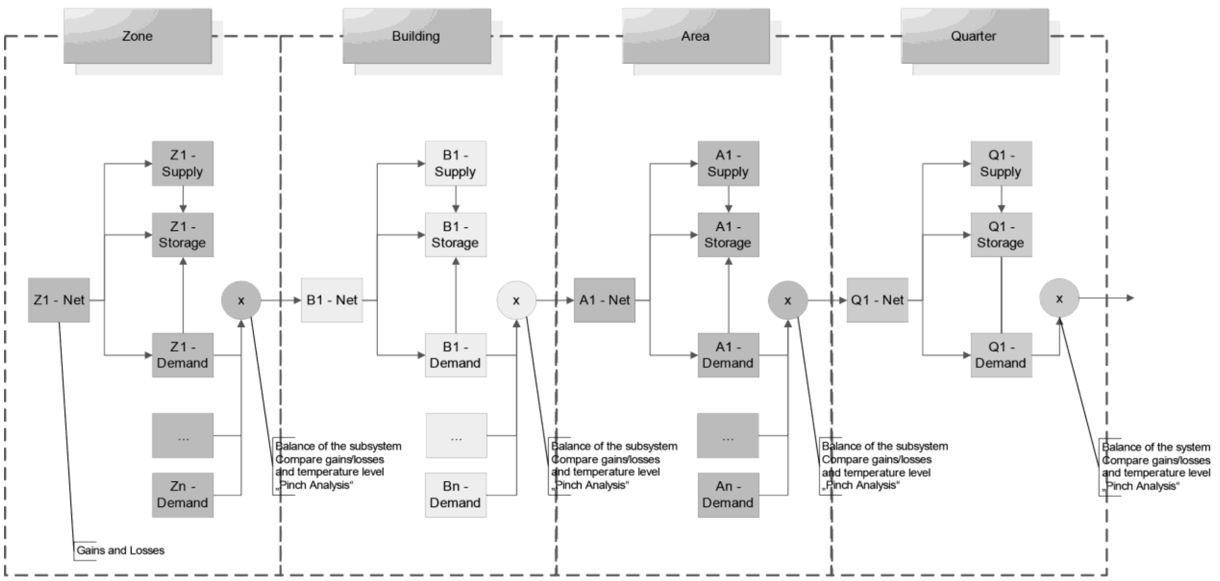

Figure 1: Scales of Balancing Steps: From Zones to Quarters, own illustration

Specific uses and time patterns are summarised to individual zones. Buildings are seen as the aggregation of a number of zones or could host only one zone. Non-building heat sinks (e.g. street lightning) and sources are then grouped to form areas. Areas could eventually correspond to building blocks. Of these areas a certain number forms the urban quarter. The expected benefit of the proposed proceeding is to localise the potential synergies on the smallest possible scale to minimise the size of distribution networks as the scales represent the physical reality. Specific measures applicable to a zone building, area or a whole quarter could be included at the corresponding scale.

To consider cogeneration and process heat as sources in the balance a high temporal resolution of the energy balances will be required to allow for an estimate of the potential for coupled usage of energy and meaningful cost-effectiveness analysis [8]. Presumably the modelling of the energy flows therefore has to rely on hourly load profiles in combination with quasi steady state or simplified dynamic calculation procedures on the level of single consumers (i.e. zones or buildings). With regard to heat exchanger in the system and the coupled use of energy it will be considered to refer to the temperature level and the mass flow of heat sources, which suggests the use of enthalpy instead of energy as the relevant thermodynamic description. A proceeding analogue to the pinch analysis as pursued by approaches such as EnerGis [9] seems promising to model these specific energetic aspects. In analogy to coupled industrial processes different levels of temperature possibly could be described within urban quarters even though these processes remain on a relatively low temperature level. In this form of analysis temperature and enthalpy of cold and hot processes are combined to form cumulative curves Linnhoff [10]. The overlap of these curves then corresponds to the maximum quantity of heat that can be recovered within the system. In more recent approaches the methodology was successfully applied to non-industrial uses as hospitals [11]. In addition current pilot projects show the feasibility of the use of heat sources like waste water [12].

The location of an urban quarter and its relation to the whole urban agglomeration as well as the spatial description of the single entities of the energy balance has a strong influence of the availability of different urban energy sources. After the description of a theoretical potential that could be the outcome of a modified pinch analysis the localisation of processes will be a prerequisite to assess losses in the network and costs of the energy distribution network as described above. The spatial analysis would then lead to the technical potential which needs to be considered when discussing the benefits of possible energy management strategies. As it is only by the possibility of trading energy that the connection of energy supply and energy demand provides a potential for energy management strategies [4] the precise location of the individual processes will have to be considered as a key variable to determine the usability of alternative energy resources. To optimise the use of energy the two should have matching characteristics in the amount of usable energy and the demand as well as their temporal availability. Figure 2 illustrates the schematic structure of an integrated network of heat sinks and sources differentiating endogenous and exogenous sources of energy.

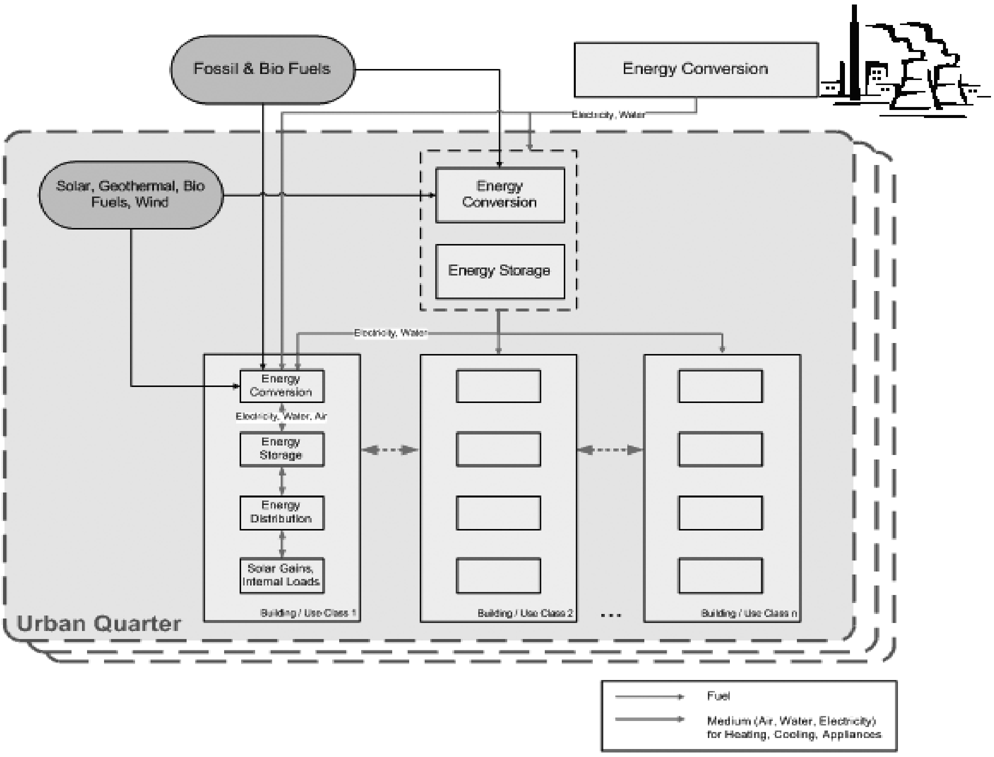

Figure 2: Schematic depiction of the energy demand and supply structure of an urban quarter

RESULTS

First steps towards a method to describe the energy balance of urban quarters were described. The method eventually would allow for an assessment of the efficiency of the use of resources in a given context as well as to identify potential synergies between the various consumers in the urban context. Linking the approach with the planning processes as well as the assessment of infrastructure costs seems feasible via the inclusion of the spatial dimension in the parameters.

The methodological discussion shows that in between the scale of single buildings and whole urban areas the specific scale of urban quarters can be identified defined by the urban morphology or built form as well as on existing actor networks and urban infrastructure.

DISCUSSION

Especially in urban areas with mixed use which seem to host the largest potential or the coupled use of energy an increased complexity can be expected as compared to residential areas with a homogeneous ownership. Therefore the application of the described energy balance will face the problem of complex interrelations between the different actors. In this translation to real cases the proceeding can be expected to resemble an energy management strategy even though the focus is initially laid on the balancing procedures.

With regard to the definition of urban quarters both a model as a social space and a morphological description are used [7]. This dual definition seems suited to integrate different disciplines in a common approach which eventually could provide the ground to describe a model for sustainability concepts as opposed to mere energy efficiency strategies.

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EXERGY AND BUILDING SYSTEMS: FULL POTENTIAL OF HEAT RECOVERY

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ABSTRACT

As a part of the broader theme of low exergy (LowEx) buildings, this project has analyzed the utilization of both energy and exergy from the wastewater stream of buildings. It demonstrates the potential of wastewater heat recovery. A realistic model of annual hot water usage for different sizes of residential structures reveals the potential to recover about 90% of the energy in wastewater when the system is optimized using exergy analysis for maximal exergy recovery. At these operating points, and by using an integrated renewable ground source heat pump, savings of upwards of 500 CHF per year and more than 1 ton of CO2 per year are achieved compared to a standard electric boiler.

The project is a part of the Swiss Federal Office of Energy funded Swiss participation in the IEA ECBCS Annex 49, "Low Exergy Systems for High Performance Buildings and Communities." The system has been modeled and will be used as the basis of a Swiss OPET CTI collaboration with Geberit International AG to bring a wastewater heat recovery product quickly to market.

The highest performance is only achieved through complete integration with the low exergy building system. By using low temperature heating with activated thermal mass, a very high heat pump performance is achieved for space heating. This "low-temperature-lift" high performance of the heat pump is extended to water heating by integrating the wastewater heat recovery. The potential realization of the complete system in the ViaGialla B35 building project in Zurich (www.viagialla.ch) will also be described. This project will be the pilot project for many advanced LowEx technologies including heat recovery and planning is nearly complete with construction set to begin in July, 2009.

INTRODUCTION

Buildings provide one of the fundamental needs of humans: shelter. But modern buildings go much beyond simply providing shelter from the outdoor environment; they also create a comfortable indoor environment that meets very specific demands. The expanded demands on buildings have led to the growth of their energy consumption as they have become more comfortable, more functional, and more spacious, now demanding around 2/3 of all the electricity produced in the world [1]

By now the negative impacts of this growth have been recognized with upwards of half of global greenhouse emissions being caused by the building sector [2,3]. Our modern built environment has only existed for a few hundred years, which leaves room for much needed improvements. One area that has hardly been considered is the potential benefits of heat recovery from the warm wastewater. In cold climates by far the largest demand is for heating, and even in temperate and mild climates heating can be the largest energy demand, here due to water heating.

A person typically uses roughly 100 to 200 L of water per day, of which usually more than half is hot water [3,4]. Most studies focus on the usage amount for supply and tank sizing, which makes it easy to overlook the energy demand. The actual energy demand for hot water is typically around 2000-4000 kWh per year per household or about 20-40 kWh per year and per m^2 of building [5,6,7]. Reasonable estimates are available for the total demand for state and national energy reports [7], but these have no indication of how hot water demand could be reduced in system designs. These reductions are important because as buildings have become more efficient hot water demand has become a much more significant portion of the overall demand. This is illustrated in Figure 1 comparing the space heating, appliance load and the water heating energy demands for various levels of building performance.

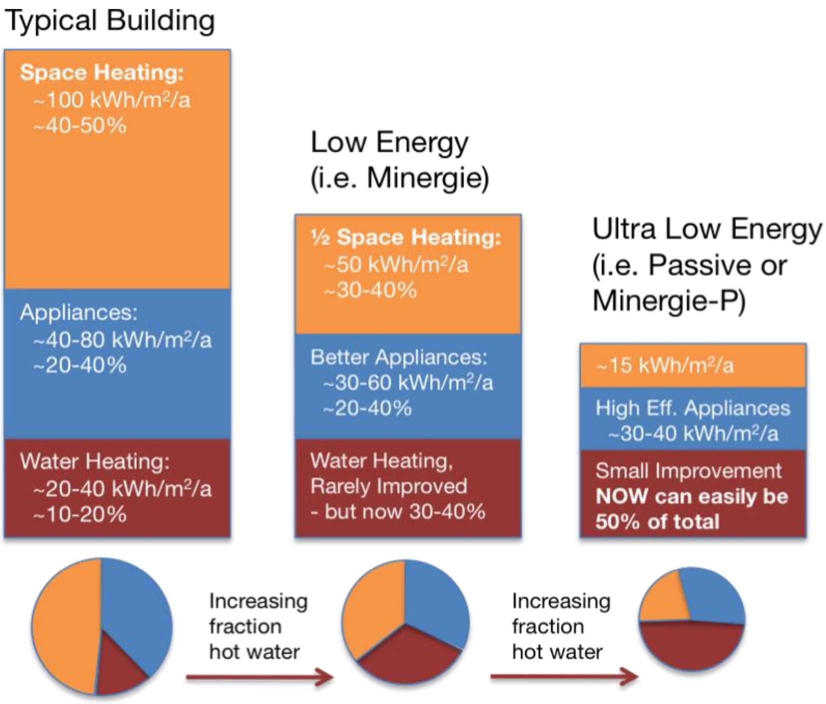

Figure 1: As building performance levels increase the focus is primarily on space heating because it was the largest part in the beginning, but now further advancements must start to address the issue of warm water energy demand.

What is more is that the building hot water systems provide a very valuable energy flux that is also energy-dense. Water has a large heat capacity and warm water used in a building is at a higher temperature. The largest hot water usage, being showers, is usually at least 40°C. This means that warm wastewater can have a very high potential value if recovered.

The concept of exergy allows us to better quantify this extra value. We can optimize the recovery of heat using exergy analysis to maximize the performance of the heating system.

For high performance buildings it is again even more significant to consider the exergy in wastewater. Figure 2 demonstrates that as building water systems become more high performance, or in this case also more ecological, the makeup of the wastewater becomes more valuable. Therefore better buildings should address the potential of wastewater

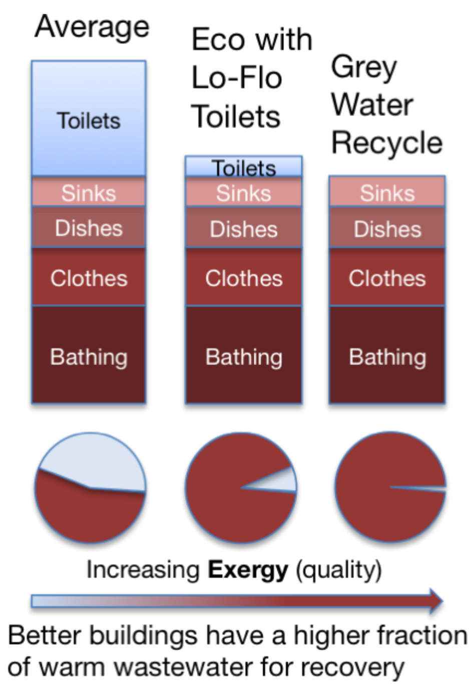

Figure 2: Exergy available in building wastewater streams

heat. By combining the need for reduced hot water energy demand with a system based on exergy analysis, an optimized wastewater heat recovery can be designed. The hot water demand is then made much smaller while still meeting the same needs for comfort and functionality.

METHOD

Water use data

In order to analyze the potential recovery of heat from a building wastewater stream, the first step is to generate a realistic data set for the stream. A statistical domestic hot water software tool (DHWCalc from The University of Kassel) [8] was used to generate one year of hot water events with a 6-minute time interval. This was done for a one, two, four, six, and eight family building using typical weekday and weekend probabilities for shower, bath, sink, clothes washing, and dish washing events [9,10]. With this data the warm wastewater flow can be estimated. One major assumption is that of the temperature of the wastewater. A conservative value of 30°C was used to account for cold water mixing and transit losses.

The design assumptions included a spiral pipe that was coiled inside of the tank to capture the wastewater. The working fluid for heat exchange was water and it was assumed to enter with a temperature of 12°C. This was chosen because it was slightly warmer than usual ground source heat pump evaporator temperature that could use the recovered heat. The tank size and heat exchanger length were varied in the analysis as well as the heat exchanger flow rate.

An energy balance was performed on the system at each 6-minute time-step. The heat exchanger energy balance allowed the determination of its exit temperature as well as the new temperature in the tank. The tank temperature was assumed to be constant over the time step and the spiral heat exchanger was assumed to act as a pipe in a medium of constant temperature. The natural convection was neglected in order to analyze the worst-case of simple conduction. Equation 1 determined the outlet temperature, T_{out}, of the heat exchanger at each time-step based on the current tank temperature, T_∞, the entering water temp, T_{in}, and the properties of the system (density, ρ; flow rate, Q; heat capacity, c_p; tank diameter and width, D_{tank} and L_{tank}; and the convection coefficient, h, based on the Nusselt number, Nu; heat transfer coefficient, k; and the pipe diametere, D_{pipe}).

$$T_{out} = T_\infty - e^{\frac{-h_{\text{fluid}}(\pi D_{\text{tank}} L_{\text{tank}})}{\rho_{\text{fluid}} Q_{\text{fluid}} c_p}} * (T_\infty - T_{in}) \quad \text{where } h_{fluid} = \frac{Nu * k}{D_{pipe}} \tag{1}$$

The outlet temperature allows the energy extracted to be calculated as well as the new tank temperature. This is then repeated over the year for all the warm wastewater events to determine the performance.

Within each time step a check was made to ensure the validity of the constant temperature (quasi steady state) assumption. If the temperature changed by more than 2 degrees in one 6-minute step, a subloop was run within that time to maintain validity of the assumption.

The exergy analysis used a simple assumption for an incompressible fluid to determine the exergy removed by the heat exchanger at each time step. Equation 2 describes the exergy value, Ex of the water exiting the heat exchanger. The total heat Q_{out} subtracted by the environmental temperature T_{env}, which was set at 5°C, and is multiplied by the change in entropy represented by the natural logarithm of the average tank temperature between the two time-steps, $T_{tank,ave}$ and the heat exchanger input temperature, $T_{in,HX}$

$$Ex = Q_{out} - T_{env} * \ln\left[\frac{T_{tank,\,ave}}{T_{in,HX}}\right] \tag{2}$$

The final aspect of the analysis involved the integration of the recovered exergy into a low exergy building system. This means evaluating the impact of the potential recovery on the performance of a heat pump that is required to supply hot water. This was done by evaluating the potential improvement to the COP based on Equation 3 where the supply temperature is the demanded hot water supply temperature and the available temperature is what can be provided by the heat recovery system. This was compared to the performance of a typical electrical and natural gas boiler systems.

$$COP = \left[\frac{T_{Supply}}{T_{Supply} - T_{Available}}\right] \tag{3}$$

The impact of the system is evaluated compared to natural gas and electric hot water heaters. The electricity price is taken to be about 0.20 CHF/kWh and the gas price is 0.74 CHF/kWh. The greenhouse gas emissions for electricity are taken from the UCTE European average of 0.47 kg-CO_2/kWh and for natural gas combustion it is 0.25 kg-CO_2/kWh.

RESULTS

The potential annual recovery of energy and exergy were calculated, and Figure 3 shows how the exergy analysis provides a unique optimization point that is not shown in the energy analysis.

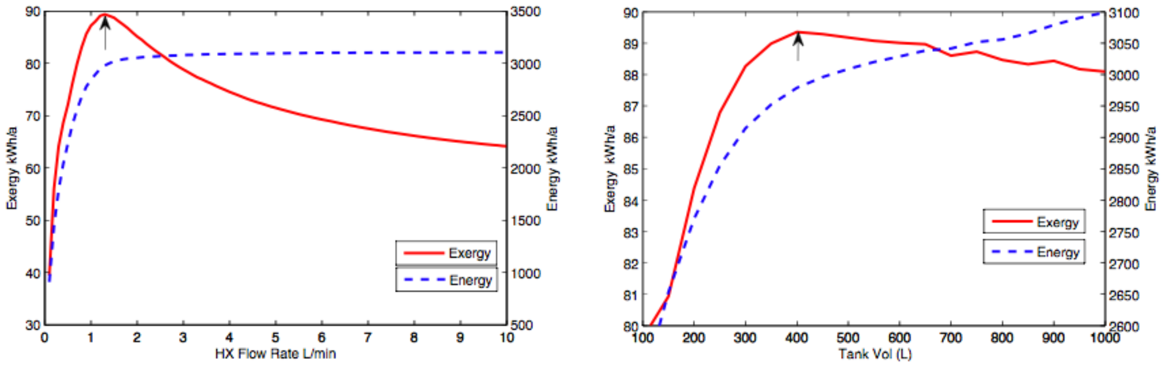

Figure 3: Plot of the exergy and energy recovery for different HX flow rates (left) and tank sizes (right). There is a clear optimum in the exergy analysis not given by the energy analysis.

Assumptions had to be made for the operation of the recovery tank. Some parameters were fixed such as the cylindrical tank shape, while others like volume were varied optimized for maximal exergy recovery. Figure 4 shows how the potential exergy recovery was analyzed for different sized tanks for the various building sizes. This was also done for the heat exchanger operation, which provided an optimal flow rate to minimize exergy destruction from high temperature differences. These specifications were then used to calculate the annual performance and potential savings of the system compared to the standard systems.

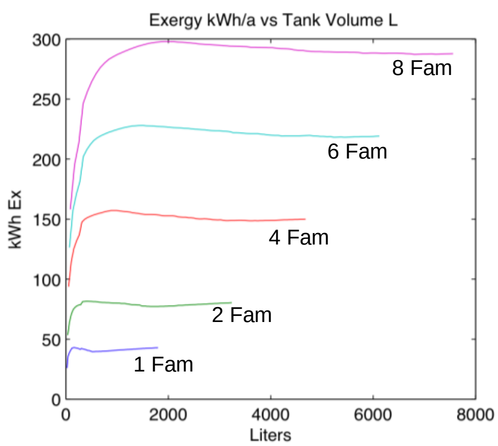

Figure 4: Tank Size exergy recovery optimization for different sizes

The savings are about 1500 kWh per year per residence. This is for an input of about 3000 kWh per year for hot water at 50°C, and when the wastewater is assumed to be 30°C that translates to about 1,700 kWh per year available to recover. The large majority of the energy is lost when one assumes a 30 degree mixed recovery. Of the 3000 kWh it is assumed that only 1700 kWh are available for recovery. The system thus recovers around 90% of the heat available in the wastewater.

The recovery translates into different levels of savings that depend on the type of heating system and the way the recovered heat is exploited. The heat can be most easily used directly to preheat water, which in turn directly reduces the demand on the system in place. In this analysis we've looked at a standard natural gas and standard electric boiler. The natural gas boiler is cheaper to operate so the cost reductions from direct heat recovery are less. They are about 100 CHF/a per residence vs the electric boiler using more expensive electricity saving about 285 CHF/a. The emission reductions also vary depending on both the boiler type as well as the source of the electricity (CH vs EU). The CO2 reductions thus range from about 180 kg per residence for a Swiss electric boiler to 700 kg for a European electric boiler with the natural gas savings falling in between at about 375 kg.

The savings can be greatly increased when integrated into a heat pump system for heating. Based on Equation 3, the heat pump COP could be increased easily from 4 to 8 with appropriate compressor technology that maintained the Carnot efficiency, η_{Carnot}. The value of the higher temperature (more exergy) warm wastewater recovery can greatly improve the performance of the system. In the case of integration with a heat pump system, the savings mentioned above are doubled with 1,300 kg of CO2 being eliminated and 550 CHF of cost reduction for an electric boiler.

DISCUSSION

The wastewater heat recovery (WRG) system shows great potential for energy savings, cost reduction, and environmental benefit. The type of operation influences the performance benefits. The direct use of the recovered heat to preheat water would be a cheaper installation than an integrated heat pump system. But the other benefits in the operation of an entire building when installing a low exergy high performance heat pump system are great.

The final design will be further optimized in collaboration with Geberit International AG. This analysis provides an initial look at the system feasibility, and how exergy analysis can be used to optimize the system. The exact recovery could vary considerably depending on the average temperature of the wastewater stream. In this case a very conservative estimate of 30°C was used, and for recovery directly after a shower the temperature could be much higher.

The pilot system will be integrated into the B35 building project in Zurich. It will combine a low exergy ground source heat pump system that minimizes the temperature lift that the heat pump provides for all space heating and water heating. This will be done through a combination of exhaust heat recovery and wastewater heat recovery. By using the wastewater heat recovery, a relatively low temperature lift can be maintained for all parts of the heat pump heating system, including for hot water. Not only that, but the hot water is planned to be distributed at a lower temperature around the temperature of a shower (the most common use). Decentralized electric heaters will provide the smaller amounts of hotter water that are needed. The overall gain in performance from the temperature reduction should outweigh the small decentralized electric demand. One future goal is to make it possible for these decentralized heaters to operate on the basis of a heat pump. The system is currently in the final planning phases, and construction is set to begin in 2010.

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A SIMPLIFIED METHOD TO ASSESS THE QUALITY OF INTEGRATION BETWEEN MEASURES TARGETED TO INCREASE ENERGY EFFICIENCY AND USE OF RENEWABLE ENERGY SOURCES IN URBAN AREAS: EXAMPLE OF THE CONCERTO INITIATIVE

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ABSTRACT

The European CONCERTO initiative aims at supporting communities for the implementation of combined actions in the field of energy efficiency and use of renewable energy sources (RES) particularly in urban areas. As part of the overall impact assessment work done on this initiative, the quality of integration between the demand side (energy efficiency increase) and supply side (use of RES) measures is being assessed.

Because of the high number and variety of project approaches (26 communities are being analysed), a simplified method has been developed to be applied even if quantity and quality of data available differs from one community to another. In particular methods based on detailed exergy calculation would allow for a comprehensive and quantitative assessment but would require a high amount of data which is not available on the same detail level for all communities.

The proposed methodology is based on a four steps approach. The first step consists in reporting the correlation between specific figures of final and primary energy use for the considered building stock. This presupposes the preliminary calculation of primary energy factors following standard calculation procedures, in particular for district energy systems. A good integration from this point of view is reached if both specific figures of final energy use and primary energy use are below a certain limit.

The second step of the assessment consists in checking whether the chosen renewable energy systems are suitable to cover the energy needs of the considered building stock in terms of capacity and temperature (for thermal systems): because of the inhomogeneous data structure across communities, this analysis is done on a qualitative basis by confronting the capacity and the temperature level required by the end-uses and provided by the renewable energy systems located in the communities.

The architectural integration of renewable energy systems into the urban structure is considered in the third step, mainly for the solar energy systems.

The last step deals with the technical and operational features of the community energy systems contributing to an optimised use of RES (storage, reduction of losses, load management and control strategies…).

The paper presents the details of this method by justifying why it is adapted for assessing the quality of integration between activities targeted to increase energy efficiency and use of RES in urban areas and illustrating it with some examples from the CONCERTO communities. As a result, inputs to define a quality standard are given.

INTRODUCTION

Energy performance indicators as well as sustainability indicators are commonly used to characterise single buildings. Similar indicators can be similarly applied at a community scale and there are currently many ongoing research activities aiming at defining such criteria (IEA ECBCS Annex 51). For neighbourhoods characterised both by high building energy performance standards and high shares of onsite renewable energy technologies, there is the need to evaluate if, for instance, photovoltaics have been only applied on very efficient buildings or if solar thermal collectors are architecturally integrated in the building envelope. These points could be included in a definition of a quality standard for the integration between measures targeted to increase energy efficiency and use of RES. The assessment of the quality of integration between all these measures could then deliver additional information on the neighbourhood performance. However, there is no available standard definition of what should characterise high quality integration.

In the framework of the European CONCERTO initiative, demonstration actions are implemented as milestones in the development of sustainable communities in new urban development areas, existing urban neighbourhoods and rural areas. They are carried out in the field of energy efficiency (thermal retrofitting of existing buildings, construction of new low-energy buildings, increasing the efficiency of every kind of energy system and introducing polygeneration technologies) and renewable energy systems. Large or small scale energy systems based on RES are being built to provide single buildings or whole districts with electricity, heating and cooling. As part of the assessment work done on the initiative (4), it is required to assess the quality of integration between measures targeted to increase energy efficiency and use of RES. To allow for benchmarking between participating communities, it is necessary to elaborate an assessment methodology adapted to each community, i.e. leading to satisfying results given the quality and quantity of data available. As the level of data quality and the amount of data might vary a lot from one community to another, the proposed methodology is based on a multi-criteria approach which tries to cover all quality aspects, both on a quantitative and qualitative basis.

The paper presents the proposed methodology and explains the motivations for the choices made. In a second step, some examples illustrate how this methodology might be applied in practice.

METHOD

Assessing the quality of integration between measures targeted to increase energy efficiency and use of RES in urban areas corresponds to evaluate if onsite renewable energy technologies are “well-integrated” in the neighbourhood. It is proposed to categorise the components of a “good integration” into:

- integration from an energy point of view: are the renewable energy technologies installed at energy efficient applications?

- integration from an exergy point of view: are the renewable energy technologies adapted to cover the energy needs in terms of temperature and installed capacity?

- architectural integration: are the renewable energy technologies physically integrated into the urban structure?

- technical integration: is the degree of utilisation of renewable energy technologies maximised through specific components?

Such aspects are usually not assessed together when dealing with buildings and communities. The methodology proposed is an attempt to consider these different aspects of on the same level, as they are all necessary conditions to reach a high quality level of integration.

First step

The first step of the assessment is of quantitative nature. It consists mainly in showing the correlations between indicators representing the degree of energy efficiency of buildings (final energy use) and indicators summarising the contribution of RES (primary energy use). The exclusive use of primary energy use figure might lead to situations where low energy efficiency figures, resulting for instance in a high electricity use, are compensated by using renewable energy source technologies (photovoltaics), which is not coherent with an optimised use of resources.

Reporting the correlations between specific figures of final and primary energy use for the considered building stock is thought to be a practicable way of quantifying the relative contributions of energy efficiency measures and use of local available RES. A good integration from this point of view is reached if both specific figures of final energy use and primary energy use are below a certain limit.

This first step of the assessment presupposes the preliminary calculation of primary energy factors. To allow for benchmarking between communities, unified definitions of factors (like the definitions provided in EN 15603:2008 (1)), are of high importance. In particular for district energy systems, the standard calculation procedure provided in EN 15316-4-5:2007 (2) allows for comparing centralised and distributed energy systems on the same basis, as the distribution losses in the pipelines are considered.

Second step

The second step of the assessment consists in checking whether the chosen renewable energy systems are suitable to cover the energy needs of the considered building stock in terms of capacity and temperature (for thermal systems). In theory, an exergy analysis would be necessary, as proposed for instance in (5) and (6). As the necessary data to perform such analysis is not available for the communities, it is not feasible to implement such analysis in practice.

Consequently, this analysis is done on a qualitative basis by confronting the capacity and the temperature level required by the end-uses and provided by the renewable energy systems located in the communities.

Third step

The architectural integration of renewable energy systems into the urban structure is considered in the third step. Given the state of the art of renewable energy technologies, only solar technologies _both photovoltaics and solar thermal systems_ can be analysed under this point of view. For solar thermal collectors, integration guidelines from this point of view are proposed in (3): the use of a solar energy system as a construction element is seen as being the first step in doing an integration work. As a second step, the “position and the dimension of the collector field should be defined considering the building as a whole” (3).

Fourth step

The last step deals with the technical and operational features of the community energy systems contributing to an optimised use of RES. This part of the assessment deals with the highest variety of technical solutions, as the degree of utilisation of each renewable energy technology can be improved by using different techniques. The techniques can be classified into two categories:

- design techniques (storage, reduction of losses…): the sufficient sizing of storage units in solar thermal systems can be seen as a design feature targeting a higher degree of utilisation of the solar thermal system.

- operational techniques (load management, control strategies…): load management strategies can be used to optimise the use of resources in function of their time availability.

EXAMPLES

The paper does not present already comprehensive results of the quality assessment, since the data collection process is still ongoing and conclusions will be drawn only after sufficient data quality will be guaranteed. Examples are given in order to illustrate the possible outcomes of applying the proposed methodology in some concrete examples of CONCERTO communities.

Three groups of already renovated apartment buildings in Hanover, Turin and Amsterdam, retrofitted in the course of urban regeneration projects, are considered. The implemented measures are described in Table 1: they include an improvement of the thermal quality of the building envelope (major renovation in Hanover, partial renovation in Turin and Amsterdam) as well as different renewable energy technologies and give so far good conditions to be used as case studies. The different steps of the proposed assessment methodology are analysed by following this case studies or including other examples.

	Hanover	Turin	Amsterdam
Thermal insulation of outside walls	X	-	-
Thermal insulation of roof or upper slab	X	X	X
replacement of windows	X	X	X
improvement of air tightness	X	-	-
replacement of space heating system	Individual boiler > district heating	Individual boiler > district heating	-
renewable energy source	District heating including biomass	PV	PV

Table 1: Description of measures implemented

First step

Figure 1 shows the correlations between calculated final and primary energy use figures for heating (space heating and domestic hot water) for the different case studies. Before renovation, all apartment buildings had individual heating systems (individual gas boilers in Hanover and Amsterdam, many different individual solutions in Turin). Assuming a primary energy factor (non-renewable part in the sense of EN 15603:2008 (1)) of 1.4 _corresponding to gas_, all communities are located on the line corresponding to this factor on Figure 1. In all case studies, the renovation measures allow for a reduction of heating energy use, but only Hanover is moving under the line corresponding to a primary energy factor of 1: the use of district heating based on a certain share of RES (arbitrary value of 0.6) makes it possible to reach a higher performance as for Turin and Amsterdam, where no RES is used for heating energy supply.

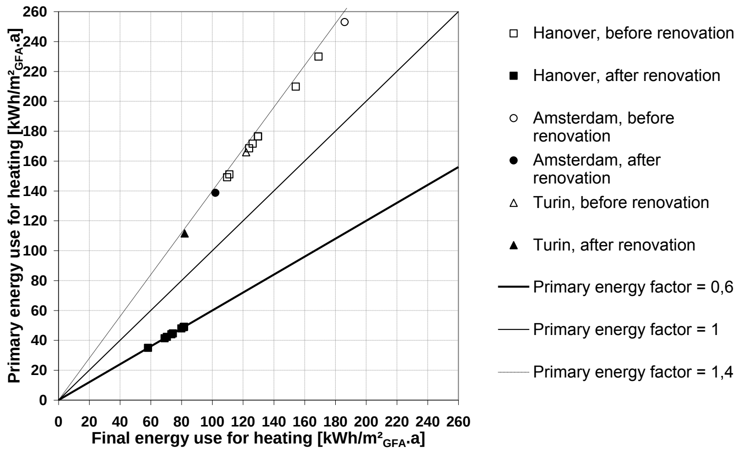

Figure 1: Correlation between primary and final energy use for heating (space heating and domestic hot water)

When Figure 1 would be drawn for the overall energy use of buildings, thus including electricity use, the contribution of photovoltaics installed on the roofs of buildings in Turin and Amsterdam (see Figure 2B) would be included in the assessment. However, no validated figures on electricity use are available at the moment. The calculations will be done in future.

Second step

This step is not relevant for the case studies chosen, as all are using high temperature heating systems. In the case of Hanover, the use of biomass combustion and district heating is a way to adapt the use of RES to the energy quality needed (high temperature heating system in existing buildings). In other examples, mainly for new urban development areas, the use of low temperature heating systems in combination with ground coupled heat pumps or solar thermal systems is a way to minimise exergy losses.

Third step

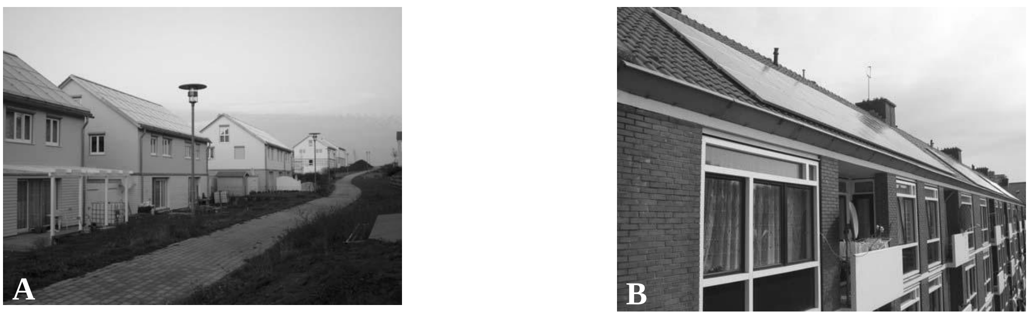

Figure 2: examples of installation of solar thermal collectors and photovoltaic modules

The architectural integration of renewable energy technologies is documented using pictures. For the Amsterdam case study (Figure 2B) and the similar situation in Turin (no picture available at the moment), the photovoltaic panels are installed on the existing roofs, without replacing any tile. This is not seen as “being integrated” in the sense of (3), as the panels don’t have any constructive function, as it might happen in other CONCERTO buildings, like in Neckarsulm (Germany) (Figure 2A) for solar thermal collectors.

Fourth step

In the case studies analysed, only Turin uses a "Community Energy Management System", mainly in doing electrical load management in dependency of the availability of electricity from the photovoltaic panels. This is an example of technical integration of RES at community scale.

DISCUSSION AND CONCLUSION

At the time being, concrete examples were the complete methodology be applied are still under analysis. However, Table 2 proposes a way to give an overview on the different components of the integration quality. The elaboration of an indicator system based on scaling the different degrees of integration will be done when having an overview of the range of measures actually implemented.

	Hanover	**Turin**	**Amsterdam**
Integration from an energy point of view	RES in district heating	*Electricity use data missing*	*Electricity use data missing*
Integration from an exergy point of view	Biomass combustion and district heating	No direct electrical heating	No direct electrical heating
Architectural integration	Not required (district heating)	PV on existing sloped roof	PV on existing sloped roof
Technical integration	-	-	Electrical load management

Table 2: Quality assessment for the case studies

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EXPERIMENTAL STUDY OF DYNAMIC AND HEAT TRANSFER OF NATURAL CONVECTION FLOW INSIDE A DOUBLE SKIN FAÇADE (BIPV)

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ABSTRACT

This study relies on the improvement of Building Integrated PhotoVoltaic (BIPV) systems which provide a free heating source as well as a local electricity production for the building needs. For integrated configurations, PV modules tend to warm up and the electrical efficiency of crystalline silicon technologies decreases then roughly. The interest of the present research concerns the enhancement of the cooling of PV modules by natural convection using the morphology of the photovoltaic-thermal (PV-T) double skin facade. An experimental set-up has been developed at the CETHIL, representing an academic approach of a double skin facade. It's constituted by a vertical channel submitted to homogeneous and non homogeneous parietal heating. Thermal and dynamical studies are carried out in parallel. Evolutions of mean quantities (velocity, temperature, heat transfer coefficients) as well as instantaneous quantity (velocity) are presented in this paper. Results obtained locally highlight the need to look further into the relation between the instantaneous flow-dynamics and its thermal evolution. The latter implies several phenomena taking place on different time scales.

INTRODUCTION

The building sector constitutes one of the most significant energy consumers; inducing then the recent increased interest in the integration of solar energy systems. Integration in facade represents a unique solution due to its potential available surface. The BIPV system considered in this paper is composed by the primary facade of the building separated from a secondary photovoltaic facade by an air gap. The photovoltaic facade is constituted by an alternation of PV panels and transparent window panes letting light enter in the building as shown in Figure 1. The main limiting factor linked to the integration of PV modules in building double-skin facades is that the electrical output is strongly related to the PV cell operating temperature (specially for crystalline silicon cells). It's thus really important to keep a satisfactory cooling of PV modules to maintain their electrical efficiency. The principle is to use the air flow in the gap between facades to cool the PV panels.

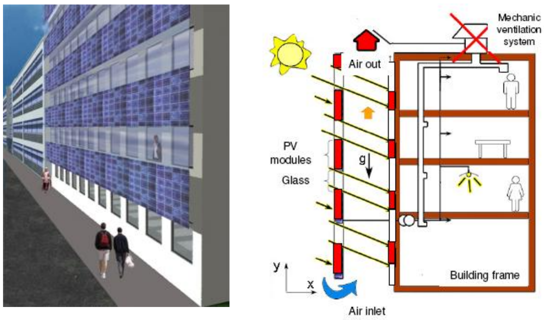

Figure 1: Schematic view of a double skin façade

The main driving force is the buoyancy, which is initiated and enhanced by the alternation of opaque PV modules (heated zones) and transparent windows (non heated zones).

As the development of hybrid (PV-T) systems integrated is relatively recent, few studies fully dedicated to this topic are actually available. Nevertheless, two approaches can be distinguished.

The first one deals with the global study of the real system, that is the complete double skin façade with PV cells and windows. Macroscopic parameters are then considered. At this scale, the determination of the mass flow rate trough analytical expressions has been recently studied by Sandberg and Moshfegh [1] and Brinkworth [2]. In the first study, this quantity is clearly influenced by the position of the PV panels in the facade and the radiation effects in the global balance, whereas in the second one, the expression mainly depends on pressure loss, thermal stratification in the channel and wind effect.

In the second approach, the spatial, temporal and local behaviours are studied. Since this approach gives really rich results not easy to analyse, it’s necessary in a first time, to simplify the complete problem by isolating and analysing a few phenomena implied. The problem considered in this paper appears then to be more academic, that is a vertical channel submitted to non homogeneous parietal heat solicitations. Convection heat transfers as well as the dynamic behaviour of the fluid flow between vertical walls are studied through simplified thermal boundary conditions. The Rayleigh number concerned in this paper is about $6x10^7$. Related to this configuration, other many applications such as heat exchangers or electronic components cooling are found in the literature works. Heat sources position, distribution, intensity and size have been considered in order to increase heat transfer. The effective result of a non uniform distribution of heat sources is presented by Dutta et al. [3]. In particular, in Zhang and Dutta [4], the coefficients reach the maximum values when heated sources are placed in the bottom of the channel. Sandberg and Moshfegh [5] also observed the strong influence of heat sources position on the mass flow. They work with inclined channels. Hernandez and Zamora [6] contribute to the position and distribution study of Zhang and Dutta [4], by adding that is the strongest intensity of heat source, the one that should be placed in the bottom part of the channel. They present as well the clear sensitivity of fluid properties in thermo physical variations. The optimal size and distribution is also presented by Da Silva et al. [7] through an interesting numerical study. Ayinde et al.[8] contribute to the dynamic study by observing (PIV system) the influence of Rayleigh numbers ($2x10^6$ to $8x10^6$) and channel aspect ratios in velocity profiles.

Nevertheless, few experiments dealing with natural convection in vertical channels submitted to non homogeneous parietal heating and under the Rayleigh number concerned in the applied configurations are actually reported [9]. Moreover in this detailed approach, few studies present the thermal and the dynamical analyses in parallel and more than that try to do the link between both.

The first part of the paper includes the description of the experimental apparatus as well as the instrumentation used for the thermal and dynamic measurements. In the results section, the first part presents a discussion between velocity and heat transfer mean profiles for three different heating configurations, whereas the second part includes the instant component of dynamical flow behaviour

METHOD

Configuration of the study

The experimental set up developed at CETHIL is presented in Figure 2.

The air channel is made by two parallel walls (1.5 m height, 0.70 m depth) with an adjustable distance *d* in between them. In this study, the aspect ratio of the channel *d/H is 1/15.*

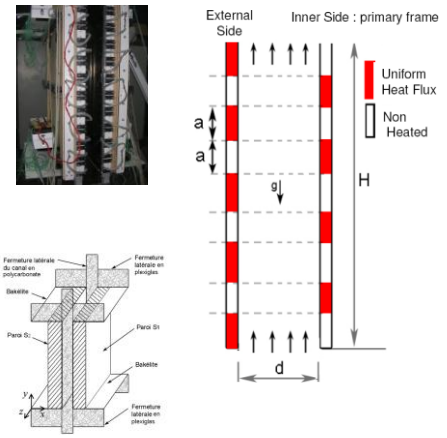

Figure 2 : Experimental Apparatus

The two plates are heated by Joule effect trough 2x15 stainless steel foils that are independent. These heating bands are placed in the inner side of the channel walls modelling merely the solar collectors.

The maximum wall heat flux of this experimental set-up is 500 W/m^2 which corresponds to maximum incident radiation flux density on a vertical wall in France. In this paper, results are presented for an injected heat flux of 230 W/m^2. The ratio heated zone/channel height, namely *a/H*, varies between 1/15 and 1. Case 1 and case 4 correspond respectively to the smallest (10cm) and the biggest (40 cm) periodicity of heated zone and reference case, to one uniformly heated wall.

Instrumentation

Wall temperature fields have been measured by 205 thermocouples of k type. Local convective heat transfer coefficients are determined by an indirect technique trough evaluation of conduction loss and radiation exchanges. Details can be found in [10]

Dynamic study and measurements are carried out with a La Vision particle image velocimetry (PIV) system. The system consists of a laser unit, a camera, a frame grabber, a synchroniser, and a data reduction software (Davis 7.2). The camera is of size 2048x2048 pixels with a frame rate of 7 Hz (for this study). Silicon oil DEHS is used as the seeding element and the droplets generated size is <1µm. The jet is injected from the low part of the experimental set up. There was a 30 minute time lapse between the seeding particle process and the beginning of the measurements, in order to avoid any influence on the natural convection flow. A minimum of 200 image pairs have been recorded for each exposure.

RESULTS AND DISCUSSION

Velocity and thermal mean profiles

Mean velocity profiles are shown in figure 3 at two channel heights (*y/H* = 0.53 and 0.99) that corresponds to the central and the exit regions of the channel. The vertical evolution of local convective heat transfer along the y-direction of one wall is presented in figure 4.

Central region (*y/H*=0.53) Exit region (*y/H*=0.99)

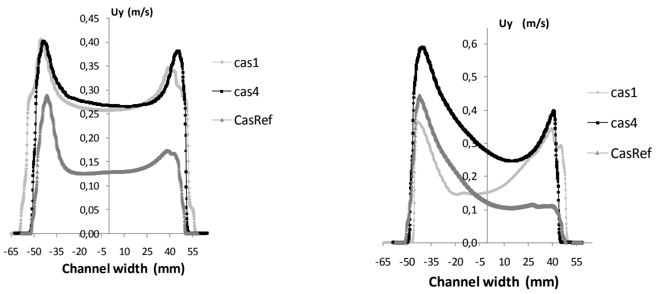

Figure 3: Mean vertical velocity profiles in two regions

Two peaks of velocity are localized (figure 3) in the close wall region for non uniform heating configurations. In the exit region, these two periodic configurations present a clear dissymmetry in the velocity profile in concordance with their respective alternation.

Comparing the three studied cases, highest mean velocities are obtained as the size of the heating source is bigger.

Indeed, regarding the mean velocity profiles, the configuration with biggest size of heating sources induces a better chimney effect. Regarding now the heat transfer coefficients obtained experimentally (figure 4), we observe that for both cases 1 and 4, heat transfer coefficient decrease on each heating zone from the leading to the trailing edge.

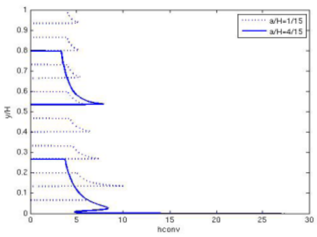

Figure 4:Heat transfer coefficients for case 1 and 4

If the inlet section is omitted, heat transfer coefficients are highest (20%) for the smallest periodicity, which corresponds to a multiplication of leading edges.

As a conclusion, even though large heating periodicity induces a better chimney effect, highest heat transfer coefficients are obtained for the smallest periodicity. Since the aim of our work is to cool PV panels, we need to go deeper on the dynamic and thermal characterization of non homogeneous parietal heating. Local indicators are thus required.

Instant dynamical behaviour (PIV) and vertical velocity fluctuations

Results presented in this section correspond to the homogeneous heating configuration, that is one wall (S1) uniformly heated along all the height. The second wall (S2) is non heated.

Temporal evolution of the flow in three different sections (inlet, central and exit regions)

Figure 5 shows the temporal evolution of the vertical velocity component at three heights of the channel (inlet, central and exit regions). The results have been obtained at a distance of 3 cm taken from the wall.

The inlet region of both sides of the channel presents a stable behaviour without significant fluctuations. In the central region, mean velocity is almost similar for both sides of the channel. However, the magnitude of fluctuations increases by a factor of 4 compared to the inlet region.
The exit region presents discrepancies between the results obtained for each side of the channel. Mean velocity increases by a factor of 3 close to the heated side with an evident increase of fluctuations, a characteristic which is the expression of a really perturbed flow. It is consistent with the dynamic structures observed in this zone and shown in Figure 6. Note that this kind of behaviour appears lower in the channel (see central region of the channel in figure 6 and figure 7). That requires a particular and complete investigation.

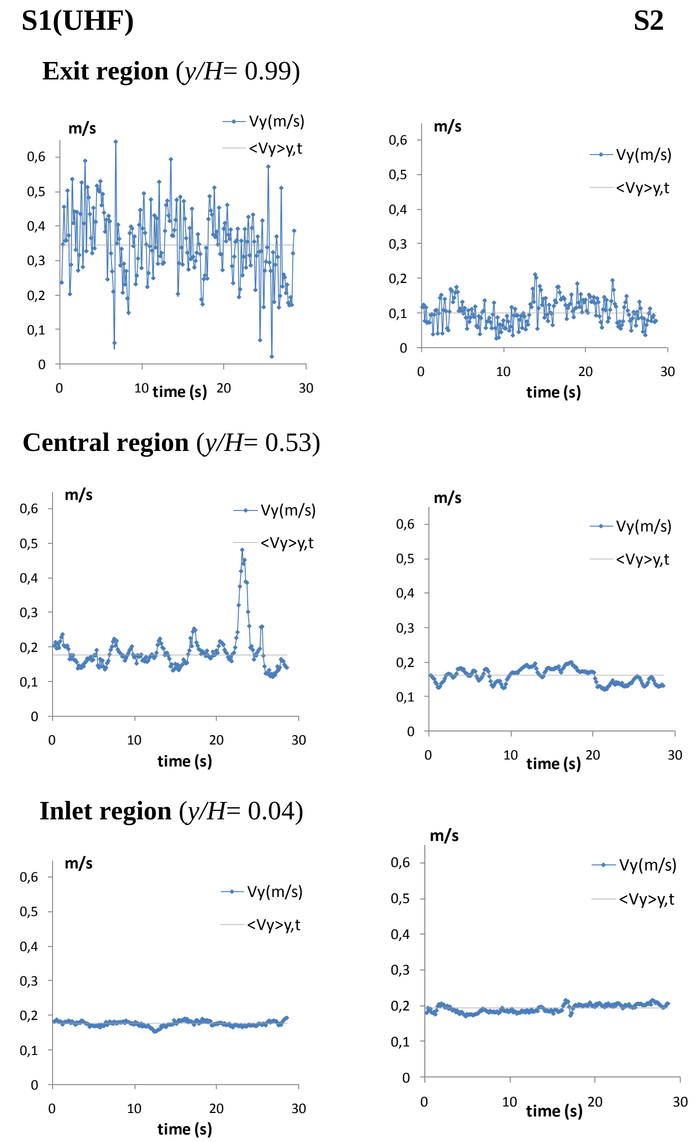

Figure 5 : Velocity fluctuations along the channel

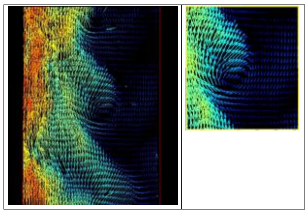

Figure 6: Vortex at exit region

Mean velocity in the outlet region (0,345 m/s) almost doubles the mean value of the inlet region (0,17 m/s). Indeed, the magnitude of fluctuations increases by a factor of 12.

<u>Temporal parietal structures observed in the flow</u>

In figure 7, the temporal evolution of a plum close to the uniform heated wall (S1) and for the central region of the channel is presented at three different times (t_0,t_1,t_2). Greater velocities are represented by darker grey while lower velocities by light grey. These plums appear locally at the wall, grow quickly and leave the wall, being then advected by the mean flow. This process doesn't develop in a uniform way but is presented in a repetitive way. This repetition as well as the plum's structure, needs to be studied in depth in order to clearly determine the frequency of the process, the characteristic size and the energy carried through this process and the relative structures. The knowledge of all these quantities will help to understand how enhances the heat transfer close to the wall and as a consequence, the refreshment of PV panels.

CONCLUSION

This paper deals with an experimental study of thermal and dynamical behaviour of a natural convection flow developed in a vertical channel submitted to localize thermally active areas distributed along the vertical channel.

Even though the chimney effect is lower for small periodicity and for the same injected flux, results indicate that this morphology is the most appropriate for the studied configuration. Local structures which evolve temporally are observed.

The analysis of the dynamic measurements indicates that the regime of the flow considerably evolves from the inlet of the channel to the outlet. Local observations have also emphasized other characteristic times such as the ones involved in plum's formation. All these results have to be studied in depth in order to complete the knowledge on the complex and interrelated phenomenon involved in the energy behavior of BIPV components.

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BUILDING INTEGRATED CONCENTRATING PHOTOVOLTAICS

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ABSTRACT

The building integration of concentrating photovoltaics is a new field for the application of solar energy systems and new system designs have been investigated at the University of Patras. The diffuse reflectors increase PV electrical output with satisfactory results. Fresnel lenses with linear absorbers of PV or hybrid PVT type can be used for the conversion of solar radiation into electricity and heat and also for illumination and temperature control of interior building spaces. Another mode is the combination of symmetric or asymmetric CPC reflectors with tracking linear PV strips and stationary thermal absorbers. Some architectural designs of building integrated low concentration photovoltaics is the subject of the present paper. System designs and architectural images give a figure of the investigated concentrating photovoltaics that aim to efficient and aesthetic building integration.

INTRODUCTION

The concentrating solar systems use reflective (parabolic, Fresnel, CPC and flat type reflectors) and refractive (Fresnel lens) optical devices and are characterized by their concentration ratio *CR*. Concentrating systems with CR>2.5X use a system to track the sun, while for systems with CR<2.5X, stationary concentrating devices can be used. Concentrating photovoltaics (CPVs) seems to be the most viable method to reduce the cost of the direct conversion of solar radiation to electricity, as the flat type PV modules can be replaced by a cheaper solar radiation concentrating system, which converges the solar rays to a PV module of smaller surface area than aperture. In addition, CPV solar energy systems present higher efficiency than the typical flat PV modules, but concentration is effective in case of high ratio of beam solar radiation, homogenous distribution of it on PV cells and effective cooling of them, to keep low their temperature.

In Photovoltaic/Thermal (PV/T or PVT) solar collectors, although electrical and thermal output is high if they operate at low temperatures, it is more practical to provide heat at a considerable fluid temperature, but keeping the electrical output at a satisfactory level. The electrical and thermal output, although are of different value, it is usual to be added in order to give a figure of the hybrid system total (electrical and thermal) energy output. In PVT systems the cost of the thermal unit is the same irrespective if the PV module is constructed with crystalline-silicon (c-Si), poly-crystalline silicon (pc-Si) or amorphous-silicon (a-Si) type of cells. Thus the ratio of the additional cost of the mounted thermal unit per PV module area cost is different and is almost double in case of using a-Si compared to c-Si or to pc-Si PV modules.

The PVT systems can be divided according to their operating temperature in low (up to about 50°C), medium (up to about 80°C) and high temperature (>80°C) systems. The PVT systems based on typical PV modules that aim to provide heat above 80°C have lamination problems due to the high operating temperatures and need further development. The solar energy systems that combine concentrating photovoltaics with thermal collectors in the same device are the Concentrating PVT collectors (CPVT systems). These systems consist of a solar radiation concentration system and their thermal unit operates with water, air or other fluid circulation, to extract the heat and keep PV temperature as low as possible. They can provide simultaneously electricity and heat, like the flat type PVT collectors, but due to the higher level of achieved fluid temperature these devices aim to become more practical and cost effective. In these systems PVT absorbers are combined with low, medium or high concentration devices, but PVT systems of low and medium *C* ratios have been mainly developed so far.

The facades and the horizontal or inclined roofs of buildings constitute appropriate surfaces for an expanded use of photovoltaics and their effective integration should be adapted in a harmonic way to the building architecture. The several types and forms of PVs constitute new and interesting material, which can be easily integrated to the buildings, giving new shapes and a symbol of the ecological concept. It is also a new material in the architect's hands, ready to be shaped and to create alternative buildings. Apart of the typical forms of PV modules, several new designs of CPVs have been recently developed and addressed to building integration and in the commercial sector, some CPVT models have been introduced in the market, as of Heliodynamics, Arontis, Power-Spar, etc. In Physics Department at the University of Patras a longtime research on solar energy systems has been performed and many collector figures have been suggested. The recent research work is mainly focused on building integration of solar energy systems and the concentrating photovoltaics is one of the favorable issues. Architectural designs based on new CPV or CPVT collectors is the subject of the present paper and these examples show the potential for a wider application of solar concentrating systems on buildings.

UPATRAS INVESTIGATIONS AND ARCHITECTURAL DESIGNS

Apart of the typical forms of PV modules, some new designs of concentrating photovoltaics (CPVs) have been recently developed and addressed to building integration. In this field the University of Patras has investigated some new modes of low cost CPVs [1-7]. The diffuse reflector concept is a first mode to increase PV electrical output [1-3] with satisfactory results. A second mode is to use linear Fresnel lenses with PV or PVT absorbers [5]. These systems can be used not only for the conversion of solar radiation into electricity and heat but also for illumination and temperature control of interior building spaces. The third mode is the combination of symmetric or asymmetric CPC reflectors with tracking linear PV strips and stationary thermal absorbers [6,7]. New architectural designs of building integrated solar energy systems of the above mentioned concentrating photovoltaics, focused on flat type reflectors and Fresnel lens or CPC reflector type concentrating devices, is the subject of the present paper.

In the previously referred works [1-3] the concept for the use of diffuse reflectors in combination with photovoltaics or PVT absorbers was analyzed, while in the present paper some new views of architectural designs are presented. In Fig. 1 the design of a building having a saw tooth roof is presented, where on the one side solar collectors (of thermal, PV or PVT type) are placed, together with the glazing, while the opposite roof side is covered by the reflector. In case of thermal collector the reflector can be specular while for PV or PVT collector the reflector should be diffuse to achieve homogenous distribution of solar energy on cell surface. The use of glazing permits a part of the radiation to be transmitted inside the building for the natural lighting of the space. Fig. 2 gives an image of a more clear application of photovoltaics on buildings with inclined roofs, where the diffuse reflector is the effective solution for a complete stationary concentrating solar system. Experimental results have shown the considerable contribution of the diffuse reflector to PV module electrical energy output. The suggested combination has a cost increase of about 10%-15%, as the diffuse reflector can be of low cost material and the gain in electrical output is about 25%-30%, thus there is a net gain of about 15%.

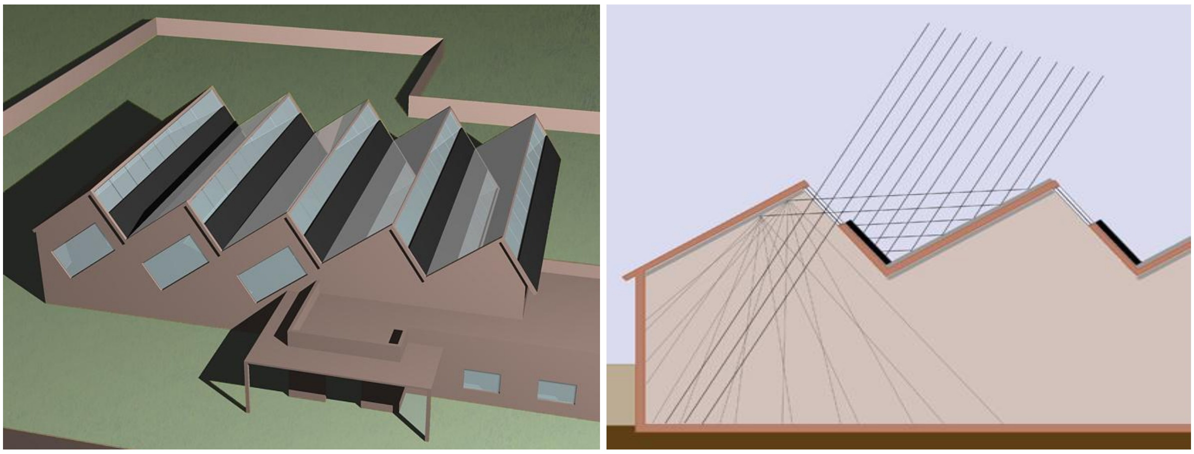

Fig. 1 Architectural design (left) and cross section (right) of building integrated PVT collector combined with booster reflectors and internal space lighting

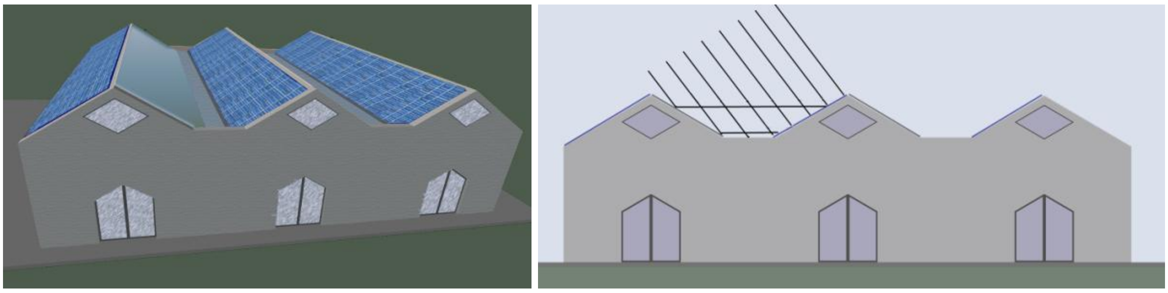

Fig. 2 Building integrated PV or PVT collectors combined with booster reflectors

Linear flat or curved Fresnel lenses and parabolic or CPC type reflectors have been considered to constitute CPVT collectors. These collectors can be used separately on flat or inclined building roofs, or can be mounted on building, being part of its structure. The new concept for the lenses and reflectors is that the optical concentrating elements can be stationary while the absorbers track the peak of the converged solar rays. In this case the diffuse radiation and a part of the beam radiation can be conversed into heat by the thermal absorber. The new designs with the Fresnel lenses are shown in Fig. 3 and the CPC reflectors in Fig. 4. In these designs the tracking PV strips follow the converged rays and the rest rays hit the thermal absorber to provide heat. The geometries of Fig. 3 have been preliminary studied in laboratory scale experiments, to observe some practical aspects regarding their operation and performance, to decide for the effectiveness of these designs. Considering the designs with the CPC reflectors, there are two main modes of parabola axis orientation, towards the winter (Fig. 4b) or the summer (Fig. 4c) solstice. The distribution of solar radiation on the focal plane is of importance for the effective conversion to electricity and the optical measurements give an idea about the limits of such mode [7]. The obtained figures are promising for applications, as the converged solar rays give a short width image on the focal plane for the tracking absorber and among the three designs of Fig. 4 the asymmetric CPC configurations are of special interest. The thermal element can be a thermal absorber as of a metallic sheet with pipes and the photovoltaic part of the system to be a PV strip of suitable width, tracking the converged radiation in front of the thermal absorber.

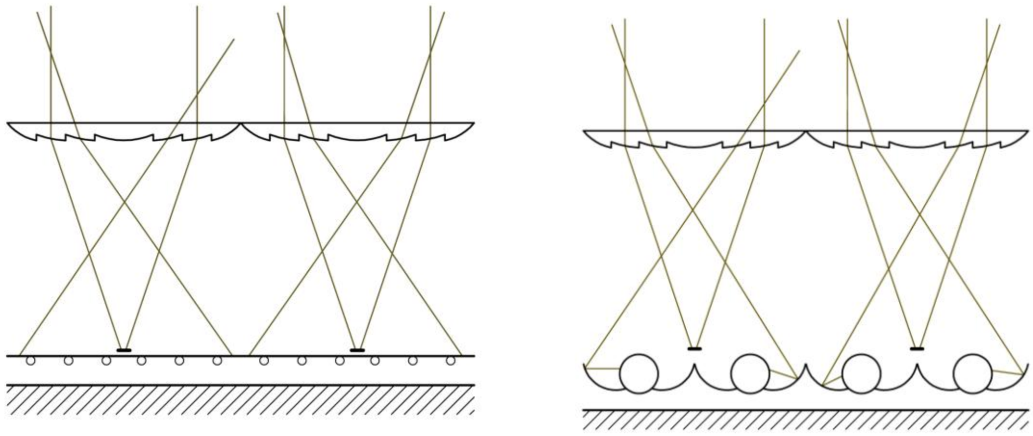

Fig. 3 Fresnel lens/PV strip with flat (left) and tubular (right) thermal absorber

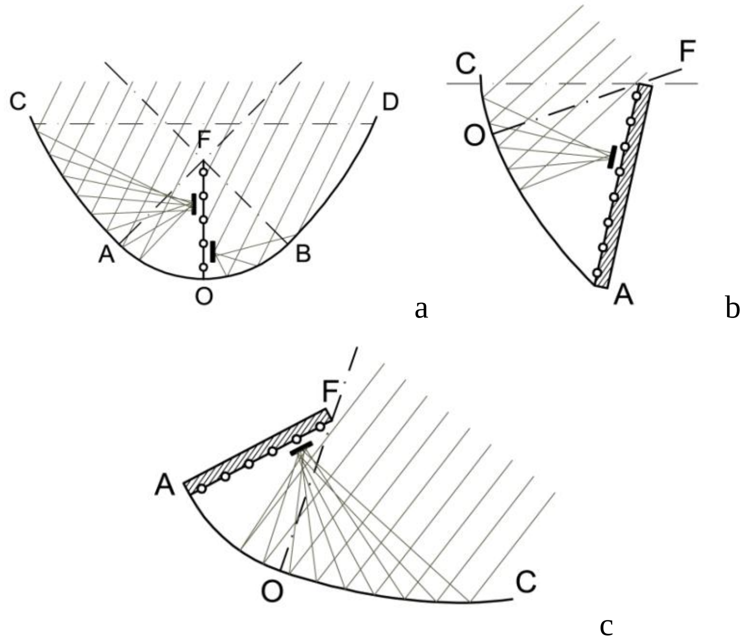

Fig. 4 The CPC reflector concept of symmetric type (a), with axis oriented to winter (b) and with axis oriented to summer (c) solstice

OTHER ARCHITECTURAL DESIGNS

In Figs 5-9 the architectural designs give an idea about a possible view of building integration of the investigated CPVT systems. Fig. 5 shows the use of Fresnel lens glazing with tracking linear absorbers. In this case the system converses the beam radiation into electricity and heat, while the diffuse radiation is spread in the interior building space. The basic advantage of such figures is that the building interior space can be controlled in illumination and temperature, avoiding the consumption of conventional energy sources to achieve these conditions. In Fig 6 the building integration of large CPC reflectors with tracking PV or PVT absorber on the rear side of the front placed building is shown. This design is a suggestion for buildings that are built in groups and where the orientation of the buildings is adapted to the South.

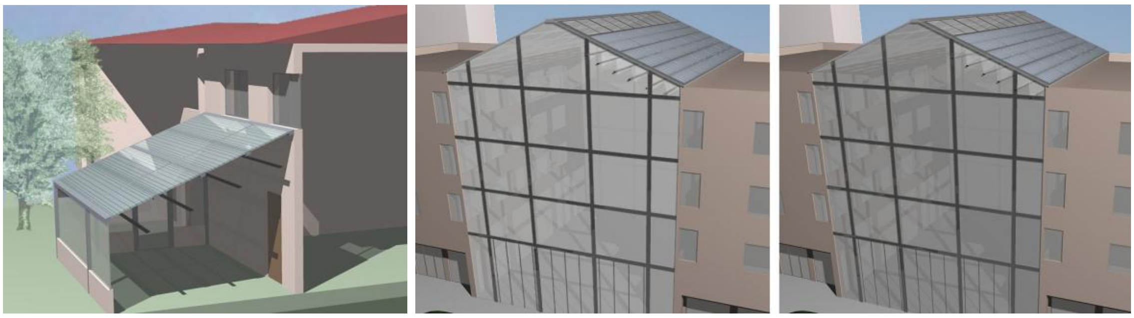

Fig. 5 Architectural design of building integrated Fresnel lenses with linear PVT absorbers

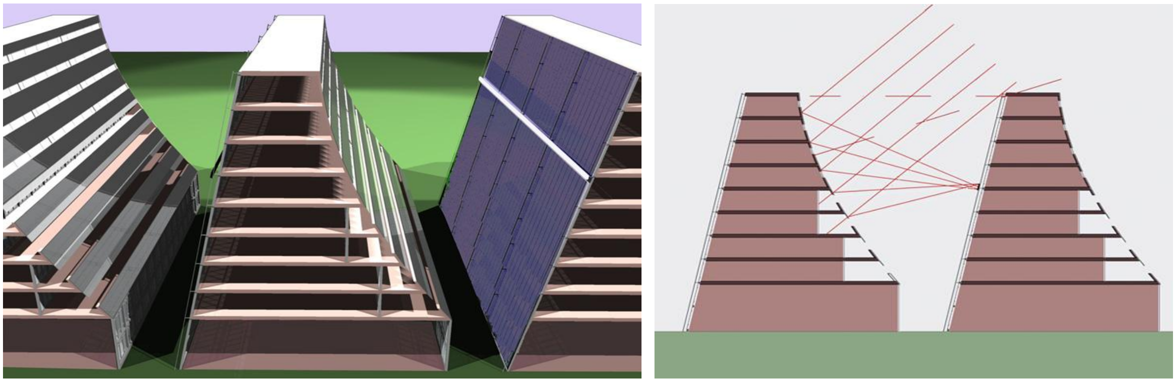

Fig. 6 Building integration of stationary reflectors with tracking PV or PVT absorber

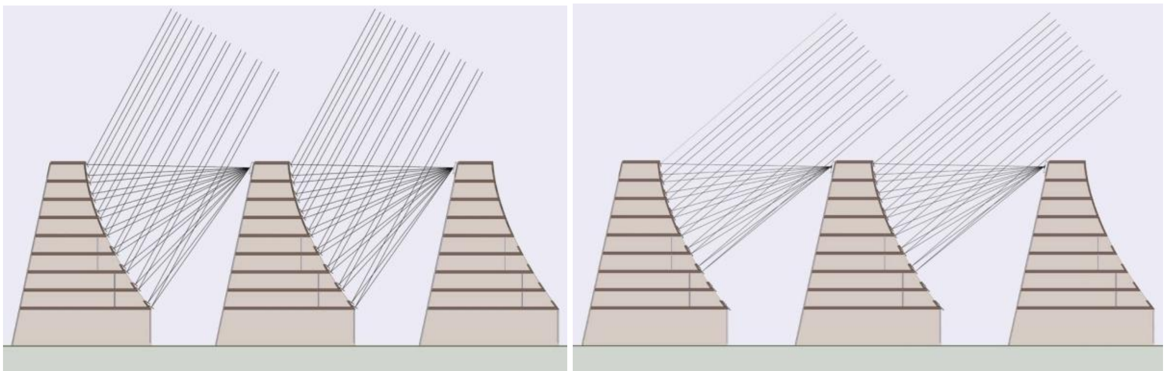

Fig. 7 Building integration of movable reflectors with stationary PV or PVT absorber

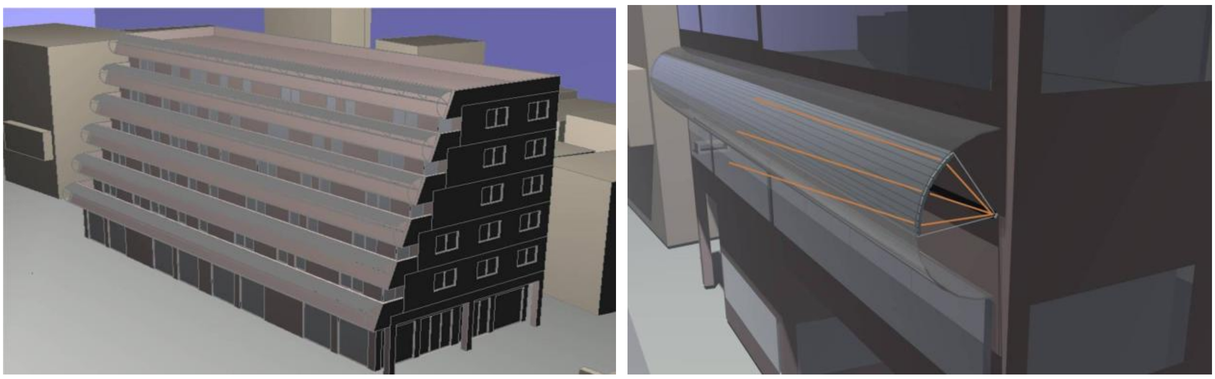

Fig. 8 Building integration of rotating curved Fresnel lenses and stationary PV or PVT absorber

It should be noticed that the reflectors can be mounted on building balconies or could be moving, combined in this case with stationary absorber, which could be mounted on the top of the front placed building, as it is shown in Fig. 7. The next figure (Fig. 8) shows a building integration of curved linear Fresnel lenses, where the lens is rotating following the sun elevation, while the absorber (thermal, PV or PVT) can be stationary. The shown system is mounted on building balconies, but it could be also placed on several other parts of building structure. Finally, in Fig. 9 the invisible solar collector is suggested, where asymmetric CPC reflectors combined with tracking photovoltaic strips and stationary thermal absorbers are presented. These systems are mounted on the inverted surface of building balconies, over the doors and windows.

Fig. 9 Building integration of CPC reflectors with tracking PV or PVT absorber on the rear side of the front placed building

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MODELING BY MEANS OF EQUIVALENT THERMAL NETWORK

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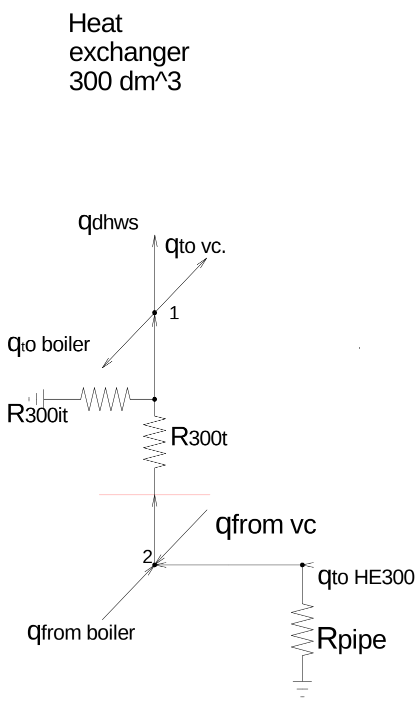
ABSTRACT

The paper describes a model called Equivalent Thermal Network that is used by the authors to analyze complex heating systems of renewable energy. The special application for this multi-purpose model is the analyses of systems that consist of several elements converting solar energy and ground thermal energy.

Such systems can include passive elements to convert solar energy, pipelines carrying flows of media, flat plate solar collectors, vacuum solar collectors, ground exchangers of different structure, heat exchangers in the form of water tanks with or without coils, flat plate heat exchangers with a flowing medium. In wider perspectives, the complex systems of renewable energy sources can also employ the other forms of energy such as electric energy generated from photovoltaic panels and bio-gasoil boilers or heat pumps. Some other forms of renewable energy are usually not modelled by this method because it is used to simulate energy flows in urban buildings. This network enables to show and analyze energy transfer and heat accumulation by means of different media in the same network.



The presented example of equivalent thermal network is created for a volume heat exchanger with a coil. The model in this case is divided in two nodes that reflect:

1- flows q into the tank and a part of pipelines with their thermal resistance R,

2- flows out of the tank, the coil, the vessel and its insulation with their thermal resistances.

Such thermal network can also reflect temperature in nodes and their thermal capacity (mc) in transient states.

The paper describes the most important aspects of the whole model for a complex system of renewable energy sources constructed and monitored in an educational centre. It also points out some conclusions resultant from the simulation analysis performed by means of the model and its verification on the basis of measurements taken on the real object.

INTRODUCTION

The concept of equivalent thermal network results from thermal – electric analogy. The idea generates such values as: thermal resistance, intensity in the form of thermal flux density and difference of potentials in the form of temperature difference. This reasoning leads to another concept of thermal induction resistance which can be important during heat transfer occurring in subsequent cycles of heating and cooling processes, especially in volume thermal exchangers. These cycles are related to the performance of municipal heating systems specific for blocks of flats or public use buildings where their energy is produced, cumulated and then distributed to particular users. On return flow of colder medium from heating devices the next cycle starts. There is also a similar cycle when cold water enters hot water system in the result of hot water usage. It can be assumed that the number of cycles is equal to the number of turns on of a boiler that delivers hot medium to a heat exchanger. Because of medium thermal inertia, this interesting component of thermal resistance reduces the drag force of heat transfer in the exchanger. Some new possibilities to present different forms energy in one diagram resultant from mathematical and physical description, emerge if thermal phenomena are brought to a model relevant to any electrical network consisting of resistors, capacitors, branches, coils, sources and even grounding.

Hybrid systems in the aspect of energy generation are the ones that combine transport of different media and delivery of various forms of energy coming either from renewable sources or from conventional boilers that combust traditional fuel. The primary idea of hybrid systems should be the most rational integration of available resources at particular location and the character of a considered object but not the intensive use of all renewable forms of energy in one complex system.

In municipal network applications of hybrid systems, the possibilities to change the location of particular devices for energy conversion or to reserve space for storage of ecological fuels, are very limited and the restrictions are usually precisely formulated.

Supply systems combining different energy sources require proper evaluation of share proportions for particular component units to avoid exaggerated dimensioning because energy effects may not justify incurred investment cost.

That is why, taking into account available resources (including financing), environment protection aspects and urban determinants (including social adaptation), the design processes should be carried out with special attention paid on control systems and their simulation analyses prior to final verification of designs.

METHOD

Hybrid system

The Equivalent Thermal Network enables analyses for design and prognosis processes of energy effects for newly developed buildings or modernized systems. It takes into account hot water and heating systems combining solar collectors of any kind, heat pump with a system of ground collectors, solar walls and a traditional boiler together with a system of photovoltaic panels. The effects can be estimated either on some roughly collected data or calculated from the precisely designed system or at any stage of the process. The early made estimations can benefit tender processes and all intermediate simulations enhancer control processes having on mind sustainable development.

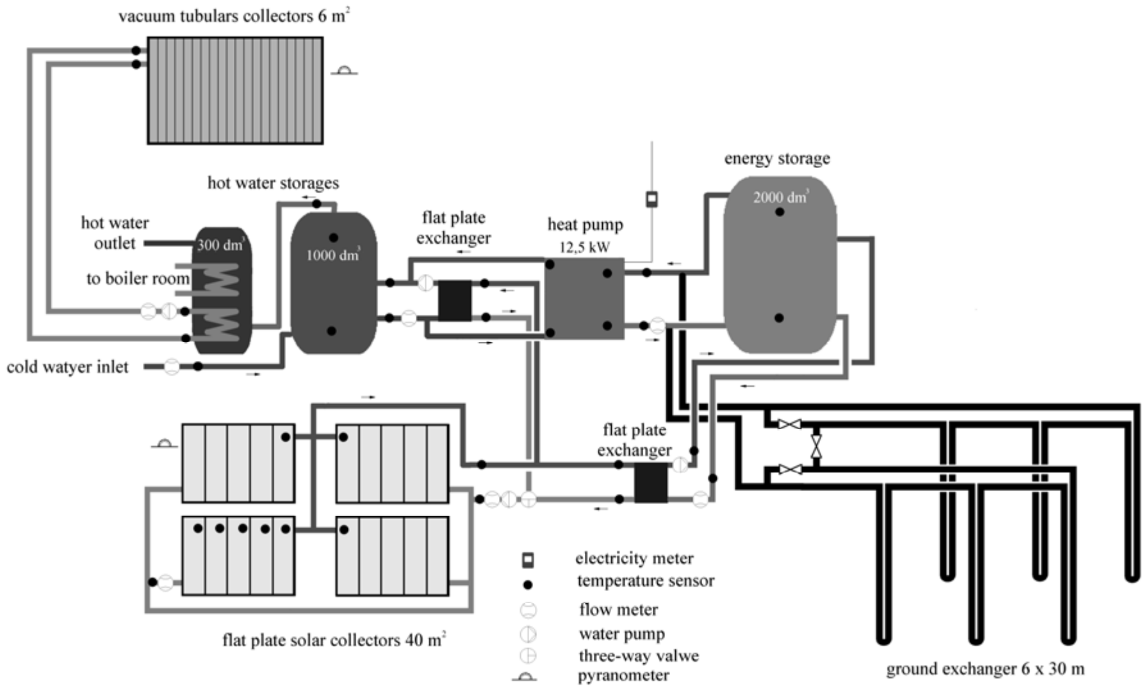


Fig. 1. The hybrid system flow chart

The hybrid system flow chart is presented in Fig.1. The solar collectors have the superior role in the whole system. The other elements such as the heat pump and the ground collector start their inputs when solar availability is less than the heat demand from the building. This demand has dominant role in the system. The input from the building appears e.g. in the form of hot water demand. The main purpose for the system operation is to provide as much supply as possible from renewable sources of energy. This depends very much on solar energy availability, ambient temperature and ground conditions which, in turn, is dependent on local environment and climatic conditions. Moreover, the interior temperature can be raised, thanks to the additional solar passive system e.g. in the form of diode walls. This system could influence the whole building directly, if incorporates exterior walls, or indirectly, if a solar wall is located only in the heat exchanger room.

The system incorporates different forms of energy, i.e.: heat (consisting of solar thermal among others) which is a direct input to the heating system, solar photovoltaic and power from mains that are indirect inputs to drive pumps or a heat pump. The whole systems is localized in the educational centre

Equivalent Thermal Network

The main assumption for the model is to base on absolute temperature values providing the possibility to compare energy flows from different media. This is necessary when heating media flow in the same direction as the temperature gradient. This phenomenon occurs whenever accumulation tanks or vessel heat exchangers are taken into account. The example of Equivalent Thermal Network is presented in Figs.2 and 3. The element shown in Fig. 2 models a single solar collector. Each node reflects a homogeneous element such as: a glass cover, an absorber and medium flow. All elements have relevant thermal capacity (mc) and thermal resistance (R), temperature is nodal potential (T) and power (P) can be generated in nodes, if this is the case such as the glass cover where solar radiation enters this layer (node1) and then its energy is generated in the form of thermal radiation, conduction and convection in the absorber (node2). No power is generated in the third node, which is medium flowing out of the collector. The environment is usually marked by “0” symbol.

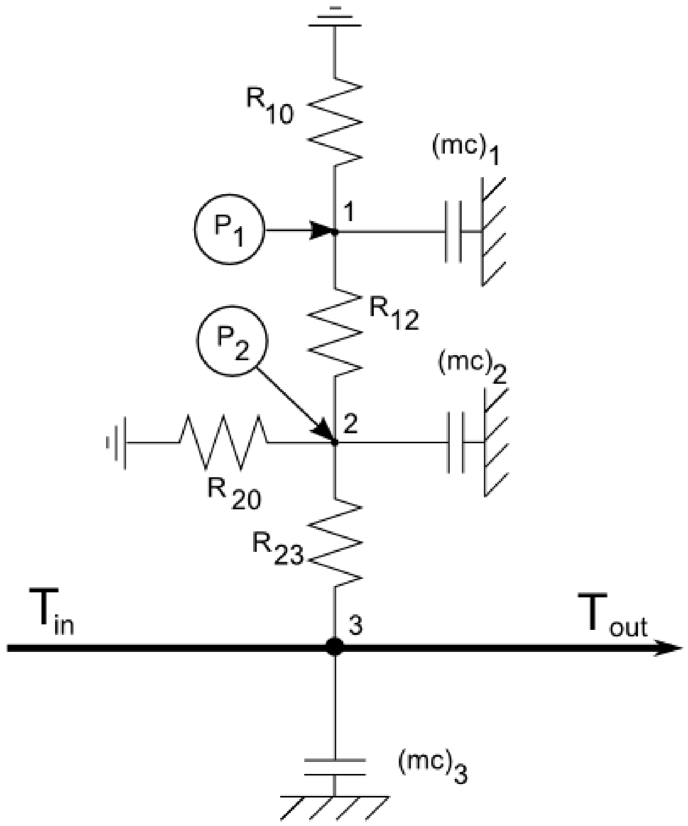


Fig.2. Equivalent Thermal Network for one collector in a transient state.

Attempting to the design process, only the constant values are required and then the steady state model is usually sufficient. When the system has been designed, the particular data can be introduced to the mathematical model and then dynamic simulations are reasonable taking the advantage of a transient model incorporating thermal capacities.

The mathematical model for such networks has to be based on matrix formulae composed on the system of differential equations of the first order, one for each node [3, 4]. Computations are performed according to the general formula of thermal balance for the network consisting of nodes and branches (eq. 1):

$$(mc)_i \frac{dT_i}{dt} + T_i \sum_{\substack{j=0 \\ j \neq i}}^{n} \frac{1}{R_{ij}} - \sum_{\substack{j=0 \\ j \neq i}}^{n} \frac{1}{R_{ij}} T_j = P_i + \frac{T_o}{R_{io}} \tag{1}$$

where:

$(mc)_i$ - thermal capacity of particular elements,

R_{ij} – thermal resistance of the elements allocated to the node,

P_i – nodal power, which can be expressed by solar gain.

Total solar gain I_T is usually calculated as the sum of three: direct beam radiation I_b, dispersed component I_d, reflected component Ia. It is interesting that this power can be dynamically modelled, according to the following solar energy gain equation, depending on geographical localization, hour (t) and day (n), according to the formula (eq. 2) [3, 4]:

$$I_T = I_b \cdot \frac{\sin\delta \cdot \sin(\phi-\beta) + \cos\delta \cdot \cos(\phi-\beta) \cdot \cos[n \cdot (12-t)]}{\sin\delta \cdot \sin\phi + \cos\delta \cdot \cos\phi \cdot \left[\frac{12}{\pi} \cdot \left[\sin\frac{\pi}{12} \cdot t - \sin\frac{\pi}{12} \cdot (t-1)\right]\right]} + I_d \frac{1+\cos\beta}{2} + I \cdot a \cdot \frac{1-\cos\beta}{2} \tag{2}$$

where:

ϕ -latitude;

δ - declination,

β – tilt angle

a - albedo.

Thermal capacity can also be a dynamic value when flow plate heat exchangers (consisting of: water flow – v_w , solid elements – e, and connected pipelines - p) are considered (eq. 3):

$$mc_i = \dot{m}_{v_w} c_w \cdot t + m_e c_e + m_p c_p \tag{3}$$

where $\dot{m}_{v_w}$ can be treated as water flow in time interval.

In practice, the elements of the equation, in particular systems, depend on allocation of physical elements (e, p) to the nodes reflecting the set of exchangers. One volume heat exchanger can be modelled by e.g. two nodes, one belonging to the primary flow and the other one – to the secondary flow, and even by four branches – each pair: inlet and outlet, belonging to one flow. Thermal resistances R_{ij} should be calculated for particular case of thermal flux considering conduction, convection and radiation. In some special cases, when heat accumulation occurs, especially in hot water storage tanks, thermal induction starts matter and can also be taken into consideration. However, the induction resistance has been established at the level between 0.1 and 0.5% of summary value for accumulating nodes and its influence to temperature distribution in relevant nodes is minor.

The dynamic of the system can be expressed not only by mc elements (eq. 3), but also when particular power can be expressed by means of time dependent function (eq. 2). This makes the necessity to compute systems of second order equations. The authors used MathCad to perform computations [1, 3]. Collectors can be connected in series and in parallel which can be presented in the more extended form of ETNetwork, as shown in Fig.3.

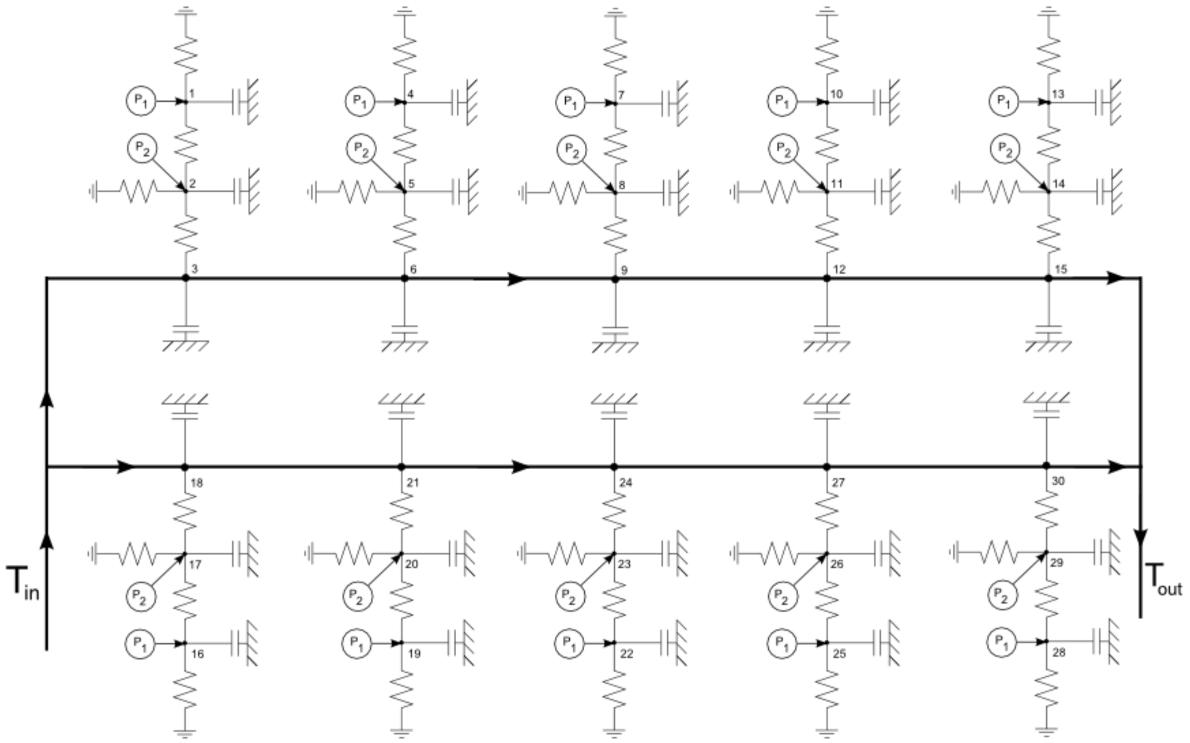


Fig.3. The battery of flat plate collectors in the hybrid system presented as Equivalent Thermal Network.

RESULTS

Some generalized results can be presented in the form of a comparison graph where measured values of node 3 (Fig. 2) and hot water outlet from the 300 dm^3 storage (Fig. 1) and simulation results for node 3 are collected in one exemplary daytime.

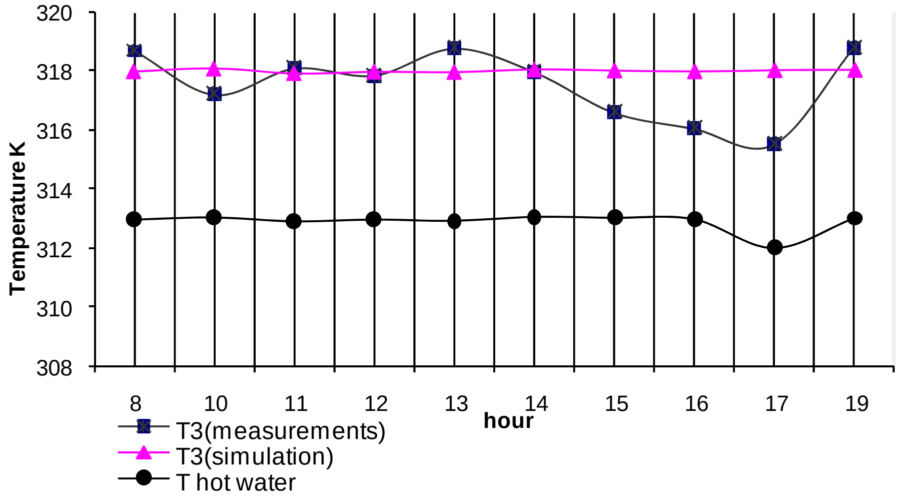


Fig. 4. The comparison graph for simulation and measurements in an exemplary daytime.

More detailed description of mathematical models used in the analysis, measurements taken and some other hybrid systems examined by the authors were presented in the reference literature [1, 2, 3, 4].

CONCLUSION

The results of the whole performed analyses give the basis to evaluate the energy effectiveness of planned enterprise, where the cycle of heat and other energy demand is in some coincidence with the availability. The ETN method takes the advantage of a model based on absolute temperature and general energy units, that is why, it can be used to calculate equivalents between available forms of energy.

The comparison between the computation results and taken measurements indicates that at the stage of design process, the energy effects can be evaluated by means of a suitable equivalent network for particular planned investment process before it is realized. The other advantage of this method is that it enables also estimate calculations which, in turn, let us estimate energy effects at the stage of a tender process. Moreover, there is a possibility from simulations to predict temperature values in particular elements of the system and thus, the analysis can be used to work out more detailed control systems.

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URBAN INTEGRATED SOLAR SYSTEMS
DEFINITION OF CRITERIA FOR THE ARCHITECTURAL INTEGRATION OF SOLAR ENERGY TECHNOLOGY

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ABSTRACT

The optimisation of solar gains and a better performance of the buildings thermal envelop entail a reduction of the energy demand of the existent housing estate, while energy production from renewable energies allows to reduce carbon dioxide emissions and to assure a local supplying of energy thus more reliable and consistent.

To compensate the escalation of energy demand plans of incentives have been developed for the utilization of solar passive, and especially, solar active technologies. Consequently the amount of solar installations on the territory is constantly growing. To prevent an indiscriminate use of solar application is necessary to analyze various method of utilization.

The results achieved were divided by argument and catalogued through summarizing files that define criteria, suggestions and examples in order to optimize solar gains and correctly integrated active solar systems.

Definition of the technical and formal criteria:

Urban scale: analysis of the location (irradiance, irradiation, albedo, wind, temperature), visual impact on the location, building characteristics (constructive elements, comfort, energy requirement).

Material and technology: behaviour of the solar element and its needs considering the technology (ventilation, maintenance, limits, possibility of innovation, sizing and double function).

General analysis: relationship between energy production and physical aspects of the installation (orientation, inclination, shading).

INTRODUCTION

In the last years an increasingly awareness of issues connected to the exploitation of energetical and environmental resources has contributed to intensify the research of more sustainable options.

Energy trends and projections indicate a constant increase in energy demand. Many important programmes have been carried out in order to redirect energy policies toward sustainability and renewable integration. As a result, the number of solar installations is increasing and, consequently, having a visual impact on the surroundings.

To prevent an arbitrary use of solar energy technology, it would be useful to respect certain criteria that concern the application of solar photovoltaics, thermal collectors and direct and indirect passive solar systems.

Figure 1: mono crystalline BiPV plant in Ruvigliana (TI-CH, photo courtesy of Ecosinergie).

Figure 2: integration of solar thermal collectors into the balcony of the Upper Stage Centre (D).

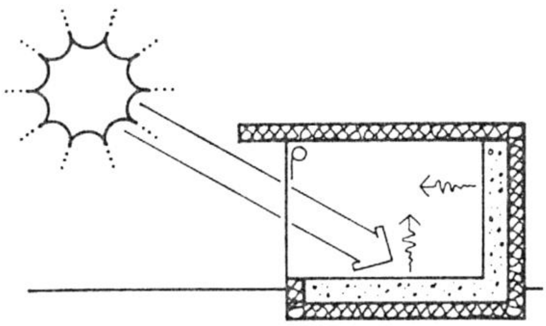


Figure 3: direct gains, non diffuse radiance. Exploitation of solar heat accumulated by natural thermal inertia on the walls and floor.

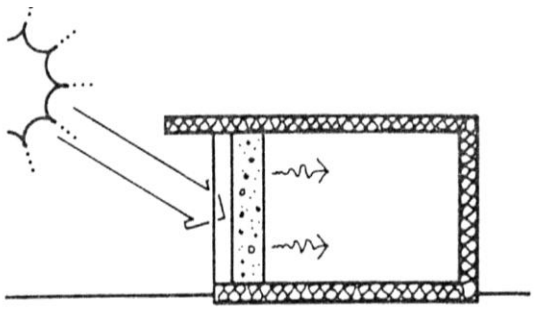


Figure 4: indirect gains, massive wall. Exploitation of solar heat accumulated by an element with high thermal inertia placed between the sun and the environment that needs heating.

METHOD

The main factors that qualify the passive and active solar features have been evaluated analyzing the distinctive elements of the surroundings, the building and the technology.

Since the measures aimed to optimize the application of passive solar characteristics, solar thermal collectors and photovoltaic technology respond differently to the analyzed indicators, it was necessary to classify every criterion depending on how much a passive or active element is affected by a determinate parameter.

The main subjects related to passive and active solar elements are divided into three categories:

0 not applicable

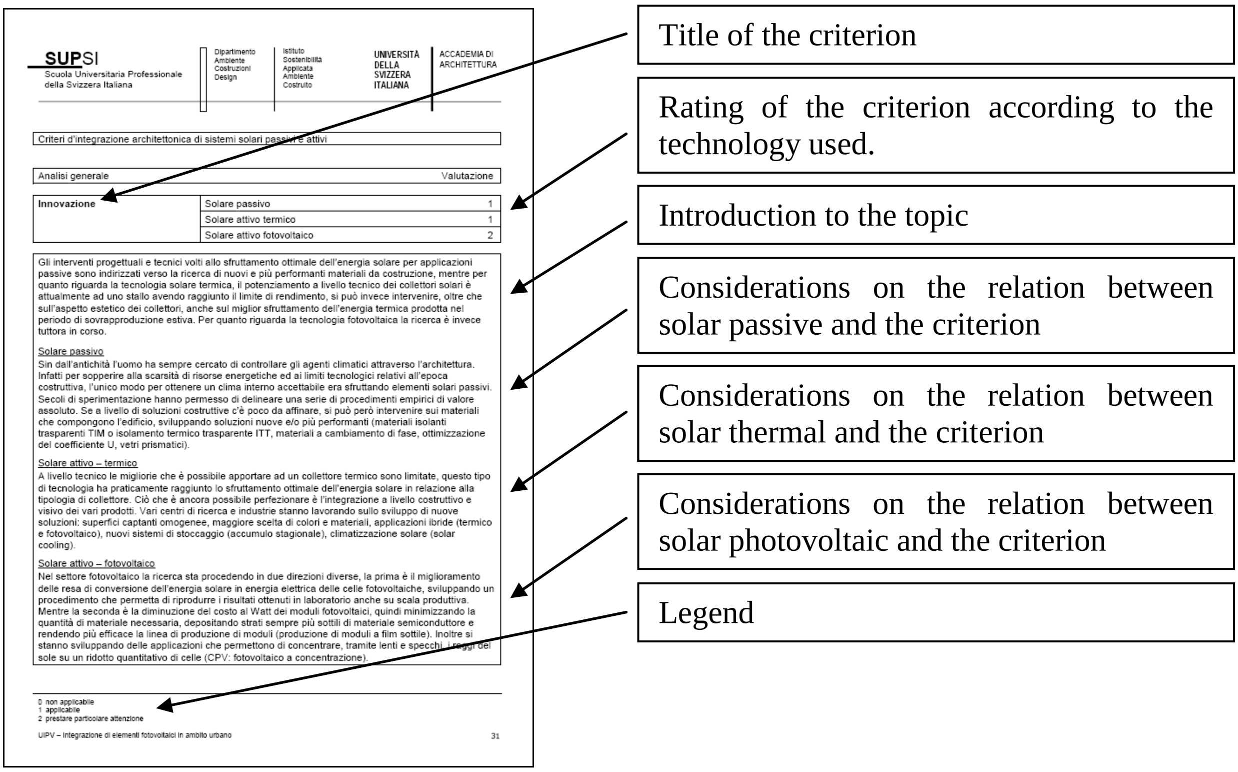
1 applicable

2 to be carefully considered

RESULTS

The outcome of the project has been collected into some guidelines (fig.5) and it will be presented to architects, designers and students highlighting the methodology for overcoming the barriers and the constrains that often limit solar integration and the benefits that follow.

We expect that these criteria will become easily accessible instruments for evaluating active and passive solar integration.



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Criteri d'integrazione architettonica di sistemi solari passivi e attivi

Analisi generale		Valutazione
Innovazione	Solare passivo	1
	Solare attivo termico	1
	Solare attivo fotovoltaico	2

Gli interventi progettuali e tecnici volti allo sfruttamento ottimale dell'energia solare per applicazioni passive sono indirizzati verso la ricerca di nuovi e più performanti materiali da costruzione, mentre per quanto riguarda la tecnologia solare termica, il potenziamento a livello tecnico dei collettori solari è attualmente ad uno stallo avendo raggiunto il limite di rendimento, si può invece intervenire, oltre che sull'aspetto estetico dei collettori, anche sul miglior sfruttamento dell'energia termica prodotta nel periodo di sovrapproduzione estiva. Per quanto riguarda la tecnologia fotovoltaica la ricerca è invece tuttora in corso.

Solare passivo

Sin dall'antichità l'uomo ha sempre cercato di controllare gli agenti climatici attraverso l'architettura. Infatti per sopperire alla scarsità di risorse energetiche ed ai limiti tecnologici relativi all'epoca costruttiva, l'unico modo per ottenere un clima interno accettabile era sfruttando elementi solari passivi. Secoli di sperimentazione hanno permesso di delineare una serie di procedimenti empirici di valore assoluto. Se a livello di soluzioni costruttive c'è poco da affinare, si può però intervenire sui materiali che compongono l'edificio, sviluppando soluzioni nuove e/o più performanti (materiali isolanti trasparenti TIM o isolamento termico trasparente ITT, materiali a cambiamento di fase, ottimizzazione del coefficiente U, vetri prismatici).

Solare attivo – termico

A livello tecnico le migliorie che è possibile apportare ad un collettore termico sono limitate, questo tipo di tecnologia ha praticamente raggiunto lo sfruttamento ottimale dell'energia solare in relazione alla tipologia di collettore. Ciò che è ancora possibile perfezionare è l'integrazione a livello costruttivo e visivo dei vari prodotti. Vari centri di ricerca e industrie stanno lavorando sullo sviluppo di nuove soluzioni: superfici captanti omogenee, maggiore scelta di colori e materiali, applicazioni ibride (termico e fotovoltaico), nuovi sistemi di stoccaggio (accumulo stagionale), climatizzazione solare (solar cooling).

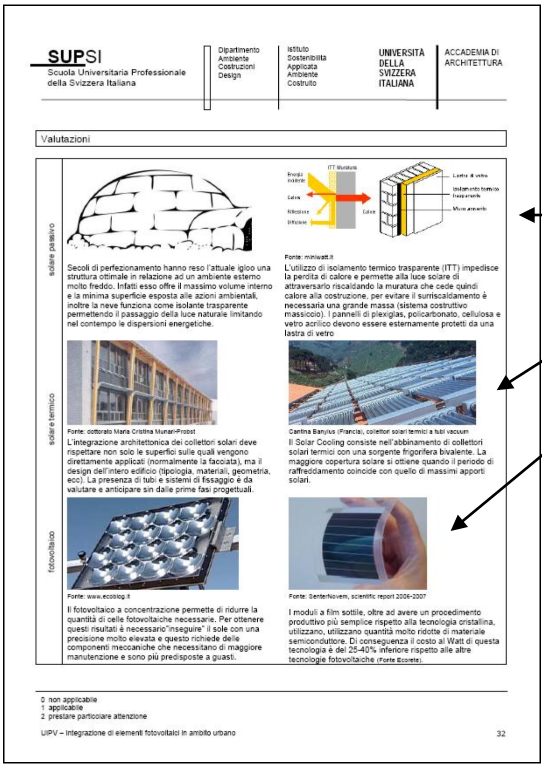
Solare attivo – fotovoltaico

Nel settore fotovoltaico la ricerca sta procedendo in due direzioni diverse, la prima è il miglioramento delle resa di conversione dell'energia solare in energia elettrica delle celle fotovoltaiche, sviluppando un procedimento che permetta di riprodurre i risultati ottenuti in laboratorio anche su scala produttiva. Mentre la seconda è la diminuzione del costo al Watt dei moduli fotovoltaici, quindi minimizzando la quantità di materiale necessaria, depositando strati sempre più sottili di materiale semiconduttore e rendendo più efficace la linea di produzione di moduli (produzione di moduli a film sottile). Inoltre si stanno sviluppando delle applicazioni che permettono di concentrare, tramite lenti e specchi, i raggi del sole su un ridotto quantitativo di celle (CPV: fotovoltaico a concentrazione).

0 non applicabile
1 applicabile
2 prestare particolare attenzione

UIPV – Integrazione di elementi fotovoltaici in ambito urbano 31

Figure 5: every criterion is articulated on a two page layout. This an example of one of the criterion, specifically page 1 of the criterion "Innovation".



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Valutazioni

solare passivo

Secoli di perfezionamento hanno reso l'attuale igloo una struttura ottimale in relazione ad un ambiente esterno molto freddo. Infatti esso offre il massimo volume interno e la minima superficie esposta alle azioni ambientali, inoltre la neve funziona come isolante trasparente permettendo il passaggio della luce naturale limitando nel contempo le dispersioni energetiche.

Fonte: miniwatt.it

L'utilizzo di isolamento termico trasparente (ITT) impedisce la perdita di calore e permette alla luce solare di attraversarlo riscaldando la muratura che cede quindi calore alla costruzione, per evitare il surriscaldamento è necessaria una grande massa (sistema costruttivo massiccio). I pannelli di plexiglas, policarbonato, cellulosa e vetro acrilico devono essere esternamente protetti da una lastra di vetro

solare termico

Fonte: dottorato Maria Cristina Munari-Probst

L'integrazione architettonica dei collettori solari deve rispettare non solo le superfici sulle quali vengono direttamente applicati (normalmente la facciata), ma il design dell'intero edificio (tipologia, materiali, geometria, ecc). La presenza di tubi e sistemi di fissaggio è da valutare e anticipare sin dalle prime fasi progettuali.

Cantina Banyius (Francia), collettori solari termici a tubi vacuum

Il Solar Cooling consiste nell'abbinamento di collettori solari termici con una sorgente frigorifera bivalente. La maggiore copertura solare si ottiene quando il periodo di raffreddamento coincide con quello di massimi apporti solari.

fotovoltaico

Fonte: www.ecoblog.it

Il fotovoltaico a concentrazione permette di ridurre la quantità di celle fotovoltaiche necessarie. Per ottenere questi risultati è necessario"inseguire" il sole con una precisione molto elevata e questo richiede delle componenti meccaniche che necessitano di maggiore manutenzione e sono più predisposte a guasti.

Fonte: SenterNovem, scientific report 2006-2007

I moduli a film sottile, oltre ad avere un procedimento produttivo più semplice rispetto alla tecnologia cristallina, utilizzano, utilizzano quantità molto ridotte di materiale semiconduttore. Di conseguenza il costo al Watt di questa tecnologia è del 25-40% inferiore rispetto alle altre tecnologie fotovoltaiche (Fonte Ecorete).

0 non applicabile
1 applicabile
2 prestare particolare attenzione

UIPV – Integrazione di elementi fotovoltaici in ambito urbano 32

Evaluation of practical examples, deepening on some aspects, presentation of specific cases, considering distinctly the three technologies.

Solar passive

Solar thermal

Solar photovoltaic

Figure 6: page 2 of the criterion "Innovation".

A total of 17 criteria have been developed, the choice of the topic was established considering properties that are frequently associated with solar design, however, seeing the complexity and the fast developing of the building solar integration sector, it is possible to extend the number of criteria.

In some cases, similar themes have been group together in a single criterion even if their rating was slightly different. See the following criteria.

Building characteristics	**Solar passive**	**Solar active thermal**	**Solar active photovoltaic**
Building class	0	1	1
Shape	2	1	1
Refurbishment	1	1	1
Requalification	1	1	1
Indoor configuration	2	1	2

Table 1: sub-criteria for "Building characteristics".

Construction units	**Solar passive**	**Solar active thermal**	**Solar active photovoltaic**
Glass surface	2	0	1
Solar shading devices	2	0	1
Thermal inertia	2	0	0
Innovation	1	2	2

Table 2: sub-criteria for "Construction units".

Comfort	**Solar passive**	**Solar active thermal**	**Solar active photovoltaic**
Visual comfort	2	0	1
Thermal comfort	2	0	0
Air comfort	2	0	0

Table 3: sub-criteria for "Comfort".

Sizing of the installation	**Solar passive**	**Solar active thermal**	**Solar active photovoltaic**
Production optimization	0	2	1
Suitable area	0	2	1
Local storage	1	2	0

Table 4: sub-criteria for "Sizing of the installation".

CONCLUSIONS

The formation of a guideline needs a set of boundaries that define especially the topics analysed throughout the project and their degree of deepening. Because of these two reasons, the number of criteria developed in this project was checked at 17. A number that still allows a rapid and simple use of the guideline.

In the following table are presented the 17 criteria developed. The rating assigned to the parameters doesn't want to be a mandatory fact, but a starting point for a careful examination of different opportunities of employment of solar technologies. The criteria are listed in no particular order.

	Solar passive	**Solar active thermal**	**Solar active photovoltaic**
Inclination & orientation	2	2	2
Shading	1	1	2
Irradiance & insolation	2	2	2
Albedo	1	0	0
Temperature	2	2	2
Location	1	2	2
Visual impact	0	2	2
Construction units	2	0	1
Building characteristics	2	1	1
Comfort	2	0	0
Energy demand	2	1	1
Ventilation	1	0	1
Maintenance	0	1	1
Technology limitations	1	2	2
Innovation	1	1	2
Sizing of the installation	1	2	1
Function	1	1	2

Table 5: list of the parameters evaluated significant for a correct design of a solar building or/and district.

These results will be presented to architecture students, underlining the methodology for overtaking barriers and constrains that often limit these applications and following benefits. The involvement of different academic institutions has been very important, since it has an important responsibility in transfer scientific ecological consciousness to students.

ACKNOWLEDGEMENTS

This project, that will be finished at the end of June 2009, is part of a bigger task called UiSol (Urban integration of Solar systems) run by the Institute for Applied Sustainability to the Built Environment (ISAAC) of the Department of Environment, Construction and Design (DACD-SUPSI), in association with Accademia di Architettura of Mendriso (AAM). The two Institutes have consolidated expertise in ecology, energy, technology, architecture and urban planning.

Most of the documents developed throughout UiSol project will be soon translated into English.

BUILDING AND URBAN INTEGRATION OF RENEWABLES; FLEXERGY, ELECTRICITY, HEATING AND COOLING

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ABSTRACT

During the last decades, the main focus of research in Building Services was on reduction of energy consumption of buildings. But no longer is it sufficient to look only at the building itself, the occupant and the energy infrastructure of the surrounding built environment must be considered too. The strong focus on the energy reduction led to situations in which health and comfort are endangered. Integration between end-user and building is the ultimate in the intelligent building concept. “Connecting” the end-user to a building is complex. User-connectivity, the combination of usability and user interface together, is studied and developed further.

A further challenge for future sustainable developments is a renewable energy infrastructure to reach an acceptable price level and a minimized environmental impact. However tools for renewable energy installations are only available on the level of individual installations. The largest potential for application of renewable energy in the built environment is defined in an earlier phase of development: the design of the energy infrastructure for district areas. To develop the required model of design support, an existing model from the mechanical engineering domain was used and combined with the architectural Open Building approach into an Integral Design methodology. With its functional decomposition this Integral Design method provides the means for decomposing complex design tasks into problems of manageable size. This functional decomposition is hierarchically so that the structure is partitioned into sets of functional subsystems. Decomposition is done until simple building components remain whose design is a relatively easy task, but each with its own focus. The paper will discuss the approach to reach these goals and show the first results.

INTRODUCTION

In Europe comfort in buildings needs 40% of the total energy. Global warming, caused largely by CO2 emissions as a result of energy consumption, shows an increasing effect. Climate change is becoming a major problem. As results of Global Warming [1] become more and more prominent, it is necessary to look for new possibilities to save energy and to generate sustainable energy to be used for comfort in the built environment. Preservation of energy resources, occupant comfort and environmental impact limitation are the key issues of modern and sustainable architecture. A major portion of primary energy consumption, about 40 %, is due to creating thermal comfort in buildings by heating, cooling, ventilating and lighting.

In office buildings most of the energy is needed for thermal comfort especially cooling. Present energy efficient technology is not sufficient to further reduce the energy use of buildings. New comfort control technology, such as individual control, offers new possibilities to further reduce energy consumption of office buildings. Dynamic online steering of individual comfort management and building management could save up to 20% of current energy consumption. Misunderstandings and wrong conceptions about indoor comfort and energy use are common. Most office users are not even aware of the fact that they can affect the energy use. The behavior of building occupants needs to be taken into account as it is responsible for almost half the outcome of planned energy reduction [2]. When the comfort control system is not working adequately, a lot of energy is wasted by too much heating or cooling. As a result of this overshoot indoor temperature is the most common issue in occupants' complaints about thermal comfort.

As until now the user has not been part of the building comfort system control strategy in offices, the energy consequences of the user behaviour are not accounted for. New technological development is needed to incorporate the behaviour of occupants of buildings. We did some development in this field. The first experiment was part of the European EBOB-project (Energy efficient Behaviour in Office Buildings). In EBOB so called Forgiving Technology was developed, with this technology each user in the building was given control of his or her personal comfort [2]. The goal of the project was to enhance operation efficiency by giving the user a choice in combination with feedback on the energy consumption/cost. In the SMART/IIGO project agent technology was used to make quick interaction possible between the user and the changes in his environment. SMART stands for Smart Multi Agent Technology [3] and IIGO [4] is a Dutch acronym for Intelligent Internet mediated control in the built Environment. The in SMART developed technology was tested in an extended field test in the IIGO-project. One of the most important lessons learned from these projects is the dominating influence of the occupant on the outcome of energy efficiency and comfort. The energy supply on a system level should be dominated by trends in demands by the occupants of the buildings (Fig.1).

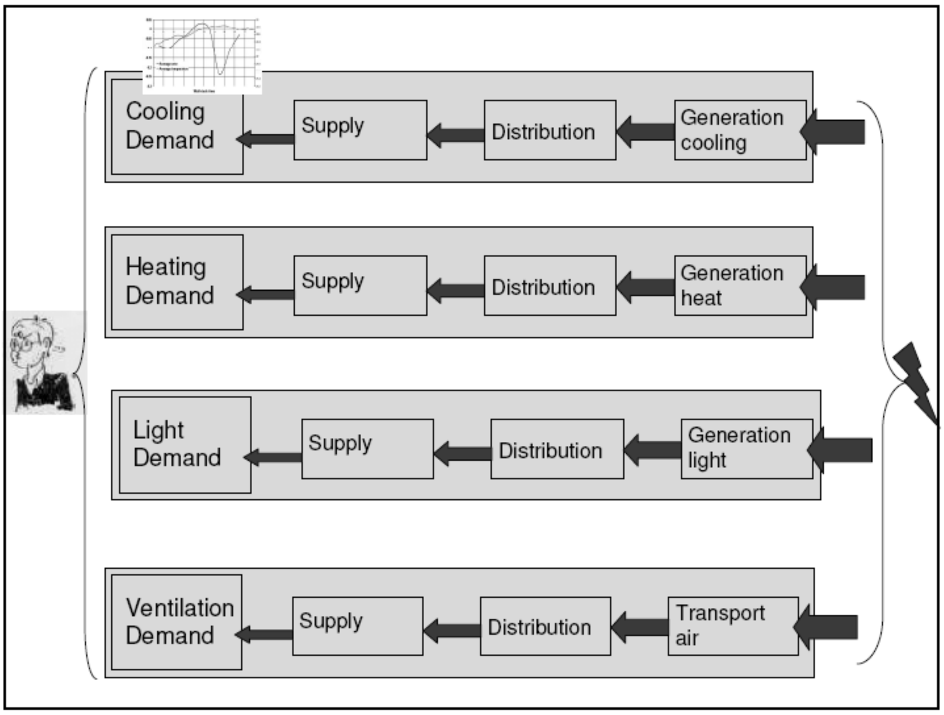

Figure 1: Human demands and needs related to energy: temperature, light and air

Such novel control systems enable to combine comfort management and improved energy efficiency. Individual comfort management makes it possible to optimize comfort, energy consumption and costs. This combination would be beneficial for building operators(financial) as well as occupants (comfort) as society (environment).

METHOD

One of the major problems in modeling design knowledge is in finding an appropriate set of concepts to refer to the knowledge, or -in more fashionable terms- finding an ontology. In the knowledge engineering community, ontology is viewed as a shared conceptualization of a domain which is commonly agreed by all parties. It is defined as 'a specification of a conceptualization'[5]. 'Ontology' in philosophy means theory of existence in the broadest sense. It tries to explain what is being and how the world is configured by introducing a system of critical categories to account things and their intrinsic relations [6]. Ontology aims to capture the conceptual structures in a domain by describing facts assumed to be always true by the community of users. Ontology is the agreed understanding of the 'being' of knowledge: consensus regarding the interpretation of the concepts and the conceptual understanding of a domain [7]. Currently the design of building environment and the necessary energy infrastructure are done by totally different and separated groups of designers. Therefore there is no shared perception (i.e. an ontology) of the design activities which designers perform in the design process of an energy infrastructure on the different levels of scale within the building environment. Without the shared perception it would not be possible to develop adequate design methodology or approaches for design support that are systematic, consistent, reusable and interoperable.

We looked at ontologies in the built environment for integrating the users. Ontologies are formal conceptualizations not made l'art pour l'art, but to help to achieve a goal or to perform a task by an actor. In this case, the task involves knowledge-intensive reasoning to understand the world not just statically, but to serve practical purposes of action by the actor in his world: a model to support the process at hand [8].

Open building

Open Building developed by N.J. Habraken [9] attempted to integrate industrial building and user participation in housing, but Habraken's concept can also be used for office buildings. It approached the built environment as a constantly changing product caused by human activity, with the central features of the environment resulting from decisions made at various levels. During the design process participants and their decisions were structured at several levels of decision-making; the infill-level, the support-level and tissue-level. On each level, there has to be made a balance between the performances of supply and demand for buildings during the life-cycle. The levels of city structure, urban tissue, support, space and infill were usually distinguished. The "thinking in levels" approach of Open Building was introduced to improve the design and decision process by structuring them at different levels of abstraction. To apply the principles of Open Building design to the optimization of the energy infrastructure of a building and the surrounding built environment, a methodology was developed by us to support the design process of building and its energy infrastructure.

Design method

To develop our required model of design support, an existing model from the mechanical engineering domain was extended: Methodical Design. This design model by van den Kroonenberg was based on the combination of the German (Kesselring, Hansen, Roth, Rodenacker , Pahl and Beitz) and the Anglo-American design schools (Asimov, Matousek, Krick) [10]. This design model was chosen as a basis because; " it is one of the few models that explicitly distinguishes between stages and activities, and the only model that emphasises the recurrent execution of the process on every level of complexity [11, p.1398]".

In order to survey solutions, engineers classify them according to various features. This classification provides the means for decomposing complex design tasks into problems of manageable size. Decomposition is based on building component functions. This functional decomposition is carried out hierarchically so that the structure is partitioned into sets of functional subsystems. Decomposition is carried out until simple building components remain whose design is a relatively easy task. This is like the decomposition which is described in the guidelines 2221 and 2222 of the "Association of German Engineers", VDI [12]. It is possible to compare this highly abstract approach with the hierarchical abstraction of Open Building which is more commonly known in the building industry, see Figure 2.

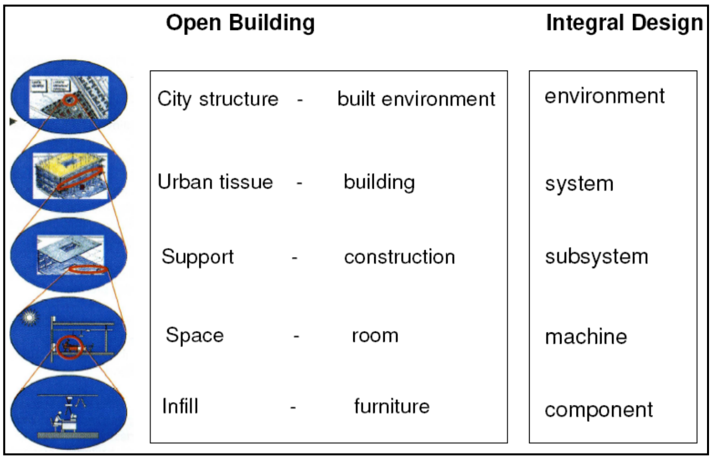

Figure 2: Comparison Open Building and Integral Design approach

Morphological Overviews

To synthesize activities of the Integral Design process morphological overviews can be used to generate alternatives in a very transparent and systematic way. General Morphological analysis was developed by Fritz Zwicky [13] as a method for investigating the totality of relationships contained in multi-dimensional, usually non-quantifiable problem complexes [14]. The Morphological overview is a key methodology that can improve the effectiveness of the concept generation phase of the design process [15]. It is this aspect which we focus on in our research.

Results

Functions have a very significant role in the design process. Generally, designers think in functions before they are concerned with details. During the design process, and depending on the focus of the designer, functions exist at the different levels of abstraction. An important decomposition is based on functions. Function-oriented strategy, preferred by experienced designers [16], allows various design complexity levels to be separately discussed and, subsequently, generated (sub)solutions to be transparently presented. The function-oriented strategy allows various design complexity levels to be separately discussed and, subsequently, generated (sub) solutions to be transparently presented. This way the interaction with the other participants of the design process is aided, and at the same time design process information exchange is structured. In order to allow a stepwise approach in which each design decision has well defined implications, four different ontological levels are distinguished for designing energetic process: Information level, Process level, Component level and Part level. Combining the concept of morphological overviews with hierarchical functional abstraction levels leads to a structure of different sets of morphological overviews for cooling, heating, lighting, power supply and ventilation. In Fig. 4 an example of the different abstraction level morphological overviews are presented. In these overviews the alternative solutions for generation, central distribution, central storage, local distribution, local storage and supply are presented to fulfil the need on the specific abstraction level of built environment, building, floor, room, workplace and person.

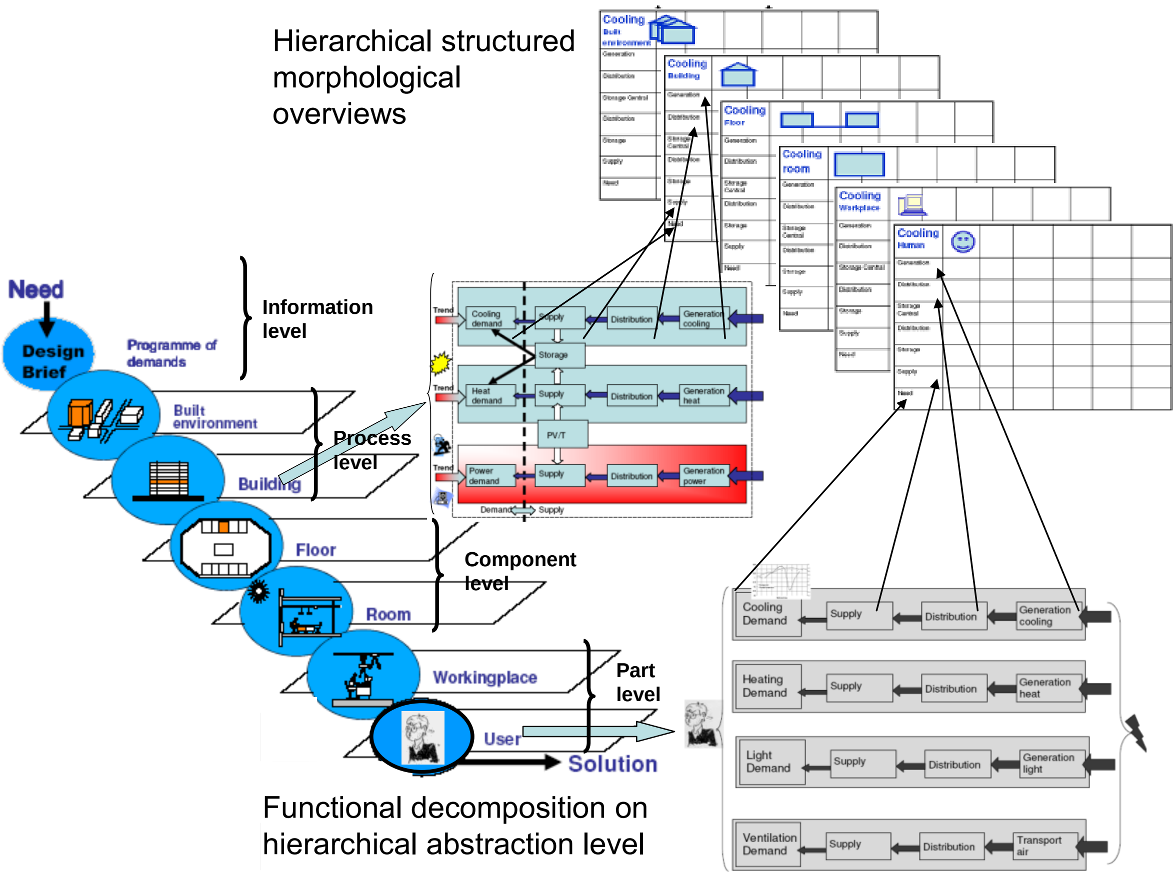

Figure 3: Set of connected morphological overviews about cooling on the different hierarchical abstraction and the infill on the built environment level

DISCUSSION AND FUTURE WORK

Taking the principles of Methodical Design and Open Building as starting point, a new Integral design approach is defined for the energy infrastructure within and between buildings. Central in this approach is the abstract representation the building design process which makes it possible to generate new solutions for a sustainable energy infrastructure. These levels provide a structured framework for morphological charts to give an overview of the possibilities and to support the design process. The possibility to combine and exchange different energy flows within the building and between buildings results in a flexible energy infrastructure called Flexergy. The participants of the Flexergy project work on new energy infrastructural concepts to use and combine energy flows on the level of building and built environment. Central in this approach is the abstract representation of the building design process which makes it possible to generate new solutions for a sustainable energy infrastructure. Work on these subjects within the project will continue till 2010.

ACKNOWLEDGEMENTS

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Decentralised Energy Production and Interactive Distribution

ALTERNATIVE COMFORT SYSTEM FOR RETROFIT IN RENOVATED SOCIAL HOUSING IN THE NETHERLANDS

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ABSTRACT

In order to achieve a reduction of the energy consumption in the build environment (30% in 2020) it is a necessity to reduce the consumption of the existing building stock. For social housing (30 %) this has to be done under the condition that the total cost of living (rental+ energy costs) for the tenants cannot be increased. In the project HEER (High Energy Efficient Renovation) a plan has been developed that should reduce the energy consumption for heating to 1/10 of the current consumption. Although passive house quality cannot be reached, the same measures have been applied: increased insulation, triple glazing, heat recovery and an airtight building envelop. Over an extended life span of thirty years the costs have to be recovered by a raising the rent. For the tenants the increased rent should be compensated by the reduction of the energy costs. The housing company wants to guarantee this. A robust performing heating and ventilation has to be implemented.

This paper describes the alternate solutions for the adaptation of the heating and ventilation system and a performance test in two renovated dwellings. Typical passive house solutions are not applicable; currently over 90% of the dwellings use natural gas for heating and hot water production and this will be the preferred choice.

Different solutions are discussed. For terrace house small collective system do have advantages in maintenance and utilization of solar thermal systems. The extra distribution losses can be compensated by the increased efficiency. Solutions for individual dwellings show a mismatch in capacity for heating and hot water production. The maximum heat demand is well below the min. capacity of today's available condensing boilers. Through simulation and experimental setup different solutions are evaluated. The field test showed that the auxiliary electricity is no longer negligible and has to be taken into account when evaluating different solutions.

INTRODUCTION

In order to achieve the goals of the Kyoto-protocol of the Dutch government has set a goal of reduction 30% emission for the energy consumption of buildings. Thanks to modern building techniques this can relatively easy be achieved for newly build houses, though it will be not sufficient to achieve the 30% reduction. Cost effective ways have to be found to reduce the (fossil) energy consumption of the current building stock. An important part of the Dutch building stock are terrace houses build in the period between 1960 to 1980. Of about 7 miljoen dwellings in the Netherlands about 10% are terrace houses build during the peak of the postwar boom. The demand for houses during the sixties and seventies led to rationalisation of the building process in order to fulfil the demand. These type of houses are te be found all over the Netherlands. In a pilot project for a 'high energy efficient renovation' (HEER) in Roosendaal (fig.1) methods based on the 'passive house' philosophy were use.

Though the criteria for a true passive house could not be achieved, all calculation were made according the passive house design rules and methods (3).

Renovation type	Basic (1976)	Passive House (2008)
Ventilation	Natural	Mechanical with heat recovery
Air tightness	Hardly airtight	Good airtight
		-
Extra	-	Solar collector (2.7 m^2)
		Solar boiler (140 l)
Glazed area front façade	23 [%]	23 [%]
Glazed area rear façade	26 [%]	26 [%]
Solar irridiation	0.6	0.3
U-values		
Ground floor	1.8 [W/m^2K]	0.3 [W/m^2K]
Façade	1.9 [W/m^2K]	0.1 [W/m^2K]
Single glazing	5.5 [W/m^2K]	-
Triple glazing	-	0.6 [W/m^2K]
Roof	2.4 [W/m^2K]	0.1 [W/m^2K]

Type of dwelling	Single-family dwelling
Orientation front facade	**East**
Footprint lxw [m]	**6x7**
Useful surface GF [m2]	**39**
Useful surface 2nd [m2]	**39**
Useful surface attic [m2]	**15**

Table 1 Building properties before and after renovation

to expand the life of the terrace house with another 40 years and reduce the energy for heating with 80 to 90%. This paper deals with the necessary adaptation of the comfort systems.

figure 1: Terrace houses in Roosendaal before (left) and after renovation (right)

Over the years the energy use of comfort heating has been the major part of the total energy consumption in the Netherlands. Thanks to better insulation and glazing this consumption has been drastically reduced over the years. In the Dutch standard [1] used to evaluate the energy efficiency a differentiation has been made into: (primary) energy for heating, hot tapwater, lighting and auxiliary electricity for fans and pumping. Figure 2 shows the reduction of the different post over the years. It shows that all post have become of equal importance.

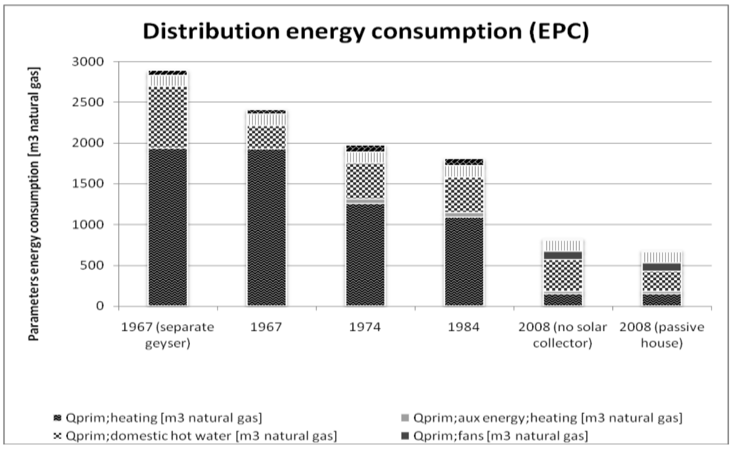

figure 2 Deminisching importance of energy for heating over the years.

In the HEER-project is chosen for a renovation program based on ‘passive house’ techniques. This means high insulation of roof and walls (U-value < 1.3 $W/(m^2K)$) triple glazed windows, air-tight envelope and a conversion from natural ventilation to a balanced ventilation system with heat recovery. The extra costs above the normal renovation costs have to be compensated by the reduction of energy costs.

COMFORT SYSTEMS.

Over 90% of all houses in the Netherlands use natural gas for heating and domestic hot water. Over the years highly efficient condensing boilers have been developed that serve as a heat source or the central heating and with have sufficient capacity (18-22kW) to produce 6-8 litre hot water per minute. Thanks to increased insulation of buildings the max. capacity for heating has reduced over the years to merely 6-8 kW for a terrace house. Today’s boilers have a modulating range of about 6-18 kW to fulfil heating and hot water demand with high efficiency. The annual heat demand for the pilot dwellings is a mere 2500 kWh ($250kWh/m^2$) and the maximum capacity needed is below the 3kW. Today’s boilers cannot handle such low demands. An alternative solution is needed.

The ventilation system is converted to a balanced ventilation system with heat recovery. In order to prevent freezing of the air-inlet these system are equipped with an 1 kW electric defrosting unit. To prevent draught problems also a post heater will be discussed, as a general rule the inlet temperature has to have a temperature of at least 16ºC. Indoor air quality in airtight dwellings is crucial, (4) this will be looked into in al later phase when the occupants have moved in.

The condensing boiler also produces hot water, for compact boilers this is done without a storage vessel, in order to get a quick response time, the boiler or a part of the boiler is kept at an operating temperature of 60ºC. An optional solar collector is considered to reduce the energy demand for hot water.

METHODS

After the constructional renovation, a provisional comfort system was installed which should be adapted after the results of the performance evaluation. The heating capacity adapted by reducing the supply temperature to a mere 40º C. A 10 liter vessel was added to match the capacity of the boiler with the actual demand.

A monitoring system was installed in one of the dwelling which continuously monitored the conditions in the house as well the performance of the systems. For the heating system the all the temperatures were monitored as the electrical consumption during start/stops and when idling. The monitoring period extended from august 2008 to march 2009.

The behaviour of house was implemented in a simulation tool HAMBASE [2] a tool for the evaluation of the heat, air and moisture behaviour of a building and its systems. The test house was divided in 3 zones: ground floor, first floor and attic. The model was tested with the results of response tests preformed in one of the pilot houses. An adaption was necessary due to the central heat-recovery who disperses heat between the different zones.

Different solution were studied and evaluated with the constraints: cost effective, based on natural gas, and robustness.

RESULTS

The monitoring of heating system showed that the current boiler configuration is no longer suitable for heavy insulated buildings. The maximum heat demand to keep the house at comfort temperature is a mere 2 kW while the minimum capacity of the boiler is 5 kW. The direct control of the temperature by means of a room thermostat led to oscillating room temperature. (figure 3)

The energy used for keeping the boiler ready for hot tapwater production showed to be 4.5 kWh day while the average energy needed for heating showed to be 6 kWh/day.

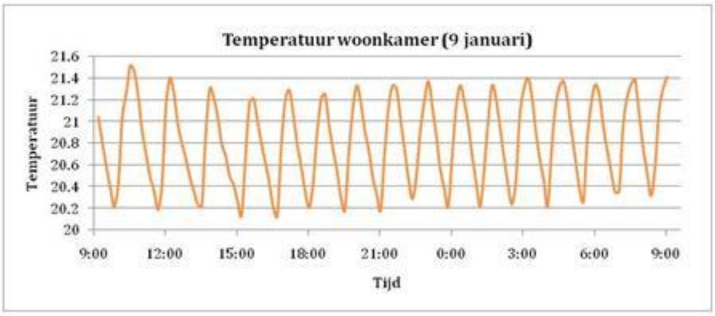

figure 3: Oscillating room temperature due to oversized boiler capacity.

Based on the monitoring result and simulation different configurations were evaluated: I. placing a 10 liter vessel to decouple the boiler and heating demand (figure 4); II. Integration with an at optional solar boiler system(figure 5) ; and III a collective system where a row of 8 to 10 houses share a boiler and central solar collector (figure 6).

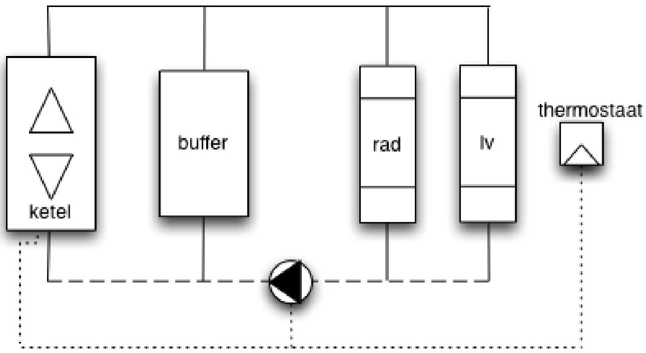

Figure 4: Solution addition of buffer vessel.

Solution I needs an extra pump, this pump is controlled by the room thermostat, the boiler control is bases on a minimum temperature of the vessel. This configuration should give a better temperature control and reduce the number of start stops of the boiler, and give a reduction of the auxiliary electricity consumption.

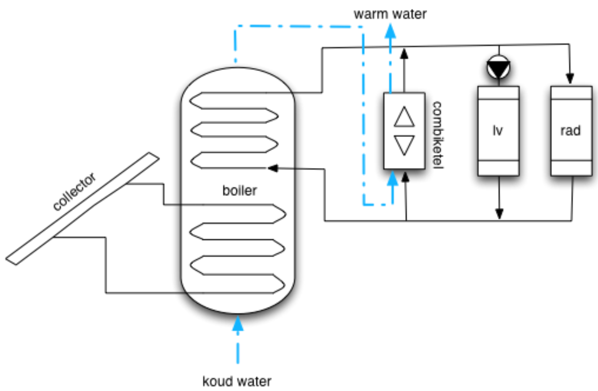

Figure 5: Solution II , combination with solar collector & boiler

Solution II has the same advantages as solution 1 but has the advantage that is saves a boiler vessel.

Solution III should have advantages in order to utilize the boiler and central collector better, but still needs storage vessel per house in order to deliver hot water within acceptable time. Also the extra distribution losses should be considered.

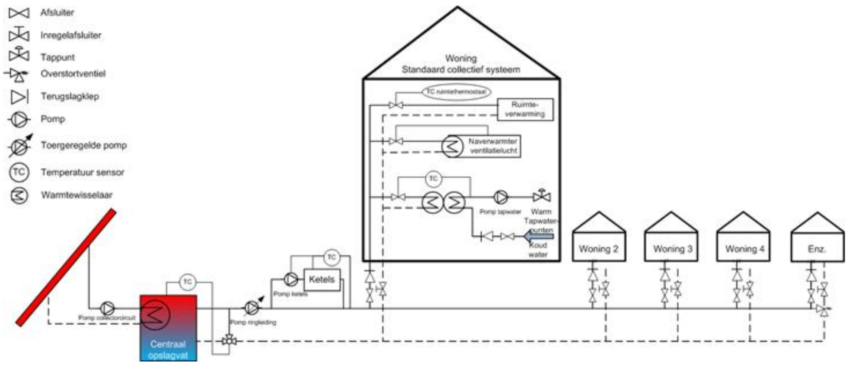

Figure 6 Solution III small distribution network.

In the next phase the new configuration will be installed in the dwellings, during this phase the pilot-house will also be occupied. The influence of the occupants as well the ease of operation of the dwellings can be evaluated.

DISCUSSION

The compact condensing boiler use for heating and hot water production is the current standard in Dutch dwellings. For (very) well insulated house like the house in Roosendaal this will no longer do. The minimum available capacity exceeds the actual demand by far, though the full capacity is needed for hot water production. In renovation projects the infrastructure to change to another heat-source (heat-pumps) is most times not applicable. The combination with a solar collector and boiler becomes an attractive solution.

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DEMONSTRATION OF INNOVATIVE ELECTRICITY MARKETING OPTIONS FROM DECENTRALISED GENERATION – THE BADENOVA SHOWCASE

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ABSTRACT

As energy supply systems change from former centralised structures to decentralised, distributed ones, new challenges rise. Decentralised electricity generation had its initial incentives from federal supply mechanisms such as feed-in tariffs. Now it needs to adjust its operation management to demands of various energy market actors, e.g. consumers or grid operators. Therefore alternative marketing options for electricity from a combined heat and power (CHP) installation in Southern Germany are assessed in this paper. Direct trading into the EEX electricity spot market is considered as well as offering positive and negative tertiary control at the power reserve market. Optimisation of net heat production costs (NHPC) has shown that in case of trading both into the EEX spot and the power reserve market NHPC even turn negative, depending on the season. Sensitivity analysis of the results has shown that the price of natural gas has prior influence on the results, but natural gas price changes may be compensated partially by electricity price changes.

INTRODUCTION

Recently, energy supply systems are underlying structural changes, due to increasing shares of small scale renewable and efficient electricity generation. This development is driven by various factors, such as supporting regulative framework conditions in form of subsidies (e.g. feed-in tariffs). The liberalisation of European electricity markets gives the chance for smaller investors and market players to engage in power production. Nevertheless, prevailing remuneration systems as the German CHP (combined heat and power) Act cannot be seen as long-term instruments for fully integrating renewable and efficient electricity generation into our energy systems. Purpose of this work is to show options for direct marketing of electricity by offering standardised electricity products at the power market. This is demonstrated exemplarily with the "Friesenheim" CHP installation owned by the public utility badenova*WÄRMEPLUS* located in Southern Germany.

METHOD

First, the cogeneration plants connected to a district heating system, with additional system components such as auxiliary boilers and thermal storages, are described by their techno-economic parameters and their current mode of operation. This leads over into description and analysis of alternative operation management strategies. The approach of this paper is based on the work of Streckiene [Streckiene et al., 2009] and goes into further analysis of economics regarding power reserve market trading. Optimisation of the system operation management is based on the modelling software package energyPRO, developed for combined techno-economic analysis and optimisation of cogeneration. Economic feasibility of direct electricity marketing (combined offering at the spot market and offering tertiary control) is analysed with focus on selected periods of time. This approach is based on recommendations for alternative electricity marketing options for decentralised generation from [Obersteiner et al., 2008]. Finally, sensitivity of net heat production costs is assessed by the variation of parameters such as size of the thermal storage, electricity spot prices and primary energy prices.

DESCRIPTION OF THE “FRIESENHEIM” INSTALLATION

The “Friesenheim” CHP installation, located in Southern Germany, was built in 1989 by a small local utility. The main intention of the installation in the past was to reduce electricity peak loads in the distribution grid. Due to liberalisation of the energy markets that started in 1998 peak load reduction was not in the focus anymore. Today the installation is heat demand driven, supplying a small local district heating system (80 heat consumers, 2.5 km of pipelines). Electricity generated is fed into the grid and remunerated after the German CHP Act. Since 2007 both plants are owned by the local utility Badenova WÄRME*PLUS*.

In the following a short overview over techno-economical parameters of the installation is given in a table:

Components	**Electric power [kWel]**	**Thermal power [kWth]**	
Total power installed	**2300**	**4700**	
2 peak load boilers		650	
5 CHP units	460	680	
Other components			
2 thermal stores with 45,000 l each, storage temperature 90°C, 3.5 MWh of storage capacity			
Fuel type: natural gas			
District heating grid with 2.5 km of pipelines, flow temperature 90°C, return temperature 55°C			
Economical parameters			
Natural gas price	47 €/MWh		
Average EEX electricity price	65.73 €/MWh		
CHP bonus	0 €/MWh		
Avoided grid utilisation	15 €/MWh		

Table 1: Techno-economical parameters of the “Friesenheim” installation

The operation of the installation began to turn unprofitable due to two mayor reasons: first, the progressive decrease in the CHP bonus (as part of remuneration after the CHP Act) led to a zero CHP bonus already in 2007. The second reason is the inappropriate system design as the huge thermal power installed faces a relatively small heating demand, especially in summer. Therefore, alternative electricity marketing options other than remuneration after CHP Act are assessed and presented in the following.

A first option is a fuel substitution from natural gas towards upgraded biogas. The German Renewable Energy Act (EEG) amendment from 2009 allows remuneration after EEG for both local combustion of biogas and combustion of upgraded biogas fed into the natural gas grid and combusted at a site other than the biogas plant. This aims at a more demand oriented renewable energy generation as biogas plants generally can be found in rural areas, far from bigger (constant) heat consumers. Heat generated in combination with electricity cannot be totally consumed at the local biogas plant, but upgraded biogas can be transported via the gas grid infrastructure to the consumers. Remuneration of electricity from smaller biogas fuelled CHP plants consists of the following components:

Remuneration components	**Remuneration [€ct/kWh]**
Basic remuneration	11.67
bonus for renewable raw material	7.0
technology bonus (for biogas upgrading)	2.0
CHP bonus	3.0
Sum	23.67
Fuel costs	
Natural gas	4.7
Upgraded biogas	8.5

Table 2: Remuneration of smaller biogas CHP plants after EEG, fuel costs

The numbers show that significant economic improvement can be expected from a fuel switch towards upgraded biogas.

A second option is a combined selling of the electricity generated directly into the spot market, without remuneration after CHP Act, and offering tertiary control (furthermore Minutenreserve) at the power reserve market. The “fair price” as part of the CHP Act is the quarterly average EEX (European Electricity Exchange) price for base load electricity. Trading into the spot market for selected hours that lie over the average base load price may lead to economic improvements, and combined offering of Minutenreserve makes further improvements to the plant’s economics. Minutenreserve can be both offered in positive (increase of electricity generation) and negative (decrease of electricity generation) direction. It is important to mention that at the power reserve market a bidding process is carried out where bids are sorted according to a merit order and accepted up to the total amount of Minutenreserve tendered. This implies the risk of acceptance or rejection, depending on the number of bidding parties. Data concerning the German power reserve market can be retrieved from www.regelleistung.net. Offering of Minutenreserve availability must be distinguished from Minutenreserve activation. Mere availability of Minutenreserve (per kW) is paid in any case, but the activation price (per kWh) is only paid in case of physical delivery/demand of electricity. Until now, the activation of Minutenreserve makes comparably small contributions to the balancing mechanism in Germany (see Table 3). Therefore activation of Minutenreserve is not included in the energyPRO calculations.

	Tender [MW]	**Activation [GWh]**
Secondary control, positive	3350	3027
Secondary control, negative	2470	4739
Minutenreserve, positive	3420	126
Minutenreserve, negative	2250	235

Table 3: Tender and activation of Secondary control and Minutenreserve, year 2007 [BNetzA, 2008, pp.47-55]

Table 3 shows that activation of negative control dominates. In Denmark, where direct electricity trading for smaller CHP plants started in 2005, the share of Minutenreserve activated is of about the same volume as secondary control activated. Further research in cost comparison between Danish and German imbalance settlement mechanism could provide information about their cost efficiency.

OPTIMISATION

In order to realise simulations for optimised operation schedules the "Friesenheim" installation has been modelled in energyPRO, a modelling software package developed for combined techno-economic analysis and optimisation of cogeneration. The software has the advantage to input a wide range of data, e.g. different energy plant types, degree day data, demands and profiles, plant operating strategies, tariff structures, spot prices, Minutenreserve availability costs, and revenues and operating costs, within the same calculation. The software provides reports with technical and economical results of the optimisation, and graphical visualisation of schedules and state of operation for the installation's components. Calculations can be done either on a short term monthly base or on annual base. In the following, the different operation strategies are presented for September, 2008, and further on for July, 2008, and December, 2007, in order to show dependence on seasonal changes, too. Measure for economical efficiency is the net heat production costs (NHPC) that need to be minimised.

First, the heat driven reference case is presented shortly, where remuneration depends on the CHP Act. Due to high natural gas prices and comparably low feed-in tariff, the CHP plant operation in September 2008 leads to NHPC of 28,259 €. With a 242 MWh of heat generated the specific NHPC amount 117 €/MWh. In fact, heat production merely from the peak load boilers would be cheaper, representing 26,144 € and 108 €/MWh respectively. Simulating heat demand driven operation for July, 2008, NHPC turn even more inefficient with an amount of 17,862 € for generating 74.5 MWh of heat, a specific NHPC of 240 €/MWh. This is due to fix costs like operation and maintenance costs that are not covered by small revenues from reduced heat delivery. NHPC for December, 2007, is 65,748 € for generating 597 MWh heat, which costs 110 €/MWh heat. This high NHPC result from lower electricity remuneration (EEX baseload price for the 3rd quarter of 2007 amounted 31 €/MWh electricity). Besides, increased heat supply is not able to cover the fix costs. Summarising, NHPC are still enormous compared to representative decentralised NHPC of about 80 €/MWh [3N, 2009].

Second, direct electricity trading into the spot market is presented as an alternative marketing option. Electricity prices are taken from historical data sets provided by the EEX. In this case, total NHPC for September, 2008, are reduced to 19,495 €, representing 81 €/MWh heat. In July, 2008, NHPC rise to 15,031 € and 202 €/MWh, representatively, due to decreased heat demand. In December, 2007 where spot market prices were relatively low energyPRO simulation calculated NHPC of 40,645 € and specific NHPC of 68 €/MWh. The Simulation results show that through direct electricity trading into the spot market NHPC are improved by 15 % (summer) to 40 % (winter), depending on the season.

Third, combined trading into the spot market and offering positive and negative Minutenreserve was simulated. For this purpose, average bidding prices for accepted offers of both positive and negative Minutenreserve have been built and included into the optimisation. Simulation results show that especially offering positive Minutenreserve decreases NHPC substantially. The impact of offering negative Minutenreserve is comparably low because bidding prices are only high in the night time, and optimised CHP operation is during the day with higher electricity spot prices and positive Minutenreserve bidding prices. In September, 2008, total NHPC decrease to 9,309 € for generating 242 MWh of heat, and 38 €/MWh, respectively. For both July, 2008, and December, 2007, NHPC turn negative (-282 €/MWh in July, and -74 €/MWh in December). This is mainly due to high gains for offering Minutenreserve. In July decreased heat demand enables offering of higher shares of positive Minutenreserve, and in December offering Minutenreserve is prioritised due to comparable low electricity spot prices and very high Minutenreserve prices. Consequently, the peak load boilers are in increased operation.

Finally, results of the optimisation cases are summarised and compared to the heat driven reference case in the following figure.

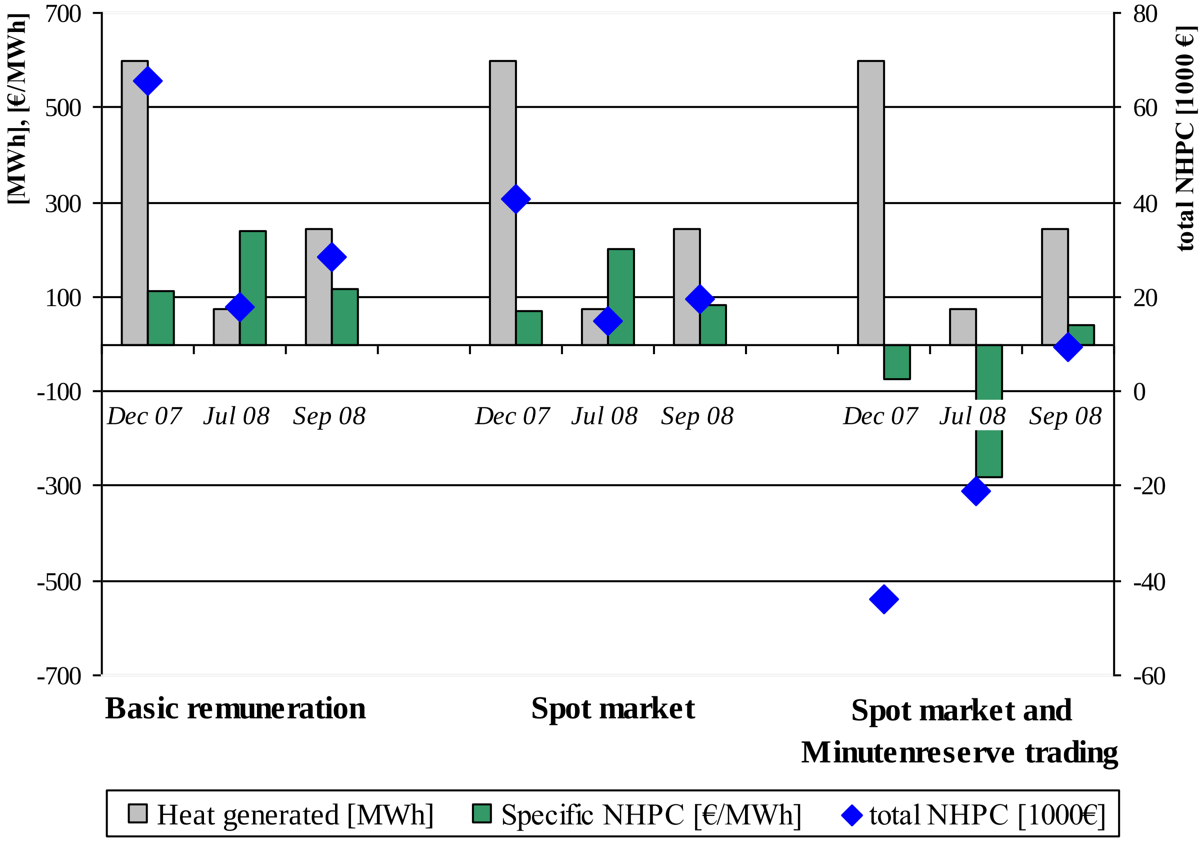

Figure 1: Electricity driven energyPRO optimisation results and heat driven reference case

The small difference between “Basic remuneration” case and “Spot market” case is remarkable, compared to NHPC behaviour in the “Spot market and Minutenreserve” case.

SENSITIVITY ANALYSIS

This analysis is done to determine how sensitive the optimisation results are. Parameters on which sensitivity is analysed are the EEX electricity spot prices, the primary energy price (natural gas), and the size of the thermal storage. Sensitivity is analysed for the “Spot market” case and September, 2008. Values for the parameters have been increased and decreased by 10, 20 and 30%. The results showed that sensitivity to natural gas price changes is highest, followed by sensitivity to EEX electricity spot prices. Varying the size of the thermal storage has no significant impact on the specific NHPC. The results are shown in the following figure.

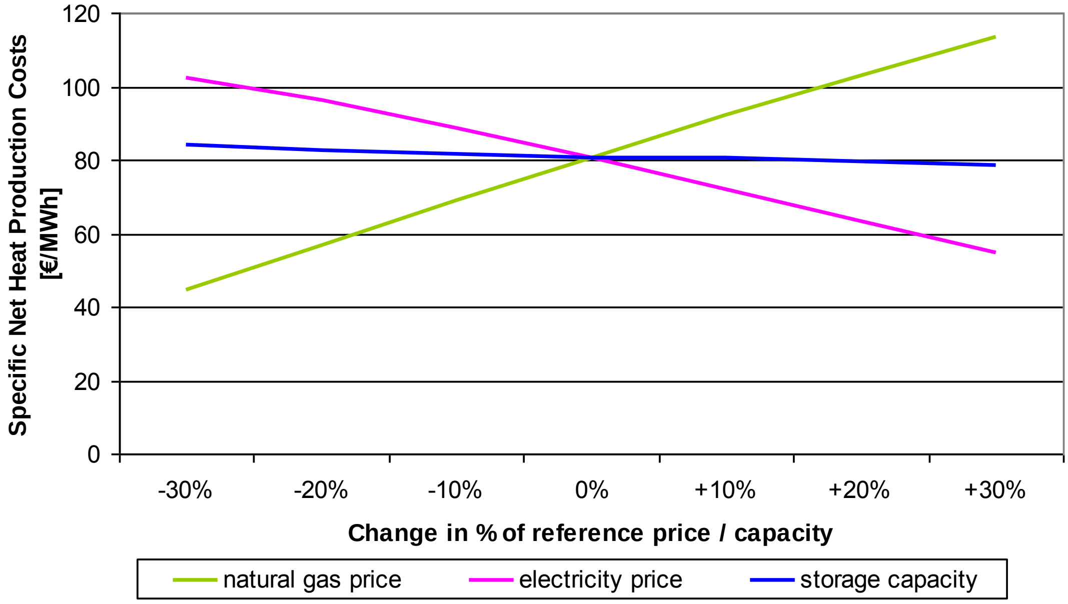

Figure 2: Sensitivity analysis for the "Spot market" case, September 2008

EEX electricity spot prices are often influenced by natural gas price changes. Therefore, if these prices change into the same direction, influences on the NHPC are minimised. But nevertheless, an increase in these prices increases NHPC, too, and vice versa, as sensitivity to the natural gas price is higher.

CONCLUSION AND DISCUSSION

The assessment of different electricity marketing options for the "Friesenheim" CHP installation showed that economics can be improved substantially by establishing electricity driven operation strategies. Combined trading into the electricity spot market and the power reserve market is the most promising option identified, turning formerly high net heat production costs into negative costs, meaning that heat could be offered for free and feasibility of the installation is still assured. Nevertheless, a full economics calculation, including investment costs, has not been done in this paper.

As good negative Minutenreserve availability prices only occur during the night time the installation of an additional electric boiler could be useful for offering negative Minutenreserve. Nevertheless, as long as Minutenreserve activation stays at the current low level in Germany, the options for improving economics of "Friesenheim" are reduced to offering Minutenreserve availability only.

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SIMULATION OF A MICRO-CHP PLANT INSTALLED IN A THREE FLOOR EXPERIMENTAL BUILDING

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ABSTRACT

ITC-CNR, the Construction Technologies Institute of the Italian National Research Council has dealt for a long time with polygeneration. During the last two years a specific case study has been carried out on a microCHP plant installed in a three-floor experimental building. Field trials permitted to analyze the micro-cogenerator characteristics and to calculate the variations of thermal and electric efficiencies and fuel consumptions related to the changing outdoor conditions. A methodology for the optimization of the cogenerator has been specified and tested, and eventually produced good results for the building-plant system efficiency and energy saving.

The experimental activity has been supported by the definition of an analytic dynamic model of the building-plant system: by using this model it was possible to carry out energetic analysis and to simulate a detailed heating plant scheme with the presence of the micro-cogenerator. The model calculates heating loads and can determine energy savings related to micro-cogeneration plant by comparing simulated results and energy consumption of a reference case, consisting of a plant equipped with traditional boiler.

A validation methodology for the analytic model has been studied and then applied to the results of field trials on the experimental building, in order to examine the model accuracy: the model has been validated by comparing experimental and simulated data.

INTRODUCTION

MicroCHP applied to residential buildings is an opportunity to reduce the demand for primary energy compared to separated generation of electricity and heat; the spread of this technology can imply considerable energy savings, provided that the commissioning phase of the plant is carefully taken into account, so as to exploit its potential.

The installation of a microCHP inside a building must be accompanied with an adequate study of the thermal loads associated with the heating, water heating and power consumption of the auxiliary devices in order to properly select the powers to take into account. The definition of a dynamic model of the building-plant system provides an instrument to calculate the energy requirements and to determine the microcogenerative system's performances, in order to provide the desired indoor air conditions and to evaluate the energy efficiency and the reduction of fuel consumption.

The model's validation, based on a comparison between simulated and experimental data acquired during field trials, can generalize the methodology used to build the dynamic model: it can be used for pre-dimensioning and evaluating performances and energy saving of future installations of microcogenerative systems.

METHOD

Field trials were carried out on an experimental microCHP plant prior to the development of the dynamic model: these tests permitted to collect data about the engine's operation and on the performances of the cogenerative package (microCHP and boiler).

The building and the heating plant were modelled using the dynamic simulation software EnergyPlus [1]: the model can calculate both the energy dissipated through the building envelope and the energy produced by the microCHP plant.

The collected experimental data permitted to make a comparison between real and simulated data and to optimise the model: it was validated through a statistical analysis, according to the methodology proposed by the ASHRAE Guideline 14 [2].

RESULTS

An experimental building located at the ITC-CNR headquarters in San Giuliano Milanese, in the south-east of Milan, was used for evaluating the performance of the microCHP and the energy efficiency of the building-plant system.

The plant is composed by a microCHP consisting of a single-cylinder internal combustion driving engine, capable of delivering up to 5.5 kW electrical output and 12.5 kW heat. The system is supplemented by an auxiliary boiler 43.6 kW heat, which acts to ensure the peaks of heat required for users, by a 500 l storage tank, which is essential because the cogenerator works on a fixed power without any modulation option and by aluminium radiators. The entire facility is monitored through an acquisition system, capable of collecting data related to the indoor and outdoor environment and to the plant itself.

The experimental activity was supported by the definition of a dynamic model of the building-plant system, in order to carry out energy analysis on a building and to simulate the installation of a heating plant equipped with a microCHP. The model calculates the building thermal loads and can determine the energy saving related to the use of microcogeneration.

The model was created by using EnergyPlus: this software is a program for energy analysis and thermal load simulation. Based on users' description of a building from the point of view of the building's physical features and associated mechanical systems, EnergyPlus will calculate the heating and cooling loads necessary to maintain thermal control setpoints, the conditions throughout a secondary HVAC system and coil loads, and the energy consumption of primary plant equipment as well as many other simulation details that are necessary to verify that the simulation is performing as the actual building would.

The building envelope was modelled by using the Design Builder [3] interface, defining three different thermal zones connected with the three floors, while the weather data were collected through a monitoring system located on the building's roof.

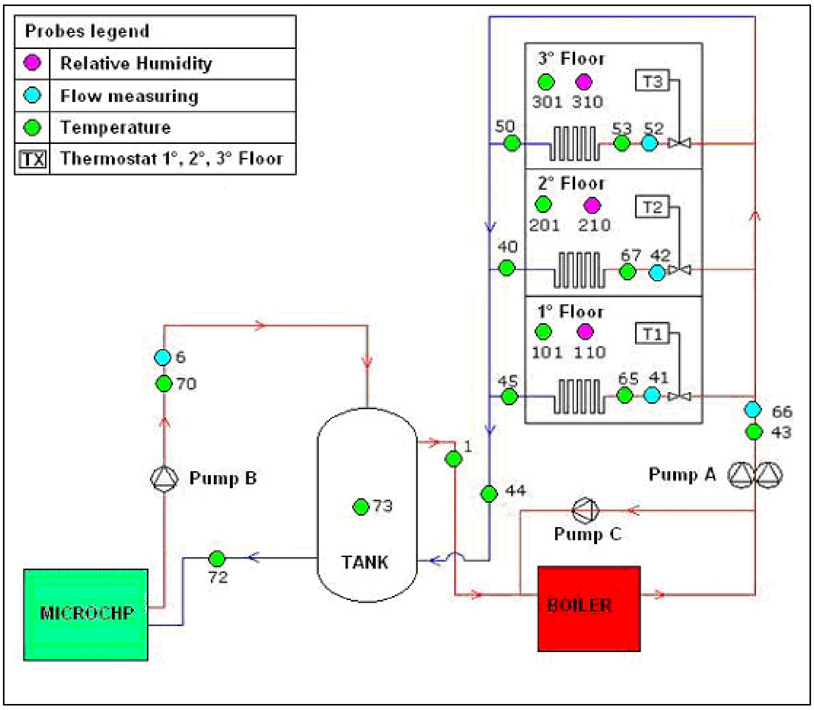

Figure 1: Experimental heating plant scheme

The model includes the following modules:

GENERATOR: MICROCHP: this element simulates the microcogenerator; it must be defined by entering some technical characteristics, such as electrical and thermal output power, electrical and thermal efficiency and cooling water flow curve.
BOILER: SIMPLE: it defines the boiler unit by entering thermal power and efficiency, outlet water temperature; water flow was set to “autosize” and will be calculated by the software during the simulation, in order to match the heating load.
WATER HEATER: MIXED: this element simulates the water tank and can be defined by entering volume, heat loss and setpoint temperatures.
BASEBOARD HEATER: Water Convective: three radiators were defined, one for each thermal zone.
PIPES: these elements are used to connect the other modules; they are defined as adiabatic pipes, so all the losses are concentrated in the water heater.
PUMP:VARIABLE SPEED: it represents the cogenerator pump and is defined through water flow curve and electrical efficiency.
PUMP:CONSTANT SPEED: it simulates the plant’s main pump and is also defined by determining water flow and electrical efficiency values .

The plant scheme is represented in Figure 2: two loops were defined, one to describe the generation side and one for the heating demand side. Each loop is divided into a Supply side, which generates the thermal power, and a Demand side, which transfers the heating power to the building.

On the Supply side the generation loop contains the microCHP and the relative bypass branch, which is used when the cogenerator is turned off; on the Demand side there is the water tank, used to accumulate the heat production of the microCHP when there is no heating demand. On the Supply side of the heating demand loop we find again the water tank: it supplies hot water, which passes through the boiler and is reheated until the temperature reaches the setpoint, if necessary.

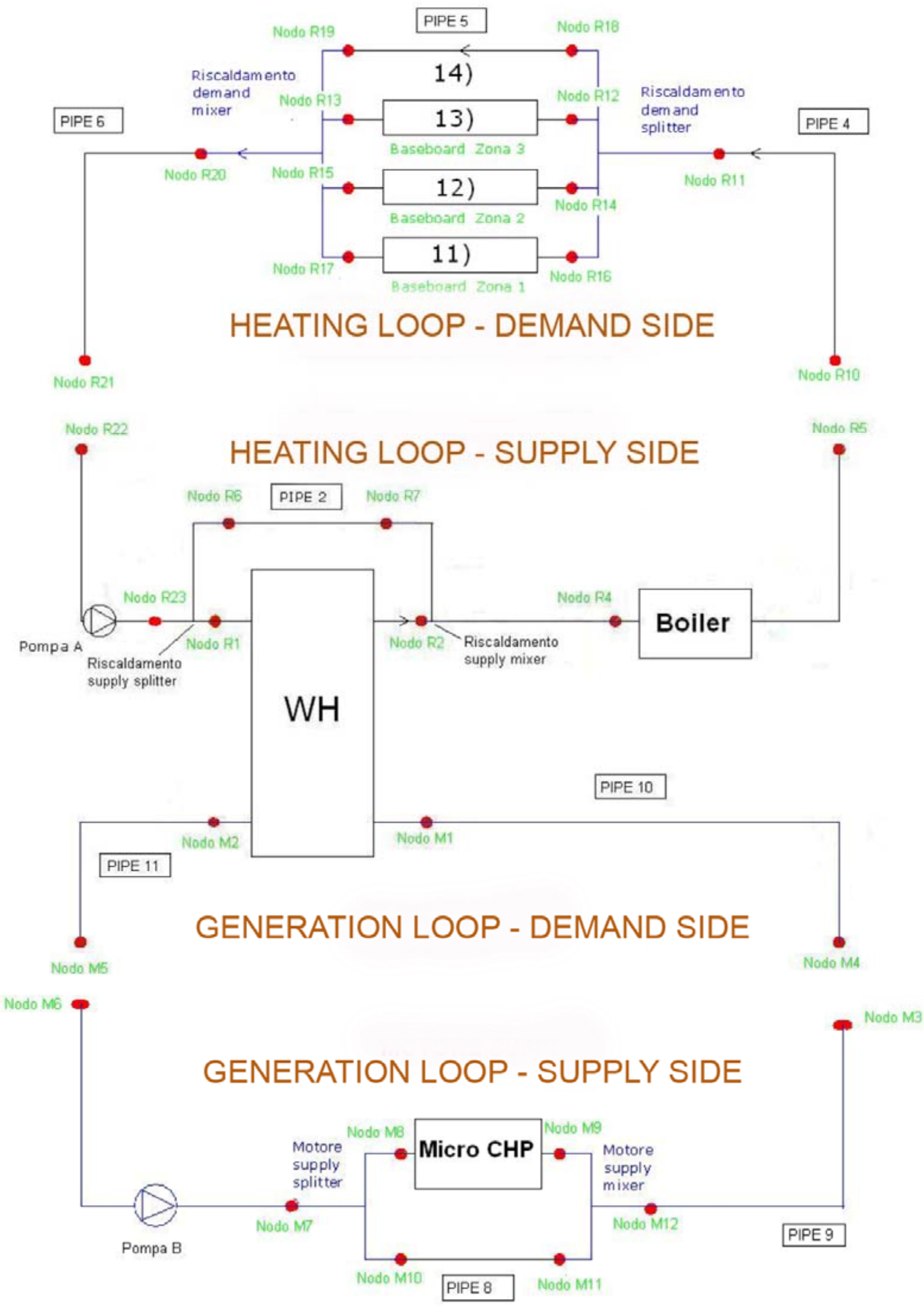

Figure 2: Model's heating plant scheme

The results from the simulation and the experimental data were compared by using two variables: the indoor temperature and the thermal power produced by the plant.
The model meets the 20°C comfort requirement in the heated zones during the day (from 6.00 AM till 10.00 PM) and 17°C during the night (from 10.00 PM till 6.00 AM); the passage from one temperature level to another is quicker in the model than in the real data: this can be related to the reduced building thermal inertia considered in the simulation (Figure 3).
The validation was carried out based on the comparison between the total thermal production (of both microCHP and boiler) measured during the field trials and the thermal production calculated by the EnergyPlus model.

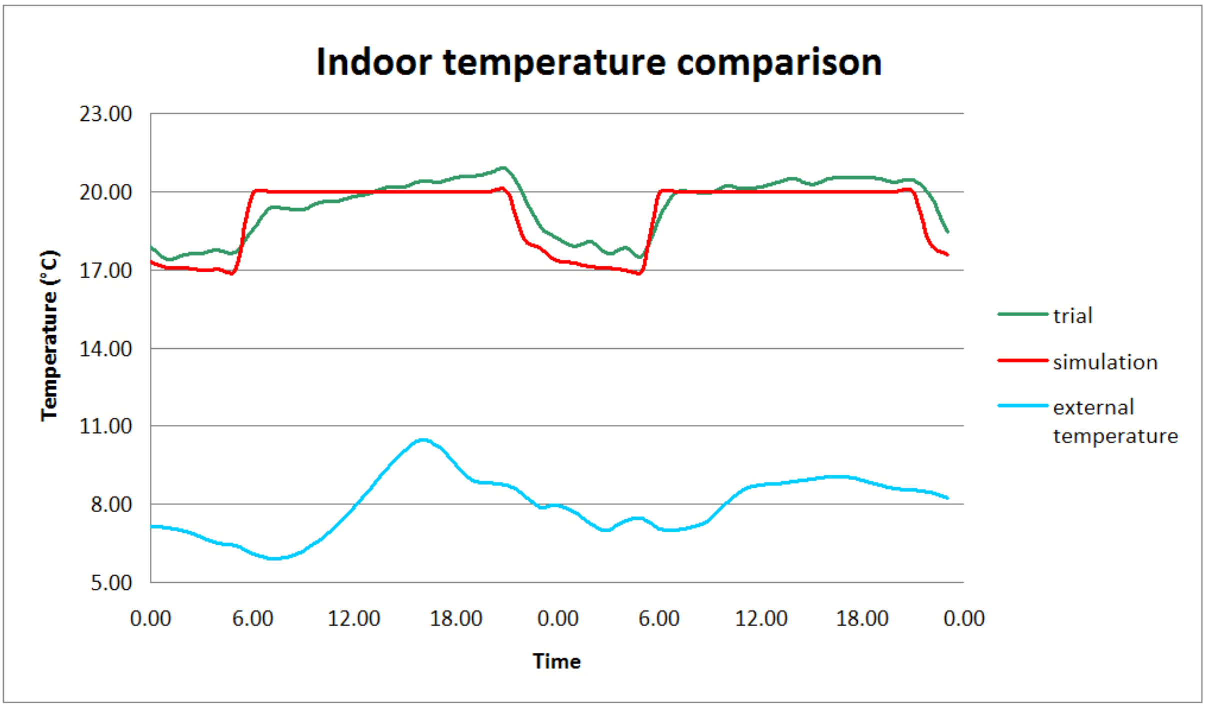

Figure 3:Comparison between indoor temperatures

The validation methodology follows the directions given in the ASHRAE Guideline 14, which considers two statistical parameters, NMBE (Normalized Mean Bias Error) and CVRMSE (Coefficient of Variation of the Root Mean Square Error):

$$NMBE = \frac{\sum_{i}^{n}(y_i - \hat{y}_i)}{(n-p)\cdot \overline{y}} \cdot 100 \tag{1}$$

$$CVRMSE = \frac{\sqrt{\sum_{i}^{n}(y_i - \hat{y}_i)^2 \Big/ (n-p)}}{\overline{y}} \cdot 100 \tag{2}$$

where y_i denotes the experimental data, $\hat{y}_i$ the simulated data, $\overline{y}$ the mean value of the experimental set of data, *n* is the amount of data comparable between model and testing, *p* is the amount of parameters of the statistical model and is 0 for the NMBE calculation and 1 for CVRMSE.

The threshold values suggested by the ASHRAE Guideline are 10% for NMBE and 20% for CVRMSE, both for the validation of a model with an hourly time step. The results are shown in Table 1.

STATISTICAL PARAMETER	THRESHOLD VALUE	CALCULATED VALUE
NMBE	10%	-0.2934%
CVRMSE	20%	17.79%

Table 1: Statistical parameters used for validation

DISCUSSION

The analysis of results shows that the model meets the indoor comfort requirements (both during day and at night), even if the boiler thermal output is smaller in the simulation, especially during the night (Figure 4). This difference may be related to the much more regular behaviour of the model: when the temperature of 20°C is reached, the simulation is able to modulate the power output, according to the required heating load. The experimental plant works in a slightly different way: the water heater follows a regulation process that is difficult to represent in the model and the indoor temperature is not fixed at 20°C, but can fluctuate between 20.5°C and 19.5°C.

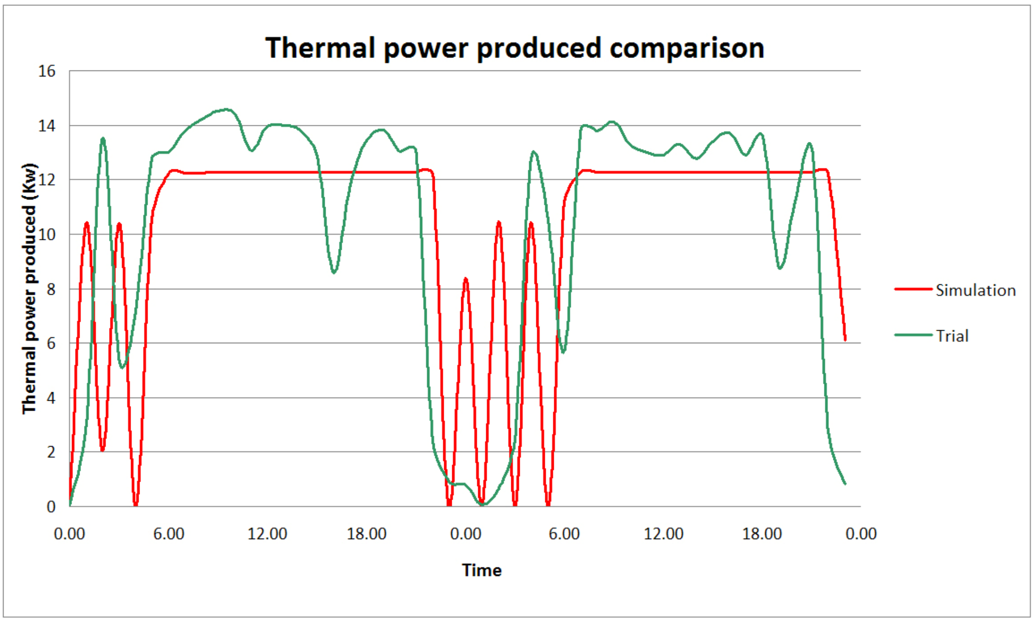

Figure 4: Comparison between thermal productions

The model cannot properly represent the building's thermal inertia: this causes the differences in the heat generation that can be observed between 0.00 and 6.00 AM. In fact, radiators are still hot for some time even if no heat is generated: this cannot be represented in the model and the radiators grow instantly cold when the heating plant is switched off.
In the morning, the plant has to meet a huge heating load, in order to raise the indoor temperature from 17°C to 20°C: during this operation, the thermal power exceeds the real thermal load, generating output peaks that are not represented in the simulation.
The model shows a more regular output of the boiler power during this period: this suggests that the boiler control scheme could be improved, in order to obtain a fuel consumption reduction and a better energy saving index. In fact, when the microCHP's thermal output is inadequate to match the request, a signal is sent to the boiler. The regulation of the boiler is based on a time delay between the heating demand and the moment when it is switched on. This kind of regulation cannot be represented in the model and this determines another difference in the heat generation data.

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Information Technologies and Software

HEAT TRADING SIMULATION TOOL

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ABSTRACT

The distributed energy generation concept, where energy is produced close to where it is being used, has been thoroughly investigated in the case of electricity networks. However, until now limited attention has been paid to its potential application to heating networks.

In a traditional district heating network, heat is generated in a large scale plant and distributed through a network of pipes to several consumer buildings. A micro Combined Heat and Power (µCHP) generation unit is an efficient means of producing both heat and electricity for a single building or a group of buildings. Within the frames of a district heating network connecting buildings equipped with such distributed generation units, a local heat trading market can be established. The core of heat trading concept is a possibility of an energy exchange between buildings via district heating network. Trading an excess of locally generated heat is possible to the neighbouring buildings or the district heating company. This kind of a market requires new business models enabling win-win situation between network operators, producers and consumers, and new simulation tools to face the increased complexity in planning and controlling district heating networks.

One of the key objectives of the FP7 project IntUBE [1] (Intelligent Use of Buildings' Energy information) is to demonstrate the heat trading concept with distributed µCHP through the design of an ICT tool. This tool enables the simulation of heat trading within virtual district heating networks and evaluation of its possible impact in terms of energy and cost savings.

CONTEXT: CONSIDERING ENERGY NETWORKS AT THE DISTRICT SCALE

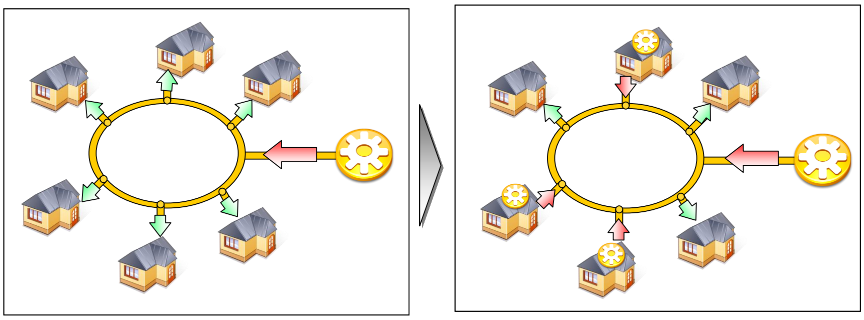
Due to constantly increasing energy consumption, distribution networks are becoming overloaded and sometimes unstable. The warming climate also puts more and more pressure to reduce GHG emissions by using renewable energy sources, but most of renewable energy alternatives in large scale are difficult to merge to urban environment. They may e.g. require plenty of space or change valuable architectural views. Decentralization of power generation using small-scale local cogeneration plants becomes an interesting option to enhance environmental friendliness, economy and energetic reliability of buildings in terms of both electricity and heat. Distributed energy infrastructure offers important advantages when compared to traditional centralized system. The system is flexible, easily scalable and increases control at local level. It allows the load to be shared with multiple producers, which enables even distribution and use of political, technological, economic and social resources, especially green energy resources. The system is robust since individual units can operate independently and fault in one unit is not fatal for the entire system.

Distributed generation provides an option for a consumer to promote individual values and support green energy. Smart energy networks also create new type of communality and responsibility of ones own actions [2].

DISTRICT HEATING AND HEAT TRADING MARKET

Different distributed generation devices and networks have been already studied. However, most of the studies focus on electricity, even though it is well known that efficiencies of devices producing only electricity are much lower than efficiencies of CHP devices. The biggest barrier to wider use of cogeneration devices is the difficulty to exploit heat, but most research projects bypass the question how the heat could be used. The district heating offers a technical solution to exploit heat produced in the distributed cogeneration devices. If the heat cannot be used in a building, where the generating device is installed, it can be transferred and used in some other building in the area. This option requires research on neighbourhood level. If the focus is only on building level or in the nation-wide networks, the potential use of heat will remain unclear.

Traditional heating networks with one large scale plant will be transformed to multi-generation networks with bi-directional energy flows enabling local heat trading markets (Figure 1).



➢Traditional district heating network with a single large scale plant producing and distributing heat to consumers

➢Several producers (building equipped with µCHP) enabling a heat trading market

Figure 1. Distributed generation in a district heating network

The heat trading simulation tool developed in IntUBE project enables the simulation of heat trading within virtual district heating networks and evaluation of its possible impact in terms of energy and cost savings. Thus main functionalities of the tool will allow to:

1. Roughly model the neighbourhood and its district heating energy network;
2. Accurately simulate the heat flows and network performance;
3. Analyse different scenarios and demonstrate heat trading concepts (e.g. addition of a new µCHP local generation unit in the district heating network);
4. Evaluate the impact of the simulation results, linked with:
    - risk minimization of district / cities energy supply vulnerability,
    - enhancement of multi-sources energy flows and reduction of distribution losses,
    - actual energy/money/CO2 savings.

FUNCTIONALITIES

This section describes the main functionalities offered by the heat trading simulation tool. These functionalities are incremental: it means that functionality “n+1” needs functionality “n” to work properly.

- **Functionality n°1 – Simulation of µCHP production in a building**

This feature provides a toolbox to model a wide variety of buildings (with diverse sizes, materials, energy consumptions and occupancy patterns, etc.) and a library of various µCHP units with different capacities. Once the location of a building and its associated climate are defined, the simulation engine computes the generation of power and heat by the µCHP and their use in the building (Figure 2).

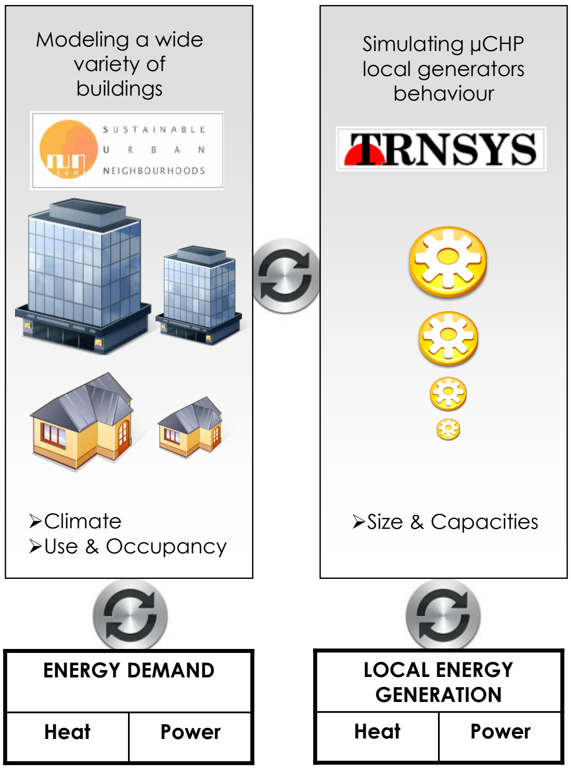


Figure 2. heat trading simulation tool - functionality 1 – energy demand and supply

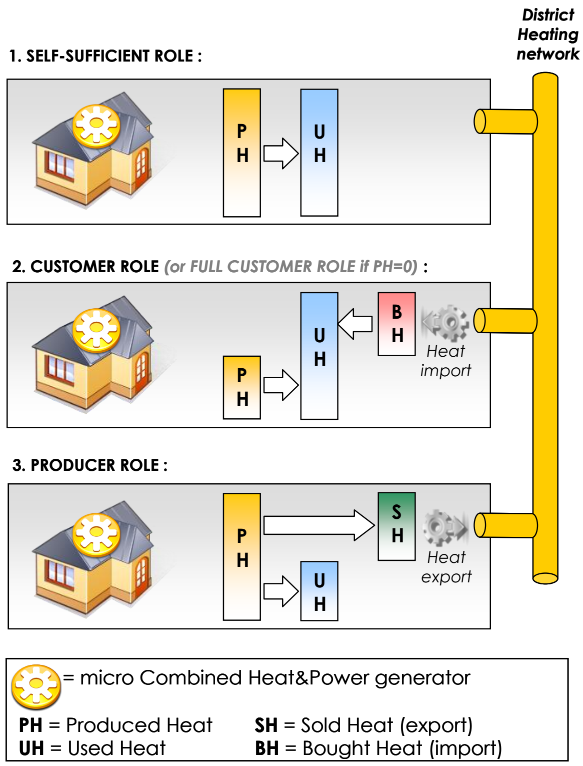


Figure 3. The different roles of a building equipped with a µCHP within the network

The concept of heat trading relies on the fact that the building equipped with a µCHP will first satisfy its own energy need. If the local unit does not produce enough energy, the building will draw the shortage of energy from the network; otherwise it will deliver the excess energy to the network. Figure 3 illustrates these three different roles that a building will alternatively adopt within the network (according to the time of the day, the season, and other influencing factors).

With an electrical load following strategy, the µCHP unit is designed to adjust the produced amount of power (electricity) with the amount required by the building. Additional power for meeting the peak power needs of the building is purchased from the main grid. Heat is consequently the by-product of energy generation. This setting is the one being used in all cases simulated in IntUBE since we focus on heat trading (However, the reverse strategy i.e. using a thermal load following strategy, with electricity being the by-product, could be investigated in the same manner).

A trivial comparison between heat demand and heat by-produced helps to determine the role of the building, each hour along the year (Figure 4). In the end, for one whole year, this functionality produces 8760 succeeding values (8760 hours in a year) that are either:

- Positive: meaning the heat overproduction represented in green (producer role);
- Nil (self-sufficient role);
- Negative: meaning the heat shortage represented in a red (customer role).

In the rest of this section, we call this outcome the “trading profile” of a building. Functionality 1 will be used to populate a repository that will contain the trading profiles of several significant building types.

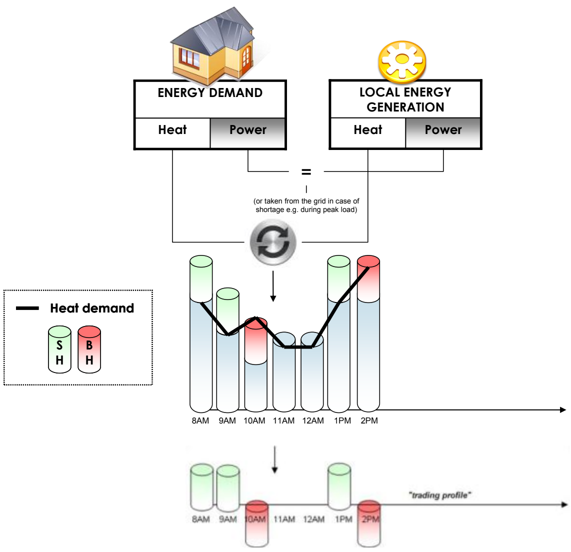


Figure 4. Determining the alternative roles of a building according to the time

- **Functionality n°2 – Detection of building combinations offering high potential for heat trading based on genetic algorithms**

This feature enables local planners determines which mix of buildings within a district is appropriate for heat trading: ratio of new/old - office/residential buildings, importance of sector-specific buildings (e.g. healthcare sector, etc.) with particular use patterns. A district formed of similar buildings, consequently getting the same energy needs at the same time, will not offer any potential for energy trading (Figure 5). In a kind of reverse-engineering process, the algorithm will identify energy-efficient heat-trading scenarios for a given location (Figure 6). The user has the possibility to evaluate building combinations in a dedicated location, and to set boundaries for each building type (e.g. no more than 30% of small residential houses). Based on all stored trading profiles (calculated through functionality 1), the simulation tool then determines the optimal combination of buildings types for the district.

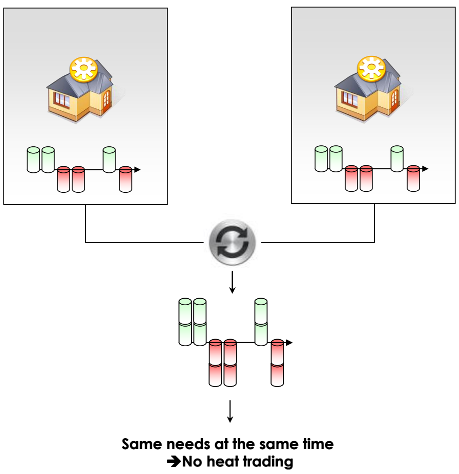


Figure 5. An unsuccessful building combination for heat trading

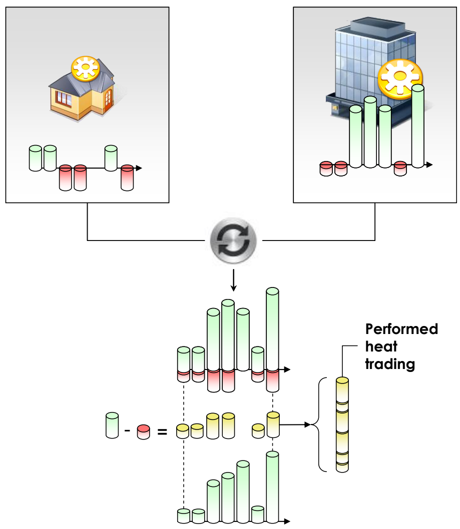


Figure 6. A successful scenario for heat trading

- **Functionality n°3 – Simulation of whole districts performing heat trading for energy and cost savings estimation purposes**

This feature comprehensively simulates district energy trading scenarios to assess their performance compared to simulations running the traditional large-scale producer scheme.

Simulations will provide indicators to decision makers on the actual value of optimized virtual scenarios employing new business models: the impact for operators, producers and consumers will be determined in terms of performance improvement of the network (e.g. heat loss reduction) and profitability (e. g. achieved energy savings, return on investment of simulated use-cases).

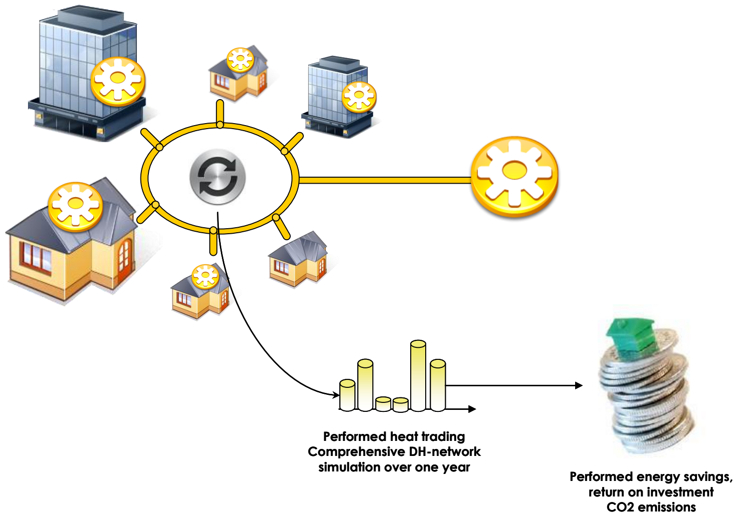


Figure 7. Heat trading simulation tool - functionality 3

IMPLEMENTATION: TECHNOLOGY USED

Functionality 1 is based on two existing software applications: SUNTOOL (FP5 project) [3], to compute the energy demand of a building; and TRNSYS, to match a µCHP unit with a building and compute its energy supply. Functionality 2 is currently being implemented in the object oriented language JAVA. It will use some outcomes from the SWOP FP6 European project, especially its Genetic Algorithm Module [4]. The implementation of functionality 3 will start soon. The possibility to start the implementation from an open source district heating network simulator software is under investigation.

CONCLUSIONS

The heat trading simulation tool will contribute to appraise the interest of energy management at the district scale. The rising complexity of district heating networks by integration of several generation units makes a simulation-based planning essential; the involved sophisticated control strategies need to be approved and validated by simulation to avoid malfunctions of the network and to ensure customers satisfaction regarding heat supply.

Even if focused on district heating networks, the present concept and principles are replicable and could to a certain extent be extended to any distributed energy generation schema.

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SOFTWARE

Heat Trading Simulation Tool		***Available languages*** ☐ **Français** ☒ **English** ☐ **Deutsch** ☐ **……….** ☐ **Italiano** ☐ **……….**
Editor **IntUBE FP7 project** **http://www.intube.eu**	***Distributor***	***Price***

Description

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Technical Data

Operating System	***Processor***
☐ **Windows 95/98** ☐ **Mac OS/X** ☐ **Windows NT4** ☐ **Mac + SoftWindows** ☐ **Windows 2000/XP** ☐ **Windows Vista** ☐ **LINUX** ☒ **Others : JAVA application; The tool can be launched in a web browser on any operating system.**	***Required memory***
	Required disk space

INFLUENCE OF PROBABILISTIC CLIMATE PROJECTIONS ON BUILDING ENERGY SIMULATION

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2 Climate Research Unit, University of East Anglia, Norwich, UK
3 Arup, London, UK

ABSTRACT

The Chartered Institute of Building Service Engineers (CIBSE) produced a technical memorandum (TM36) presenting research on future climate impacting building energy use and thermal comfort. One climate projection for each of four CO2 emissions scenario were used in TM36, so providing a deterministic outlook. As part of the UK Climate Impacts Programme (UKCIP) probabilistic climate projections are being studied in relation to building energy simulation techniques.

Including uncertainty in climate projections is considered an important advance to climate impacts modelling and is included in the latest UKCIP data (UKCP09). Incorporating the stochastic nature of these new climate projections in building energy modelling requires a significant increase in data handling and careful statistical interpretation of the results to provide meaningful conclusions.

This paper compares the results from building energy simulations when applying deterministic and probabilistic climate data. This is based on two case study buildings: (i) a mixed-mode office building with exposed thermal mass and (ii) a mechanically ventilated, light-weight office building. Building (i) represents an energy efficient building design that provides passive and active measures to maintain thermal comfort. Building (ii) relies entirely on mechanical means for heating and cooling, with its light-weight construction raising concern over increased cooling loads in a warmer climate.

Devising an effective probabilistic approach highlighted greater uncertainty in predicting building performance, depending on the type of building modelled and the performance factors under consideration. Results indicate that the range of calculated quantities depends not only on the building type but is strongly dependent on the performance parameters that are of interest. Uncertainty is likely to be particularly marked with regard to thermal comfort in naturally ventilated buildings.

INTRODUCTION

Developed countries (as within the EU) are encouraged by environmental, economic and energy security reasons to take on a more sustainable approach to energy production and consumption. Buildings are reported to make up 40% of current energy demands within the EU. By introducing high standards of energy efficiency in buildings and energy ratings, the European Energy Performance in Buildings Directive (EPBD) aims to reduce significantly energy use and related carbon emissions.

Computer models are used to assess the effectiveness of design decisions on the energy use and comfort within buildings. To model energy and comfort factors a description of the surrounding environment (specifically a weather description) is required. The current generation of dynamic building simulation models use industry accepted weather files that are considered to represent a Typical Meteorological Year (TMY) - according to some definition - for the given location of the modelled building. These files represent a typical yearly weather pattern, based on an evaluation of recorded weather data between 1983-2004. Using these files offers simulated evidence of a building design's energy performance under recent climatic conditions, but takes no account of the impact of a changing climate.

In 2002 the UK Climate Impacts Programme (UKCIP02) released data on modelled future climate. Four different scenarios were considered (based on different levels of anthropogenic CO2 emissions) for three future time-slices (2020s, 2050s and 2080s). The Chartered Institute of Building Services Engineers (CIBSE, TM36) demonstrated increased difficulty in designing low energy solutions whilst maintaining thermal comfort during summer, when considering some of the climate change scenarios within building energy simulation.

The use of future climate files in building energy modelling is now recognised as appropriate practice for considering energy and comfort concerns within buildings (CIBSE, TM48). To date, however, a deterministic modelling approach is taken; one weather file is applied as representative of the region's climatic conditions. Such an approach offers insight into the variability of energy and comfort demands of the representative year, but do not give any insight of the potential variation in performance from year to year. Little (if any) statistical confidence can be given in determining the effectiveness of a given building design in meeting stipulated energy-use and comfort criteria.

The UK Climates Impact Programme for 2009 (UKCP09) provides future probabilistic climate projections for the UK. As a result, multiple future weather files can be generated with an associated probability that can then be used for probabilistic climate impacts modelling. This paper provides an introduction to the use of probabilistic climate projections in understanding probable future climate impacts on building energy and comfort modelling.

A brief review of climate modelling uncertainty is given before two building models are presented with control climate data (both by deterministic and probabilistic weather considerations).

CLIMATE MODELLING UNCERTAINTY

Though theory and modelling results are accepted as correctly showing a trend in climate change influenced by anthropogenic CO2 emissions, modelling limitations and variability in interaction of systems driving climate exist that add uncertainty in future climate projections. The uncertainty of CO2 emissions has been considered in the past with average climate changes being associated with different emissions scenarios. This uncertainty falls under the title of pathways for forcing agents, as of [1], and is considered by some as too complex to quantify the true uncertainty in modelling. The time lag between emissions and climate change, however, are considered sufficient to consider emissions scenarios as thresholds for differing climate response.

The uncertainty in feedback processes (e.g. reduced albedo by reduced ice and snow cover increasing global warming effects) has resulted in different climate models offering different climate projections for the same emissions scenarios [1]. This model uncertainty is reported as the reason for developing probabilistic climate modelling techniques with ensembles of climate models. For further detail on the philosophy of probabilistic modelling see [1, 3, 8, 11, 12].

IMPACTS MODELLING WITH PROBABILITY

Climate projections can be used to understand the impact of climate change on physical systems that can help guide strategy on management of resources and control demand. Applying probabilistic projections has greater potential of applying risk-based decision making than a deterministic approach with different emission scenarios. An example of using probabilistic data in impact assessment for water resource management is given in [9].

As climate influences building energy use and thermal comfort, designing a building that will be low energy and thermally comfortable now and in the future is important for reducing CO2 emissions as well as reducing the supply-demand gap associated with sustainable energy sources and technologies. Accounting for uncertainty provides a risk-based decision tool that gives confidence in the theoretical performance of a low energy building design. Though this process (if acted upon) is recognised as adding uncertainty in terms of emissions scenario, it is not considered in this study.

Different metrics are available to rate the success of a building design, such as: heating and cooling degree-days (CIBSE, TM41), heating and cooling energy demands, heating and cooling systems efficiency, predicted thermal comfort (BS EN ISO 7730:2005 or BS EN 15251:2007).

For thermal comfort it is possible to present the data as a distribution of frequency of comfort rating over the course of a single TMY. In this instance introducing a probabilistic representation of the climate should add to the confidence in probable distribution of thermal comfort.

For energy demands a single TMY offers one result for the expected energy demand and system efficiency, and does not take account of the variability of such a system. The question remains, however, whether considering the energy demand in a probabilistic fashion is of any benefit to improving understanding of energy demand and/or efficiency?

WEATHER GENERATOR

As part of UKCP09 a weather generator has been developed to offer spatially downscaled yearly weather files from probabilistic climate modelling results. The generator offers control files (representing the observed period 1961-1990) as well as future scenarios (from perturbed observed parameters) for different levels of CO2 emissions. The generator provides a resolution of 5km x 5km (spatially independent) grid squares for the UK at either daily or hourly time steps. The generator is based on a 30 year period of observed data and as such one run generates a sequence of 30 years of weather data for a given grid square and time step. For further detail see [7].

As a first stage investigation, 1,500 weather files relating to the control scenario were produced from the weather generator at the Climate Research Unit (CRU), University of East Anglia. The files were produced for the 5km x 5km grid associated with the London Heathrow (LHR) weather station utilising the same programs as applied in the UKCP09 weather generator.

As an example of the variability in the weather files used in this study, figure 1 shows the variation in monthly mean, maximum and minimum dry bulb temperatures for the 1,500 generated weather files. On each figure the mean of the 1,500 values are presented (using +) along with the value calculated from the latest CIBSE LHR weather file that is used as standard in current building energy simulation work (represented by x).

The probabilistic climate data shows a potentially large variation in the monthly dry bulb temperature values. A difference in the mean values of the probabilistic data and the mean values from the current standard CIBSE LHR weather file are present.

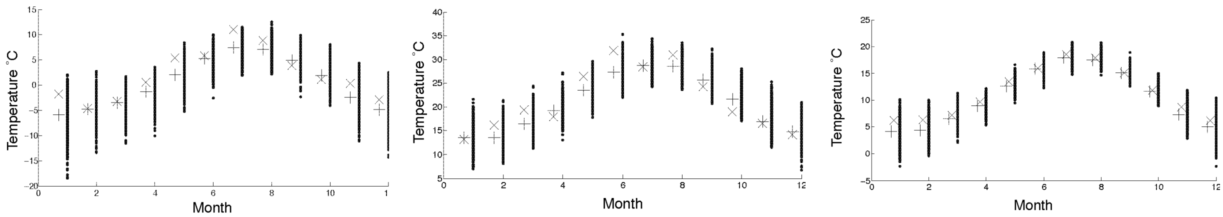


Figure 1: Variation in 1,500 control weather files - minimum (a), maximum (b), and mean (c) monthly temperatures

The CIBSE weather file utilises the 20 years of observed data (1983-2004) to determine (by statistical methods) the most typical meteorological month for each month from the 20 years of weather data. The most typical months are then concatenated to provide a typical meteorological year, see [5]. Widely practised in producing weather files for building energy simulation, the method does not account for all possible weather years, and figure 1 suggests that it doesn't capture the true 'statistically typical' climate as presented by the probabilistic climate data.

To understand the influence of the probabilistic consideration of climate on building simulation, two case study buildings are presented.

BUILDING MODEL DESCRIPTIONS

Two office use buildings were modelled using EnergyPlus (a dynamic simulation modelling tool). Both are existing buildings built post 1984[1] one designed to be fully mechanically controlled for thermal comfort and the other designed as a low energy building. In both models the heating and cooling system capacities were constant for all weather files.

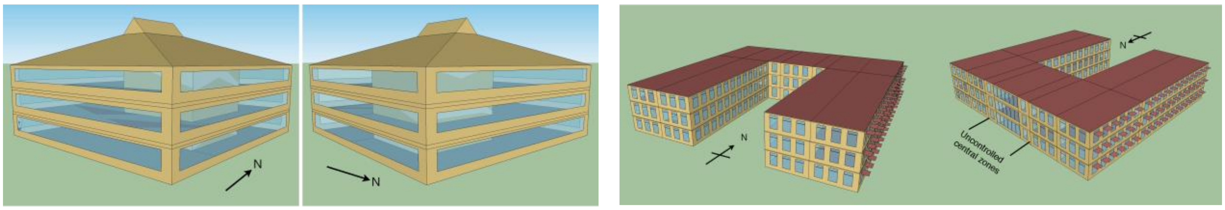
The mechanically controlled building is heated and cooled by a network of ceiling mounted fan-coil units that circulate the indoor air to achieve a required heating or cooling set point temperature. The heating load being met by a gas-fired boiler and the cooling requirement coming from an electric air-cooled chiller (figure 2(a)).

The low energy building is a mixed mode building[2] that utilises external shading, exposed thermal mass, natural ventilation and an adiabatic spray for cooling and a system of water-fed baseboard heaters for heating. The water is heated by a gas-fired boiler (figure 2(b)).

SIMULATION RESULTS

Both building models were run using a distributed computing protocol (in this case XGrid, [4]) on a total of 8 *x* 2.8 GHz processors. The difference in the building model complexities and size resulted in a considerable difference in simulation run time for each of the 1,500 runs. The light-weight mechanically controlled building ran 1,500 times within approximately 6 hours, whilst the mixed-mode building took approximately 168 hours (7 days) to complete 1,500 runs. These time-scales highlight practical barriers in applying probabilistic climate data to building energy simulation; the time and technical ability required in using a grid based method for multiple simulation may be beyond the capability of smaller companies involved in design and planning of low energy buildings.

Once simulated the energy and temperature metrics were processed for each model to provide histogram representation of the frequency of expected thermal comfort and energy related performance.



(a) (b)

Figure 2: EnergyPlus Building Models viewed in Google SketchUp, (a) light-weight mechanically controlled building and (b) mixed-mode office building

THERMAL COMFORT

Using BS EN 15251:2007 showed both buildings provided good thermal comfort during occupied hours, whether using the probabilistic or deterministic consideration of weather. This method considers adaptive comfort - recognising the ability of individuals to adapt to their environment, provided conditions remain within a limited range of the expected conditions - see [6, 10] The method of BS EN ISO 7730:2005, however, has historically been more commonly applied and uses a complex relationship of internal temperature with clothing and activity level from which a mean vote of comfort is calculated, [2]. An index of Predicted Mean Vote (PMV) is used to measure perceived thermal comfort on a seven point scale (-3 is too cold, 0 is thermally comfortable and +3 is too hot).

[1]Introduction of building energy regulations from the 1984 Building Act of the United Kingdom.

[2]Mixed mode refers to a cooling strategy that combines passive and active cooling methods to reduce energy consumption.

Utilising ISO 7730:2005 showed a greater prediction of discomfort than EN 15251:2007 - as a result of tighter control conditions. Figure 3 shows the distribution of hourly recorded PMV for each occupied zone of the building during occupied hours. Figures 3(a) and 3(b) show the PMV distribution for the light-weight building - for the single weather file consideration and probabilistic consideration, respectively. Figures 3(c) and 3(d) are for the mixed-mode building single and probabilistic considerations, respectively.

Energy Use

Focusing on the cooling demand, table 1 shows the difference between the single run annual cooling loads and mean annual cooling loads from the probabilistic weather considerations. The probabilistic annual cooling loads were normally distributed for both buildings.

	Light-weight Building		Mixed Mode Building	
	Annual Cooling (kWh)		Annual Cooling (kWh)	
Probabilistic	29356 (Mean)	1919.4 (s.d)	4048.7 (Mean)	710.48 (s.d)
Deterministic	22506	-	2444.5	-

Table 1: Annual cooling energy demands predicted by single run and probabilistic weather runs

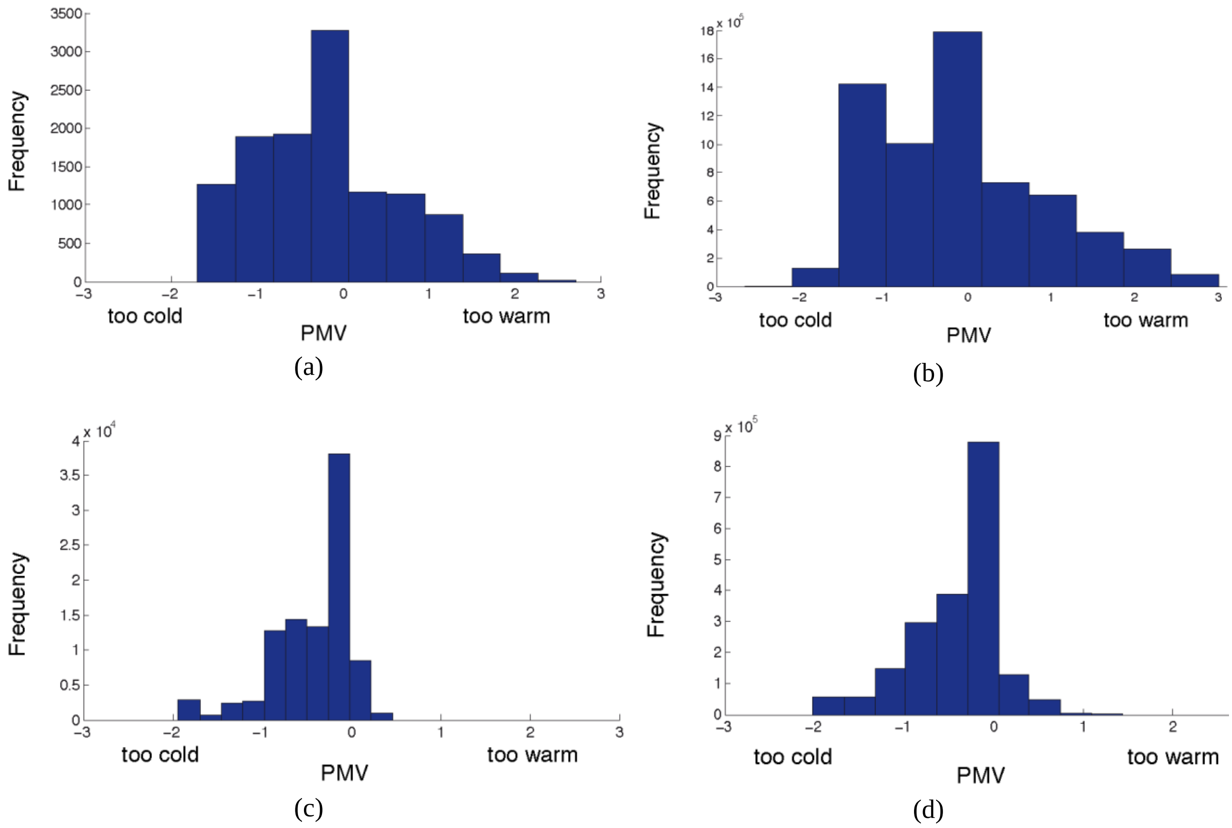


Figure 3: Normalised frequency histogram of operative temperature deviation from the limits of considered comfort.

DISCUSSION

The distribution of hourly predicted thermal comfort (considered by Fanger's theory) differs between the single weather year and multiple (probabilistic) weather year consideration. For both building models the probabilistic consideration increases the range of calculated PMV whilst maintaining a similar shape of distribution. For these models the probabilistic weather data strengthens the pattern of expected thermal comfort resulting from considering a single weather year.

The predicted cooling loads show significant sensitivity to the probabilistic weather considerations. Utilising a single weather file showed a large difference in the simulated annual cooling load to the mean annual cooling load of the probabilistic runs. The single run predictions on cooling load were ~ -3.5 and ~ -2.2 standard deviations from the probabilistic mean annual cooling load for the light-weight and mixed-mode buildings, respectively. In confidence terms, the probabilistic weather consideration shows a confidence of 99.9% and 97.7% that annual cooling load will be greater than that predicted by the deterministic measure for the light-weight and mixed-mode buildings, respectively.

A deterministic consideration of weather could lead to significant shortfall in meeting EPBD demands for low energy, thermally comfortable buildings.

CONCLUSION

Devising an effective probabilistic approach highlighted greater uncertainty in predicting building performance, depending on the type of building modelled and the performance factors under consideration. Results indicate that the range of calculated quantities depends not only on the building type but is strongly dependent on the performance parameters that are of interest. Uncertainty is likely to be particularly marked with regard to thermal comfort in naturally-ventilated buildings.

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MODELS FOR OPTIMISED OPERATION OF HEATING SYSTEMS WITH VARIABLE TARIFFS

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ABSTRACT

With the rising demand of greenhouse gas emission free energy the distribution grids evolve more and more from a centralised to a decentralised structure. With this development different technologies of distributed generation must be integrated into the grid, which leads to challenging optimisation tasks. In the low voltage grids photovoltaic plants, electro-vehicles and small cogeneration plants (CHP) operate more or less uncoordinatedly. With a high amount of these distributed generators (DG) this may cause violations of power quality criteria and avoidable losses, which should be managed by a grid oriented management system based on modern information and communication technologies (smart grid). On the other hand the thermal load of the buildings must be supplied locally. One proposal for combining global grid optimisation tasks and local plant conditions is to introduce local variable tariffs for feed-in of electricity produced by controllable generators. Challenges of a tariff leaded local energy management system can be faced by model based methods, using reduced models for real time optimization. This is suitable for microcontroller based controller devices. Starting from the detailed model this paper extracts such reduced models which can be used for optimal scheduling of energy systems.

INTRODUCTION

With the rising demand of producing energy climate friendly our energy distribution grids evolve more and more from a centralised to a decentralised structure. With this development a lot of different technologies must be integrated into the existing structures, which leads to challenging optimisation tasks. In the low voltage grids near the consumer photovoltaic plants and small cogeneration plants (CHP) feed-in more or less uncoordinatedly. With a high amount of these distributed generators (DG) this may cause violations of power quality criteria, which must be avoided by a grid oriented management system. On the other hand the thermal load of the single residences must be supplied locally. For an efficient heat supply CHP and solar thermal plants can be used in combination with an auxiliary heater. Figure 1 shows the components and the power flows between them of such a local system. All these components influence each other, which must be considered by the local plant management. One possibility for combining global grid optimisation tasks and local plant conditions is to introduce local variable tariffs for feed-in of electricity generated from controllable generators. [1] discusses several tariff options to control energy flows within electric distribution grids. The highest effect for the grid has been achieved by a tariff with a global variable and a local variable component.

The challenge lies in developing less complex models, still adequately describing the system, for such kind of tariff driven operation management. Within this paper we will focus on the development of such models with reduced complexity of thermal systems, which can be used for operation management tasks. With conventional thermal simulation tools it is possible to describe thermal systems in detail. But due to their complexity they are not suitable for optimisation tasks. In the presented work we used the open source simulator ColSim (www.colsim.de) for modelling a real system. With the knowledge of the detailed system behaviour reduced models have been derived. The new model has been described as mixed integer linear program (MILP), which for example can be solved with the program glpsol from the GNU Linear Programming Kit. The model objective function minimises the operation cost of the system by shifting CHP operation to times of high remuneration. The model constraints satisfy the thermal power balance by using a solar thermal collector, a CHP, an auxiliary heater and a thermal storage. Further constraints restrict CHP operation or describe storage losses. The optimising routine has been integrated into ColSim which results in a predictive operation strategy overlying the temperature based, heat driven control.

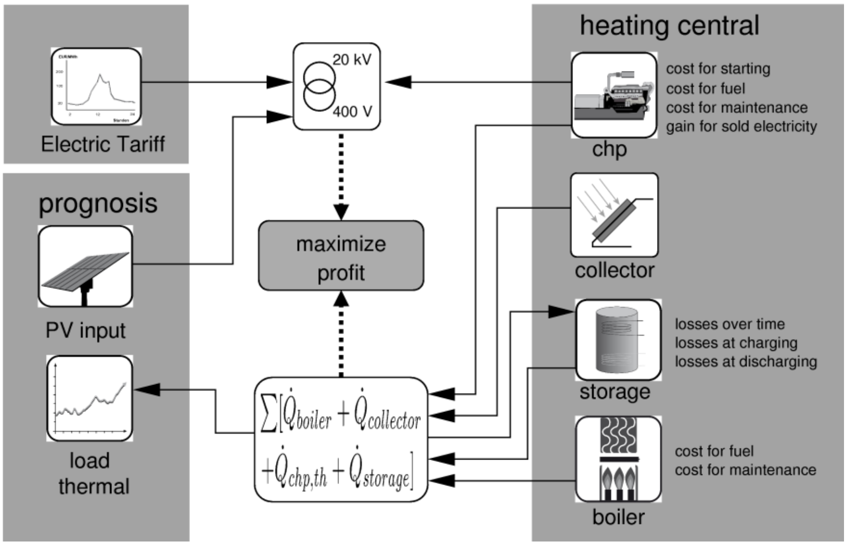

Figure 1: The components of a local energy management are shown. The components interact by power flows

MODELLING AND CONTROL OF THE LOCAL ENERGY SYSTEM

With conventional thermal simulation tools it is possible to describe thermal systems in detail. But due to their complexity they are not suitable for optimisation tasks. In the paper the open source simulator ColSim (www.colsim.de) for modelling a real system has been used. This type of programs is applicable to make an almost perfect model of the real system and to evaluate different control strategies for the system. But a larger number of components like CHP, which are restricted in their operation, increase complexity. If the operation of such a system should be optimised, conventional simulators cannot solve this task properly. For this they must be used in combination with other mathematic optimisation algorithms. The temperature based control, which guarantees heat supply at any time, is overlaid with an optimised schedule. For optimisation tasks typically a new abstract modelling is necessary. This section starts with the detailed model and control strategy of the system in ColSim. From this detailed model a reduced model based on mixed integer linear programming will be derived. This model later on will be used for optimising the system behaviour.

Detailed Modelling of the thermal system with ColSim

A typical thermal system is build, consisting of a cogeneration plant (CHP), an auxiliary boiler, a solar collector and a thermal storage. Figure 2 shows the hydraulic schematic of the system. Typically, such a system is controlled by temperatures.

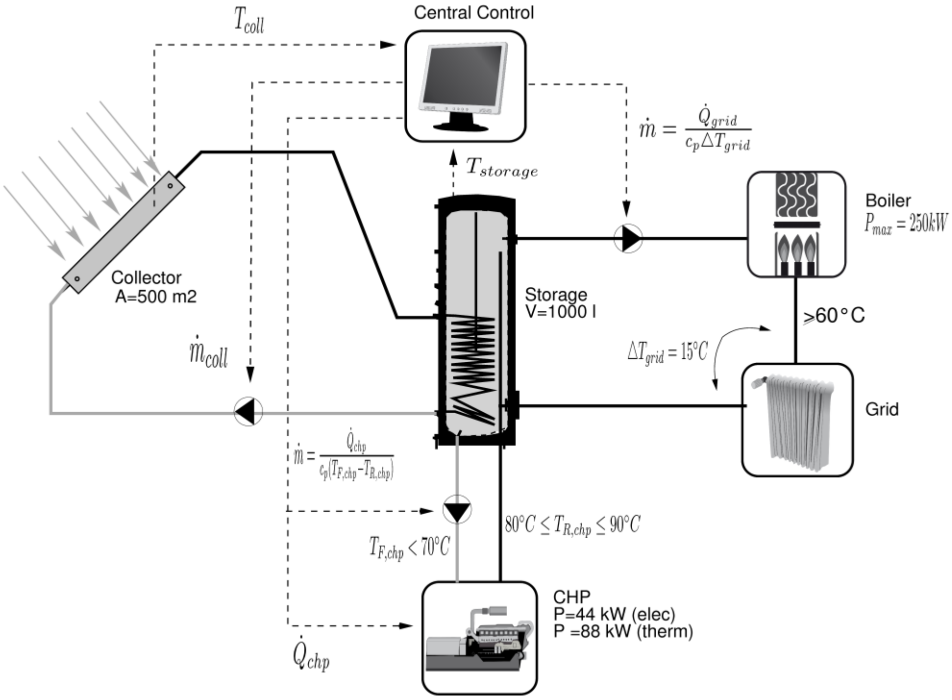

Figure 2: Hydraulic schematic and control schematic of the heating system.

The CHP is turned on when the temperature of the highest level of the storage is less than $T_{sto,min}$ (70 °C). It is switched off if the lowest temperature in the storage exceeds $T_{sto,max}$ (80 °C). For the simulation it was assumed that the CHP provides a constant forward temperature $T_{F,CHP}$. This is valid because typical aggregates have intern mixing branches to guarantee a constant output temperature. With this temperature the fluid flow through the CHP

$$\dot{m} = \frac{\dot{Q}_{chp}}{c_p(T_{F,chp} - T_{R,chp})} \tag{1}$$

can be calculated with the thermal power $\dot{Q}_{chp}$, the heat capacity of the fluid and the input temperature of the $T_{R,chp}$.which is taken from the storage. This flow is controlled by the pump. Typical solar thermal installations are also integrated into the system with a thermostat that measures the temperature gradient across the collector and compares it to the temperature of storage (incorporated in the control centre). The pump is modulated accordingly by this controller. Before the fluid reaches the load the auxiliary boiler guarantees that the output temperature is at least $T_{set,aux}$ (60 °C). If the fluid is colder it is assumed that the fluid is heated up to $T_{set,aux}$. For that it is assumed that the power of the boiler can be modulated arbitrarily Finally, the heat circle mass fluid rate was also regulated in order that the thermal load always cools the fluid by a constant ΔT_{grid} (15 °C).

$$\dot{m} = \frac{\dot{Q}_{grid}}{c_p \triangle T_{grid}} \tag{2}$$

In typical CHP systems this temperature controlled operation strategy is motivated by the target to maximise operation time of the CHP. So if storage capacity is available the CHP will run to recharge the storage. If an additional, not arbitrarily controllable device like a solar collector is added the control strategy is not so easy any more. If also electricity generation should be optimised, which is motivated by recent changes in the supporting laws for photovoltaics and cogeneration, this thermal driven operation is not optimal anymore. So a

CHP schedule which regards the previously mentioned restrictions should be generated. This is discussed in the following.

Mixed linear Programming (MILP)

The target of the mathematical optimization is to find the maximum or minimum of an objective function f, which is defined on the bounded area S. It can be understood as the solution of an over-determined system of equations. For the unit commitment we use the method of mixed integer linear programming (MILP). In a linear problem (LP) the objective function and all constraints must be linear. LPs can be solved efficiently by the simplex algorithm, which guarantees the optimal solution. If some variables are integer (e.g. binary) the problem is divided into several LPs (e.g. with Branch&Bound algorithm) where the integer conditions are relaxed but bounded. The new problems can be solved again with the simplex algorithm. At the end at least the maximal deviation from the optimum is known. In the last 20 years many problems in the area of transport and production were described as MILP. From the simulation, analysis and identification of the complex system parameters previously introduced a simplified model was developed. The derived model is formulated in the solver-independent language AMPL and is solved with the program glpsol from the GNU Linear Programming Kit.

Modelling with reduced complexity

In [2] an optimisation routine based on MILP for systems with CHP, boiler and storage has been derived. This section extends this by a model for the solar collector. The central constraint of a heating system is to fulfil the thermal balance in each time step $t \in \{1, ..., T\}$

$$P_{load}[t] = P_{chp,th}[t] + P_{boiler}[t] + P_{storage}[t] + P_{collector}[t] \tag{3}$$

By studying the detailed collector model [3] which is e.g. implemented in ColSim the collector output power can be calculated by

$$\dot{Q}_{coll} = A[\tau\alpha I - K_0 dT - K_1 dT^2] \tag{4}$$

Where $\dot{Q}_{coll}$ [kW] is the collector power, A [m^2] the collector area,τ the transmission rate, α the absorption rate, I [kW/m^2] the irradiation. Ko [kW/Km^2] and K1 [kW/K^2m^2] the loss coefficients and dT [kW/Km^2] the temperature difference between the inside of the collector and the ambient temperature.

However, the derived model can be only described by liner constraints. Hence, a linear equation was proposed in order to implement the collector model in MILP

$$\dot{Q}_{coll,max} = A[c_1 I - c_2 dT] \tag{5}$$

The simulation language R (www.r_project.org) was used to define the regression coefficients. In the MILP model $\dot{Q}_{coll,\max}$ was taken as maximal output power of the collector. The optimiser must decide if the collector is operated in stagnation or the power is used within the grid. This is implemented with the binary variable $s_{coll,on}[t]$, which tells for time step t if the collector is in operation or not. To limit the number of possible solutions the power should be in the interval [0.9,1] $\dot{Q}_{coll,\max}$ in case of operation. This is guaranteed by equation (6). This keeps schedules more continuous and therefore more realistic.

$$\dot{Q}_{coll,max} \cdot s_{coll,on} \leq \dot{Q}_{coll}[t] \\ \dot{Q}_{coll}[t] \geq \dot{Q}_{coll,max} \cdot 0.9 \cdot s_{coll,on} \tag{6}$$

Optimisation routine

For the optimisation it is necessary to define an objective function. In this case the contribution to profit should be maximised. It contains costs for fuel and maintenance of CHP $C_{CHP}[t]$ and boiler $C_{boiler}[t]$. Each start of the CHP engine causes deterioration which is modelled by starting costs for the CHP $C_{start,chp}$. Sources for profit are selling of electricity G_{el} and heat G_{th}. To support usage of the collector instead of CHP a virtual gain for operation of the collector $G_{collector}$ is introduced. So only with very high feed-in tariffs the CHP operates and the collector is shut down. Equation (7) shows the used objective function.

$$max\,(profit) \\ max \sum_{t=1}^{T} \left[G_{th}[t] + G_{el}[t] - C_{chp}[t] - C_{chp,start} - C_{boiler}[t] \right] \tag{7}$$

APPLICATION TO THE DEMAX SHOWCASE

The model approach was used to simulate different extensions of the thermal system of the DEMAX showcase in Bamlach. Originally the system is powered by 2 micro CHP with 5.5 kW_{el} each, 2 auxiliary boilers (225 kW each) and a storage with a volume of 2000 l. The system model presented in this paper was extended to a 44kW/88kW (el/th) cogeneration plant (CHP), a solar thermal installation with a total area of 500 m^2, a thermal storage with a capacity of 1000 l and a PV installation with 18 kWp. The heat demand was given by a profile that represents the thermal heating and hot water consumption.. Configuration of the system is shown in Figure 2.

The so far introduced MILP model was used for optimization of a ColSim model that represents the system. For the year 2007 measurements of the system and prices at the EEX spot market were used as perfect prognosis input for the optimization. The electric demand was used to define a local variable tariff that describes the net load of the settlement. To get the total tariff the EEX price was added. The resulting tariff was given as input to the optimiser. Also the thermal load curve and weather data were used.

The tariff optimised CHP schedule was overlaid to the temperature controller in ColSim. The remaining components (auxiliary boiler and solar collector) remained only temperature controlled. On the one hand this is a validation of the MILP model with reduced complexity. On the other hand this is a simulation of the planned control structure in Bamlach. In the showcase the CHP gets a schedule and only is allowed to deviate, if critical temperatures are reached.

The analysis of the whole year showed the behaviour of the system as expected. Total operation hours of the boiler and the solar collector were very similar in the detailed model with given CHP schedule and in the reduced model. Furthermore, in the simulation was not any obstacle that does not allow this optimization to a real heat system.

Figure 3 shows both scenarios for a period of 57 hours. The lower diagram shows the results of optimization. The upper plot shows the simulation results if the optimised CHP schedule was set in ColSim. It can see that the behaviour from the thermal storage, the boiler, and the collector are very similar.

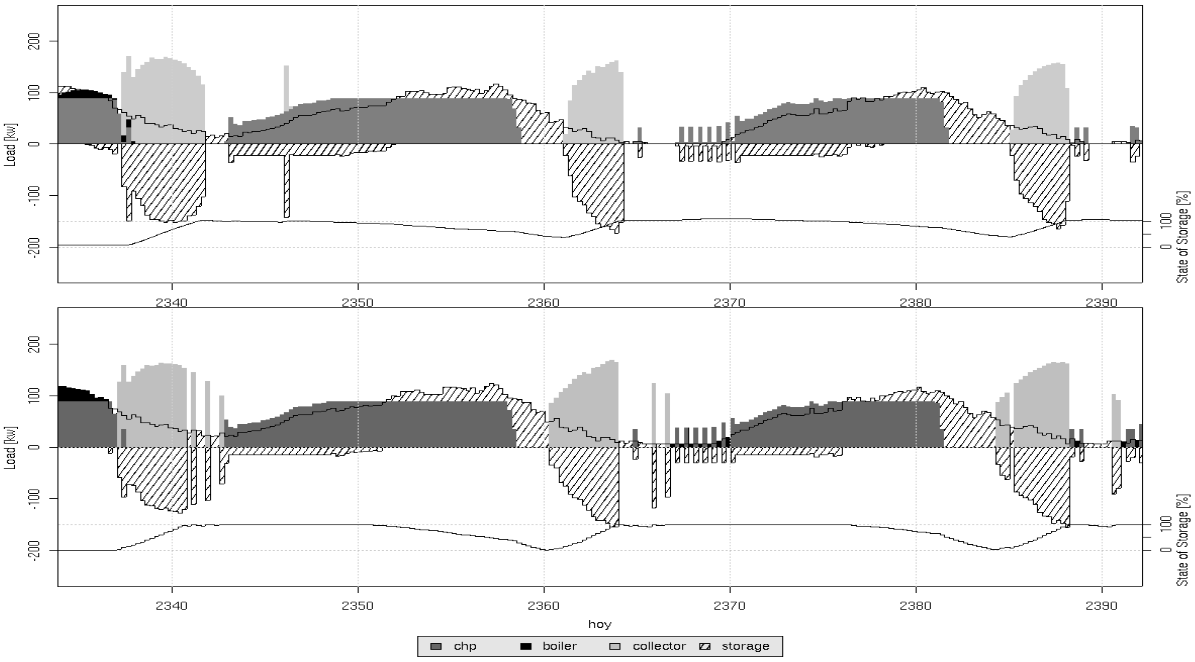

Figure 3: Comparison of behaviour of complex and reduced models

Regarding economics, the results obtained in [4] that have the same approach as the present paper show that approximately 20 % of costs are saved with optimised operation schedule as input into the ColSim model. This also verifies the results from [2] in the sense of saving costs.

CONCLUSION

In the present paper it has been demonstrated that it is feasible to develop models with reduced complexity of thermal systems, which can be used for model based optimisation of plants' operation management. The achieved gains motivate plant operators and consumers to change their generation and demand. Additionally, recent changes in the support laws motivate them to match demand and generation profile in the local energy system. These facts show that substantial optimisation potentials exist in local energy management.

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SIA 382/2 AND 3 – STANDARDS AND TOOL FOR OVERALL ENERGY PERFORMANCE OF BUILDINGS

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ABSTRACT

In a project of the Swiss Association of Engineers and Architects, SIA, a tandem of new standards on the load and energy need calculation of such buildings (SIA 382/2) and on the system choice, the system efficiency and energy performance of heating, ventilation and cooling systems (SIA 382/3) has been created based on the relevant CEN standards. The focus is on buildings which not only need heating, but also cooling and/or humidification / dehumidification, i.e. basically non residential buildings. For these buildings, however, not only the ventilation/cooling/humidification part is covered, but also heating is included, and the requirements are based on an overall energy performance of the building, using either primary energy, greenhouse gas emissions or national weighted delivered energy values, in analogy to the energy certificate.

The standards require an hourly time step approach. Building simulation programs are allowed, if they fulfil validation related requirements. However, a standard method is proposed and a respective tool has also been developed. It uses the simplified dynamic room model and some of the system calculation methods given in CEN standards. The tool is based on the former SIA tool on electric energy requirements (SIA380/4) and is largely extended in the system calculation area. The tool allows for the load calculation and system sizing as well as the annual system efficiency and energy consumption, using the same input data. It is aimed at an overall building optimisation in terms of the delivered energy weighted by the above mentioned factors.

For some system aspects, there were not sufficiently good models available, and new developments were necessary to meet the requirements of both a simple input structure and an enough good representation of the part load behaviour in an hourly time step environment.

Currently (June 2009) the draft standards are revised after public enquiry and the tool is available as a beta version. The finalisation is foreseen for end of September 2009, the standards probably coming into force by January 1, 2010.

The project can be considered an important step towards an overall building energy performance optimisation.

INTRODUCTION

In response to the European standard series on building energy performance, which have been developed in respect of the European Energy Performance of Buildings Directive (EPBD, [1]), the standards of the Swiss Association of Engineers and Architects, SIA, in this area are currently revised or have been recently. This is, among others, also true for the current standard on cooling load calculation.

Until now, for buildings which not only need heating and ventilation, but also cooling and/or humidification/dehumidification, i.e. basically non residential buildings, the energy requirements in SIA standards have been spread out in different standards or pieces of standards. The heating energy requirements are the same as for heated only buildings and calculated according to the monthly method in SIA 380/1 [2]. Some requirements on ventilation and cooling systems energy use are in the standard on electrical energy, SIA 380/4 [3], for which there has been a computer program available since a couple of years [4].

However this situation is unfavourable in respect of an overall building energy optimisation, which requires a tool considering all aspects at a time. The unidirectional view with emphasis on heating energy demand, accompanied with some additional considerations on electrical energy, is supported by the energy regulations. However, this is not adequate to the large non residential buildings, leading to non optimal solutions. E.g. a good insulation and a compact building body may be adequate to reduce heating energy demand, but at the same time enhances cooling energy needs and reduces daylighting possibilities and enlarges lighting energy demand. Although detailed building simulations have gained territory during the last years, they do not replace the regulatory energy requirements and are often used to answer special questions such as comfort considerations in special situations etc.

METHOD

General

During the last 3 years, SIA has run a project which goes in another direction. In this project, a tandem of new standards has been created:

- SIA 382/2: Calculation of heating and cooling load and energy needs for buildings with room conditioning systems [5]
- SIA 382/3: System choice, system efficiency and energy performance of heating, ventilation and cooling systems [6]

The focus is on buildings with cooling and/or humidification/dehumidification, however, also the heating aspects are included for these buildings. Both standards are based on the relevant CEN standards. The standards require an hourly time step approach. Simplified standard calculation methods are given. Detailed building simulation programs are allowed, if they fulfil validation related requirements. Their use is even necessary for cases which are not covered by the standard method.

A calculation program was developed in parallel to the standards, covering all the calculations necessary and giving the possibility for an overall optimisation. This is based on the above-mentioned calculation tool on electric energy requirements according to SIA 380/4, but extended in several areas.

The requirements are based on an overall energy performance of the building, using delivered energy values weighted either by primary energy, greenhouse gas emissions or National factors, in analogy to the energy certificate.

Room Calculation

For the calculation of the room behaviour, the simplified dynamic room model from EN ISO 13790:2008 [7] is used. For the consideration of thermally activated building components – an important system solution in Swiss non residential constructions – a modification, shown in figure 1, was added to the model. This enables the simultaneous calculation of two different emission systems.

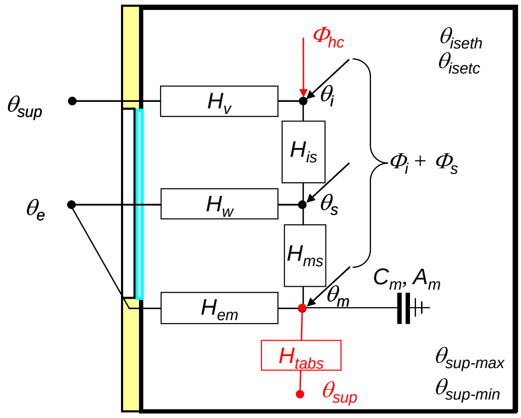

Figure 1: Schematic of the room model from EN ISO 13790 with modification

The same model is used for both the load calculation, addressing the sizing and dimensioning of HVAC equipment, and the energy needs in order to calculate the overall energy performance. For the two applications, different data for both building use and climatic conditions are used.

System Calculations

In the system calculation part, the general methodology given in EN 15243 [8] is applied: for all subsystems, the supplied thermal and auxiliary energies are calculated and the recoverable and non recoverable energy losses are determined.

The standard system calculation method covers the sub systems emission, distribution and generation. Models are given for the most common system and component types. Where available, the models are taken from the relevant CEN standards: EN 15241 [9] for the ventilation calculation, some parts of EN 15243 for the water based distribution systems, EN 15316-4.1 [10] and 4.2 [11] for the generation with boilers and heat pumps. Where necessary, the models are adopted for an hourly time step calculation.

For some system aspects, there were not sufficiently good models available, and new developments were necessary to meet the requirements of both a simple input structure and an enough good representation of the part load behaviour in an hourly time step environment. This is e.g. the case for the chiller calculation: a new model was developed, which needs only slightly more than the EER values for the four rating points according to international test standards as input parameters, but yet describes a full performance map. The model is described in detail in [12].

Calculation Tool

The tool is based on the former SIA tool on electric energy requirements (SIA380/4) and has been largely extended in the system calculation area. But also in the room/building calculation, additions and improvements were made:

- Building elements against ground and unheated spaces
- Thermal bridges
- external shading
- Window ventilation

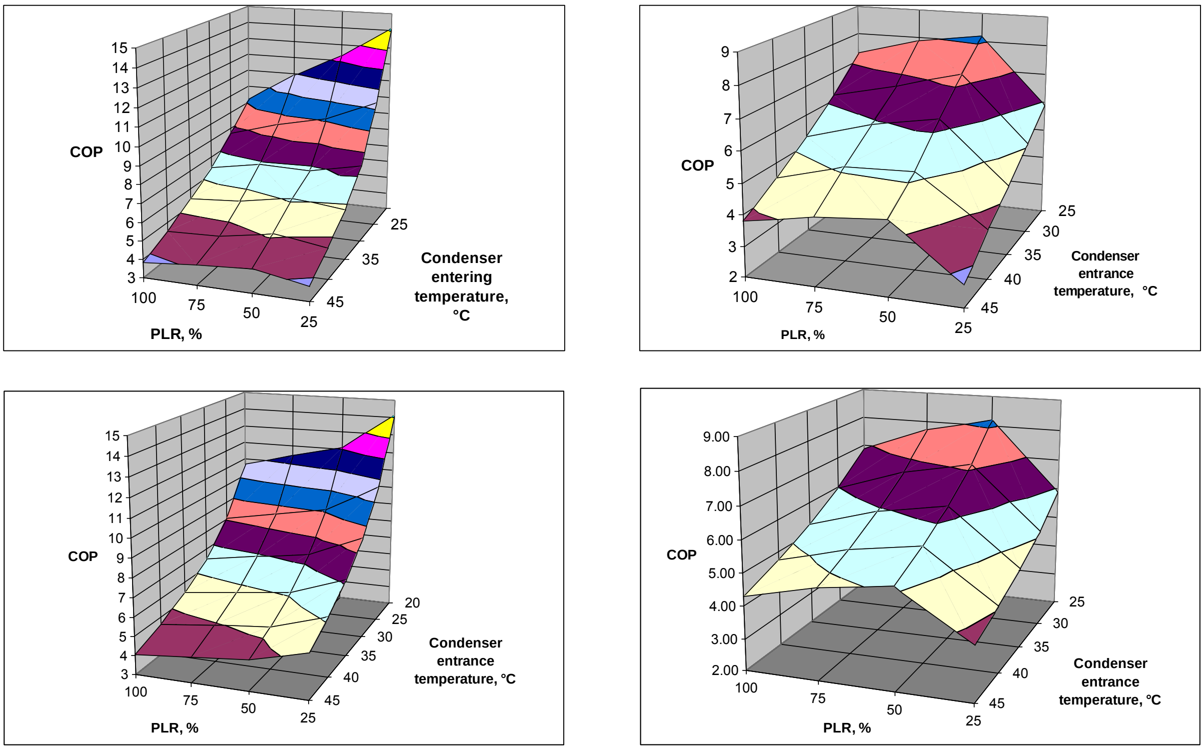

Figure 2: Performance maps of two chiller types: original data (upper row), model generated (lower row) for chiller type 1 (left) and type 2 (right)

For the system calculation, the goal is that all energy relevant processes are covered and can be influenced. This involves a definition on component level and puts the difficulty of a good balance between level of detail and user friendliness.

The system calculation starts from the room and considers emission losses (in form of temperature deviations due to control) and auxiliary energy consumption (by room based equipment such as fan coil units). It allows grouping of rooms and assigning them to an unlimited number of ventilation and water based distribution systems.

The distribution system calculation considers heat losses from ducts and pipes and the auxiliary energy for pumps, depending on the control type (single or multi stage, continuous control). The distribution systems are again assigned to generation groups

The generation groups may consist of up to 3 generators, which can be run in parallel or alternatively. The generators include:

- Air, water or ground source heat pumps
- Boilers (gas, oil, solid fuel)
- Chillers (with /without free cooling)
- Heat rejection systems (dry, wet, hybrid)

For some system types such as direct cooling with borehole fields or solar energy systems, interfaces to existing tools are foreseen.

The generation calculation again covers heat losses (e.g. from boilers), auxiliary energy consumption (for pumps, fans, burner compressors etc.). A generation group can have pumped circuits itself (such as internal distribution circuits, borehole circuits, heat rejection circuits etc.). The possibilities are shown in figure 3.

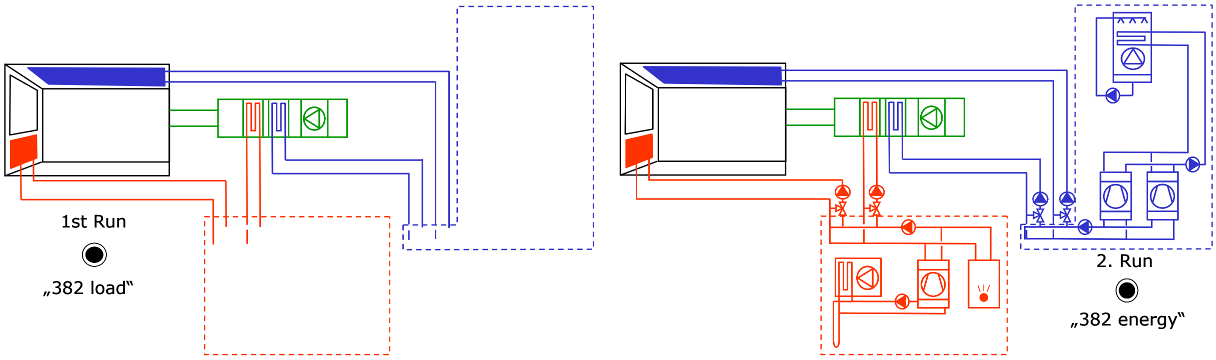

Figure 3: System schematics at the load calculation level (left) and the system calculation level (right)

Since the tool shall allow for the load calculation and system sizing as well as for the calculation of the annual system efficiency and energy consumption, using the same input data, a methodology for the calculation procedure had to be defined. It is a two stage process as shown in figure 3 above and figure 4.

For the load calculation, climatic data for a heating and 3 cooling design periods are used. The internal loads are switched off for the heating design period, and their monthly simultaneity factors are switched off for the cooling design. The system side has to be defined to the level of grouping in order to get the loads by group to enable sizing of the components.

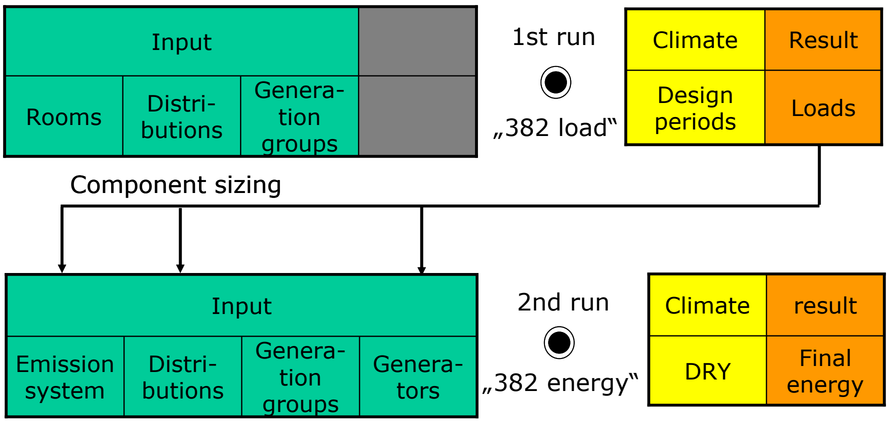

Figure 4: Two stage calculation procedure for load and energy calculations

With the load results, the systems can be defined more in detail, e.g. by “filling up” the generation groups by a set of sized generators, giving the possibility of consideration of part load behaviour and control schemes.

An important issue is that the calculations can be performed adequate to the design stage. Many of the features described above are not known at an early design stage, but the program shall enable calculations as early as possible, in order to support important energy relevant decisions. Therefore, the input shall be able to “grow” with design stages. Good and reliable default values play an important role for this.

Result Presentation

The tool gives a big number of result tables and charts. The core is the standardised table of the delivered energy by carrier, weighted with the primary energy, greenhouse gas and national weighting factors. The limit and target values are calculated individually for each project by calculating a comparison project with standardised input values.

RESULTS

The draft standards currently (June 2009) being revised after the public enquiry process, and the tool is available as an beta version. The finalisation is foreseen for end of September 2009, the standards probably coming into force by January 1, 2010.

It is planned that this set will replace the current approach of a monthly heating energy calculation and some additional requirements on system components for the envisaged building types. It will take time and need some application experience for a later integration in the Cantonal building regulations. To prepare this, it is envisaged to use the tool for not only heated buildings in the frame of the voluntary MINERGIE® label.

CONCLUSION

The project can be considered an important step towards an overall building energy performance optimisation.

ACKNOWLEDGEMENTS

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DEVELOPMENT OF A DURABILITY DATABASE FOR SUSTAINABLE BUILDING COMPONENTS

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ABSTRACT

The knowledge about durability is very precious in order to operate suitable choices for a sustainable building process. The study of building components' durability, based on the evaluation of their spontaneous durations (time in which the required performances remain spontaneously at the programmed levels) and on the acquisition of the knowledge about performance over time, gives the possibility to evaluate a technical solution, not only considering its initial performances and costs, but also according to its LCA and LCC.

That has consequences both on the design, because it permits a choice based on the sustainability of building components' employment, according to the differentiated obsolescence of building's parts, but also on the management, allowing an optimized maintenance planning, useful for the life-cycle management and the life cycle costs evaluation.

In order to make such durability-based decision, it is necessary to implement existing methods and tools for Service Life prediction. Among these, the Factor method presented in ISO 15686-2 is doubtless the most usable, because its application is operatively easy and, economically, the most favourable. Starting from the knowledge of Reference Service Life (evaluated in defined conditions), it is possible to correct this value through the use of seven factors and to calculate the Estimated Service Life (ESL). That's the reason why, it is fundamental to provide a data collection of reference Service Lives which can help and drive the designer in obtaining the value of Estimated Service Life in each context of application.

In collaboration with the C.S.T.B., Durability of Building Components Group of Politecnico di Milano is collecting data coming from researches at Politecnico's itself and from the Italian durability research network. The aim is to provide an open database which can be constantly implemented through the auxilium of researchers, owners, designers, manufactures, insurance companies, property asset managers from all over Europe, leaking and driving the insertion thanks to controlling grids purposely prepared.

Service Life management systems are, therefore, analyzed from the point of view of the information due to allow designers to manage Service Life prediction and maintenance planning. Databases will supply the input data to predict Service Life of each single building component and will be available on internet in order to be a valid tool for designers. The paper reports on methods and tools developed to supply data and information in an easy-to-use form, on durability of building components about both the manufacturing processes quality and the products' Service Life.

INTRODUCTION

A sustainable building process needs to address service life of building and of its components since the first stage of design. Service life data are needed, in particular, to perform a reliable Life Cycle Assessment, to compare different design solutions using the LCC analysis and to forecast maintenance costs. It is therefore necessary to identify the most suitable tools to manage life cycle and the required data (types and sources) for a Life Cycle Management process.

A LCM process can be divided into sub-processes (inventory registration, condition survey, service life performance analysis, maintenance analysis, maintenance optimization, maintenance planning). Some of these sub-processes are more data demanding than others, but they all need different data, according to the design stage. If the LCM is undertaken in an early phase of the design process, then some rough data and easy to use service life prediction method will be useful, otherwise, if the design process is in an advanced phase, statistically accurate data and more precise service life prediction tools should be adopted.

Some data sources are quite rounded up or derive from sources that are not interested in technical service life as, for example, insurance data, so it is important to know when they can be used or which is the acceptable error in each different design phase. On the other side when planning maintenance the knowledge of building components' performances decay over time is needed and such complex data are not easy to be found.

The knowledge of the failure rate course at the beginning and at the end of service life permits, in particular, to plan predictive threshold interventions at the mean value of service life. Therefore, the information about building component's duration turns out to be an essential input data for the maintenance design. Considering this, the experimental and methodological research activity on durability involves important effects in facility management, that is why the proposed database for Service Life planning contains explicitly the information about maintenance frequency and it is structured in order to make collected data immediately usable during LCM.

THE IMPORTANCE OF BUILDING MATERIALS AND COMPONENTS DATA COLLECTION

The necessary information to correctly choose building materials and components comes essentially from two sources:

- data provided by manufacturers, which are usually more commercial than technical;
- experience gained from the observation of building products' behaviour over time which allows stakeholders such as designers, installers and maintainers accumulating a precious know-how they are not always available to share;
- laboratory experimentation.

Although information papers (technical and nontechnical ones) can provide enough data for a correct evaluation and choice of construction products, such data are often scattered inside not standardized documents, which can require long and difficult interpretations. As a consequence, the comparison among analogous materials made by different manufactures can be very complex and many times impossible: the less scrupulous operator may be used to choose the same materials and components, without a careful evaluation about their employment. The predisposition of standardized technical information should favour a better knowledge of building products and, as a consequence, a higher quality level of building designs.

Moreover, it is also important to take into account different required performance levels according to the intended use: for instance, private and public buildings can require different performance levels which can vary significantly. That is why, for example, the hotel field differs from the common residential field for many performance requirements or why flooring materials, even if they have to satisfy "usual" needs (users' safety, comfort, usability, etc.) generally express different performance levels [1].

Among such information, service life and reliability data should be provided because the experience shows the existence of an unavoidable phenomenon of performance decay over time, which has to be taken into account. When such performances do not reach anymore the required acceptable level for the technological system, it is necessary to activate suitable maintenance interventions in order to restore their intensity. Thanks to the durability assessment it is possible the acknowledgment of a technical element's attitude to supply, over an established time and with a programmed intensity, the initial technological performances. This, also, for the following reasons:

- **for legislative impositions:** standards such as the Italian law n. 109/94 and the following decree (which has the force of law) n. 163/06 have obliged to draw up "performance specifications documents" and maintenance plans for every public works' design; as the maintenance plan provides the scheduled maintenance activities in order to maintain over time the wanted functionalities, characteristics of quality, efficiency and economic value, the necessity to know Service Life turns out to be evident;
- **for economic reasons:** the value of built works has assumed more and more importance in the conscience of users/owners (both public and private); the life-cycle management process turns out to be of fundamental importance in the economic evaluation of every single partnership, especially now that, in Italy, it becomes more and more diffused the use of alternative tools for finding the necessary funding for public works, such as the project financing or the Public-Private Partnership;
- **for environmental reasons:** the shortage of materials and the progressive impoverishment of fossil energetic resources have pushed the building field to face such a thematic; nevertheless also the problem of buildings' environmental impact has assumed big importance in the last few years, bringing towards a collective sensitization for esteeming environmental impacts of realized works (see ISO 14040 "Environmental management - Life cycle assessment - Requirements and guidelines" and ISO 14044 "Environmental management - Life cycle assessment - Requirements and guidelines").

THE PROPOSED TOOL FOR BUILDING MATERIALS AND COMPONENTS DATA COLLECTION

Through the analysis of Service Life management systems from the point of view of the necessary information to allow designers evaluating duration and planning maintenance, CSTB and Politecnico di Milano are structuring an international RSL database [2]; such a database will contain the input data necessary for service life management. This RSL database has been developed to collect a series of grids in which set of RSL are stored and indexed [3].

The set of RSL consists of:

- the duration in years, choosing among different type of RSL distributions, as shown in fig. 1;
- the failure mode;
- the selection of the several levels of factors in the grid;
- the complementary information such as year, place, sources, data quality, observations.

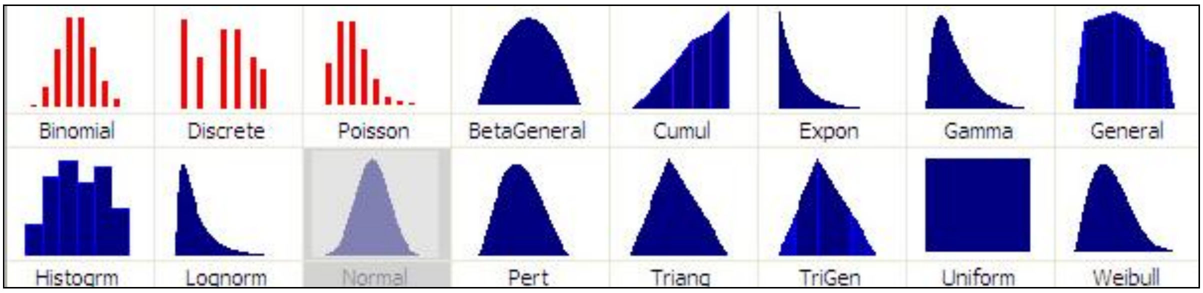

Fig. 1 - Different type of possible RSL distributions in the "SLP platform" database.

During the documented Service Life capitalization for each grid, users can integrate RSL data according to the collected information. This information can have different origins:

- experience;
- ageing tests in natural environment;
- accelerated ageing tests;
- numerical simulation;
- bibliographical studies.

Another important peculiarity of this database is the possibility to be implemented by anyone, after the validation by the database administrator.

After the login, it is, in fact, possible to choose:

- to create or to modify a grid;
- to add new data;
- to consult already existing data.

The insertion of new data or the modification of already uploaded data is driven by a wizard in order to make such a tool as user-friendly as possible (fig. 2).

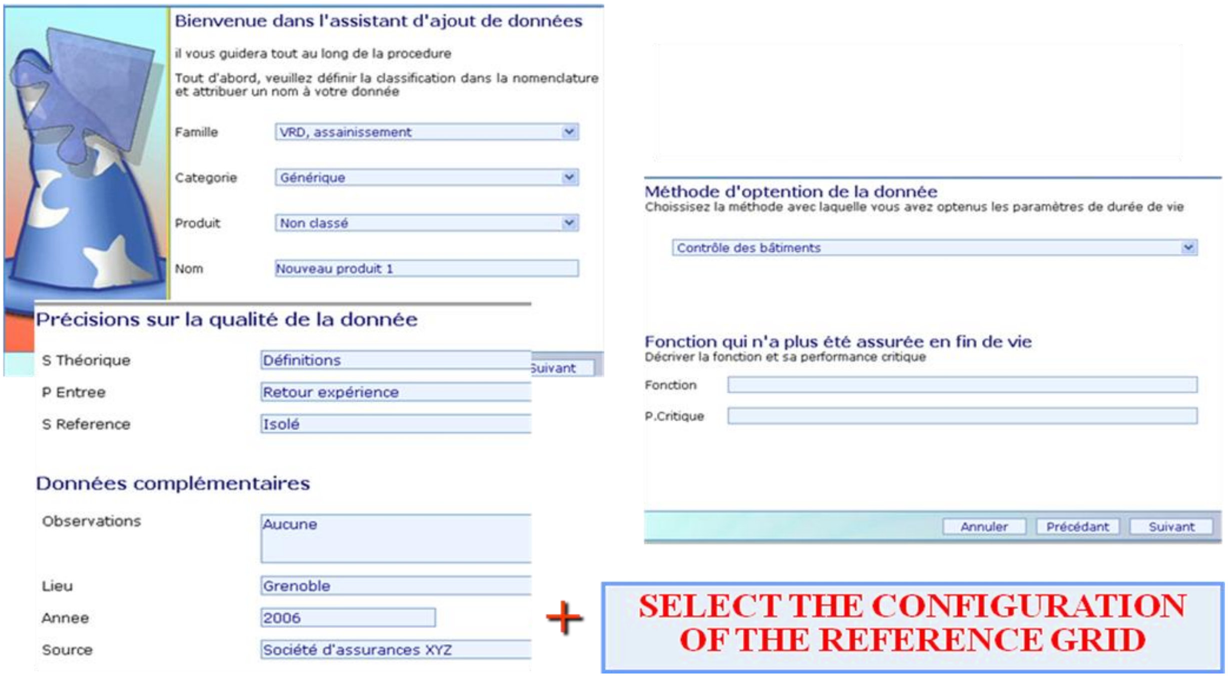

Fig. 2 - Wizard procedure to add Service Life data.

The SLP platform will not only contain a collection of data, but it will be also a service life prediction tool: the Durability of Building Components Group has been developing it in order to implement it with an evolution of the Factor method, which makes Factor method as more objective and scientifically validated as possible. This is possible on one hand through the use of evaluating grids [4] and on the other hand by the adoption of the Monte Carlo method (see Moser [5] or Re Cecconi [6]).

The collection of building materials and components' information appears as a very useful tool to improve the quality level in the construction field: if it is structured in order to provide all the necessary information in a clear and effective way, it can allow a fast and correct choice and use of the building material or component to employ.

The definition of such a database is based on the following considerations:

1) it has to provide a complete, but brief, information (an excessive quantity of data can jeopardize the compilation, the updating and an effective use of data themselves); it is difficult to foresee the suitable quantity of data to give, but among these it is necessary to make a selection according to the main users' needs and to the intended use (the evidences-based design approach), with a possible deepening to study materials' characteristics;
2) it has to allow a precise and fast searching (from this point of view, the needs/requirements classification is useful because it gives the possibility to select a specific set of data);
3) manufacturers have to provide technical information in a uniform/standardized way (linking it to predefined fundamental needs or requirements) and share it through the database;
4) the database has not to be used to choose building materials and components without a critical evaluation by designers, thanks to a reasoned and accurate comparison among their performances and characteristics according to the intended use;
5) also external users can add information inside the database (in particular, data coming from the actual use of building products, evaluating them after the installation).

The identification of the necessary data for building design and maintenance planning is important for a precise definition of the database. In particular, in order to create easy-to-use tools, different levels of information about performances and Service Life will be individualized, according to the stage of the building process: from few needed data in the preliminary design to numerous input and output data for the executive design.

CONCLUDING REMARKS

It has been shown that the type and accuracy of data which are needed when planning the service life of a building component depends on the stage of the design process when the planning is done and on the method used to estimate the service life of the component. Of course different methods will also give different reliability of the obtained results.

The creation of a database as the one above described can have two important positive aspects:

- on one side it can guarantee an easy and widespread availability of the necessary information about building materials (including innovative ones), allowing a better evaluation and choice of building materials themselves;
- on the other side it can push/force manufacturers to standardize the way to present building products, providing comparable data: in a virtuous framework of product's qualification, this prospective should bring to improve the entire construction market: this is then more important if we consider that building products are now to comply with harmonized standards, in the framework of CDP and in future they will have to comply to 7^{th} Essential Requirement on Sustainability and then also to Durability.

These consideration have guided Politecnico di Milano to propose a tool for building materials and components data collection and service life prediction that can be used in different stage of the design process because it provides different type of data with different accuracy and is able to measure this accuracy in order to give, when necessary, reliability information.

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Building Simulation for Architectural Design: a Programming Exploration

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Abstract

This paper presents a discussion of the use of building simulations in the context of architectural design. It advocates for the potential of recent use of computer science techniques in architecture, such as parametric scripting design and physically realistic building simulations, to re-evaluate the notion of low energy buildings.

Purpose

The introduction of parametric models for design has had a large influence on computer-aided modeling [1]. This paradigmatic shift has enabled new possibilities to describe variations in geometric constructions. bringing new flexibility in form generation and opening the way for mass-customizing or form optimization through automatic exploration of solution space. However, since parametric modeling has enabled to describe and explore families of designs, the designer has now to select among numerous cases specific designs that have potential for further development and, ultimately, construction.

In parallel, numerical simulation of architectural designs, such as structural analysis, building thermal behaviour or lighting analysis have been proposed to evaluate architectural qualities of a building project. However, to be able to provide accurate or meaningful results, such tools are typically in need of levels of detail that are usually not available at early design time [2]. As a result, simulations are often used in later project phases where the complete rethinking of the design is not an option any more.

This paper proposes an approach based on the use of building simulation at the core of early conception phases where the model is a response to a simulated environment. It describes a shift in the designer's role to better integrate building simulation techniques into a computer-aided design system. These tools have the ability to predict realistic building behaviours that in the end empower the designer to make informed choices among the variety provided by parametric design in order to meet the architectural program requirements while providing an economy of means. A similar example of the use of an interplay between physically realistic simulation and a parametric engine for early design stage focusing on structural behaviour can be found in [7]. This example however does not insist on the advantages of the use of scripting by the designer himself.

Scripting for Design and Simulation

Starting from precursors AutoLISP and MEL, new architectural modeling tools (Rhino, Catia, GC, etc) include the ability to automatize modeling operations by writing series of instructions in a *script*. Originally intended to automate repetitive tasks, designers have reinterpreted the tool to explore the potential of programming for form definition, hence starting the field of *algorithmic architecture* [3]. While modeling tools with graphical interfaces are still the primary tools used in practice, the importance of programming is increasing, redefining the role of the designer into a “digital tool maker”[4].

Several arguments support the utilization of architectural design scripting tools to assess the performance of early design variants:

Detailing The ability of design scripting techniques to quickly and repeatedly generate complex geometrical objects enables to feed building simulations with the appropriate level of detail while allowing rapid change and exploration of variants as needed for the design phase.

Interoperability The use of programming for form generation provides a higher-level of coordination able to arbitrate results from simulation engines bearing different description scales and natures of performance metric.

Optimization The availability of optimization toolboxes implementing techniques such as GA or topological optimization can be leveraged to help the designer to locally optimize the considered model.

Common framework New means of interaction between designers and simulations can be developed by integrating geometric modeling, performance assessment and possibly also building automation control in a common programming formalization framework.

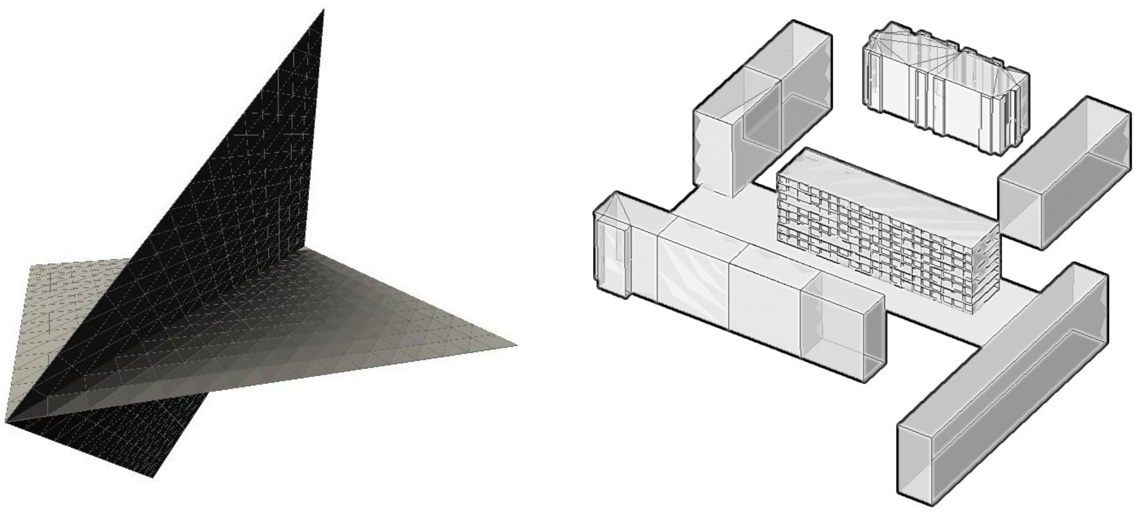

Figure 1: (left) irradiance simulation example and (right) context for the study of solar irradiance (darius golchan atelier d'architecture et d'urbanisme, Geneva, CH).

PHOTOTROPIC ARCHITECTURE

In an exploration of the use of scripting linked with building physics simulation software, the present study focuses on simulation of solar radiation. To this end, a general purpose CAD scripting interface constructed as a library for the Processing.org [9] environment, the ANAR+ library [8] is combined with the Radiance software, an open source physically realistic radiosity software commonly used in lighting analysis [5]. Using cumulative sky models including the sun path and reflections by the sky vault, this backward ray-tracing method is able to extract the effects of model geometry and orientation on its potential for solar energy harvesting, such as mutual shadowing or inter-reflections [6] (Fig 1, left). Provided an annual cumulative sky, this technique provides a rapid assessment of the annual solar energy harvesting potential of a given design, while the parametric description of the geometry embeds the degrees of freedom as defined by the designer and enables modifications according to simulation results. This instantiates a feedback loop between the geometric definition and the physically realistic simulation. The designer could choose to interpret himself the results and modify the geometry or could, given the programming interface, easily define automatic transformation algorithms, such as optimization techniques.

In order to illustrate the topic, the paper presents an example in which the technique has been applied for an experimental practice context: the scripting and simulation framework is invoked to support the definition of a competition entry for a conventional housing building in Geneva, Switzerland. The local context is modeled using established techniques (Google Sketch-Up export) and imported in the scripting environment (Fig. 1, right). The projected building itself is defined parametrically only using scripting.

The design choice made here consists on the translation of local simulation results into differing glazing orientations. The degrees of freedom of the parametric model are (1) the depth of the glazing within the structure, arbitrating between balcony and interior, and (2) the rotation angle for the individual window (Fig. 2). Here, the emphasis is put on keeping into account construction constraints by limiting the number of possible variations in angle.

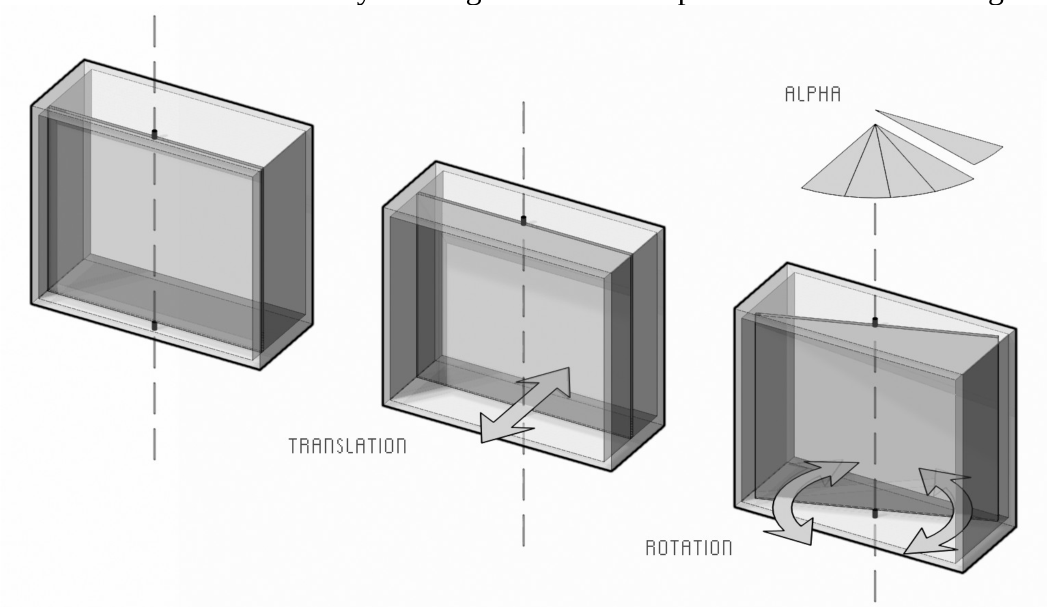

Figure 2: Degrees of freedom for an individual window.

The rationale of this choice is primarily to transform the facade into an expression of the solar context. But it also intends to improve the energetic behaviour of the building, by for instance trying to average out radiations for avoiding overheating; or to orient towards maximum radiation to make efficient use of translucent PV or phase transition glazing. Such aims could make use of optimization techniques. However, in terms of architectural design, the translation of the simulation results should leave to the designer the decision on how to incorporate considerations such as differing typologies, program, construction constraints and building expression.

The parametric scripting interface enables the modulation of these considerations to the will of the designer. By defining how the simulation results are to be interpreted in terms of form redefinition, the designer keeps control of the influence of simulation results upon other architectural considerations. The simulation results provides the opportunity to make an informed choice regarding contextual physical behaviour at very early design time.

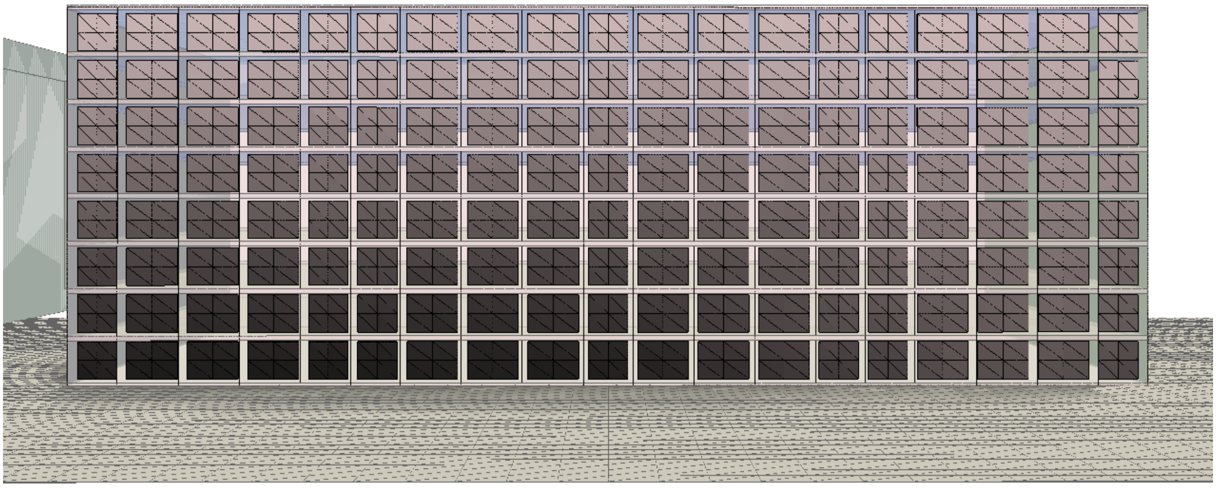

Figure 3: Initial simulation results for straight arrangement of windows.

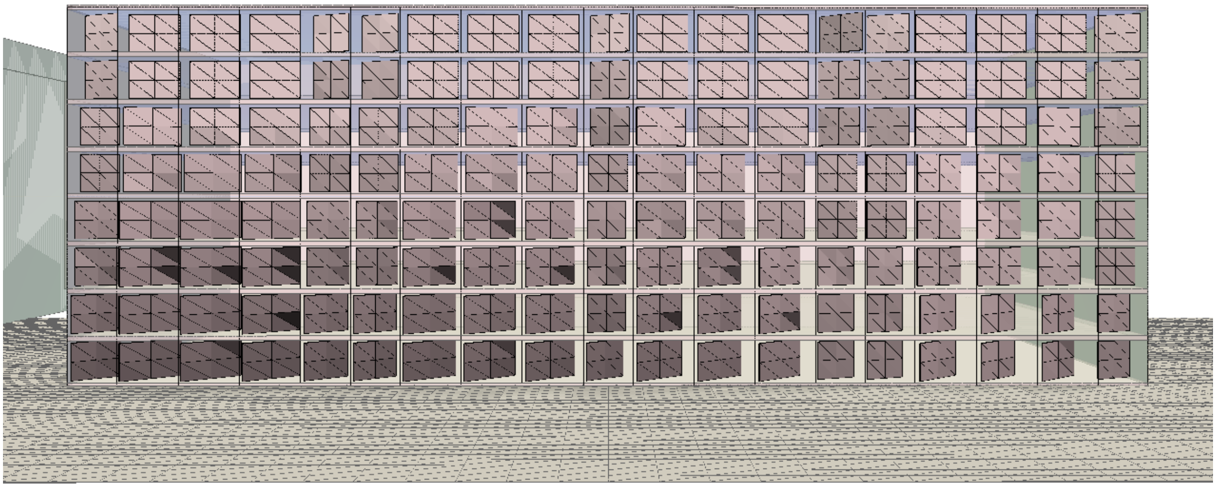

Figure 4: Reconfiguration using a fixed set of rotation values mirroring the solar context.

In Fig. 3 is displayed the initial position of the glazing, with simulation results as shades of gray. These results are used to differentiate the set of windows into 5 subsets, each applied with a given rotation. The process depicted in Fig. 4 results in a form mirroring the solar context. However, in this case the mapping between the energy value and the rotation is arbitrary: the designer chose a set of rotations evenly distributed between $-\pi/8$ and $\pi/8$. Given the parametric nature of the geometrical modeling, the designer can choose to modify the set of rotation dynamically and try, for instance, to manually average the amount of energy radiating on each window by adjusting the values and repeatedly checking the status by launching simulation runs. The result depicted in Fig. 5 is achieved by providing numerical feedback in addition to visual shades of grey.

The power of scripting also resides in the potential of using automatic search techniques. The repetitive use of simulation in a feedback loop altering the parameters of the architectural form transform the parameter search into a continuous refinement, which may be steered using weighted random search as, for instance, a genetic algorithm, or using local rules as in a cellular automata. The results presented in Fig. 6 and 7 were produced using a variation of the latter in which the local parameter values are changed according to neighbouring parameters and energy values, with a neighbourhood consisting of *up*, *down*, *left* and *right*.

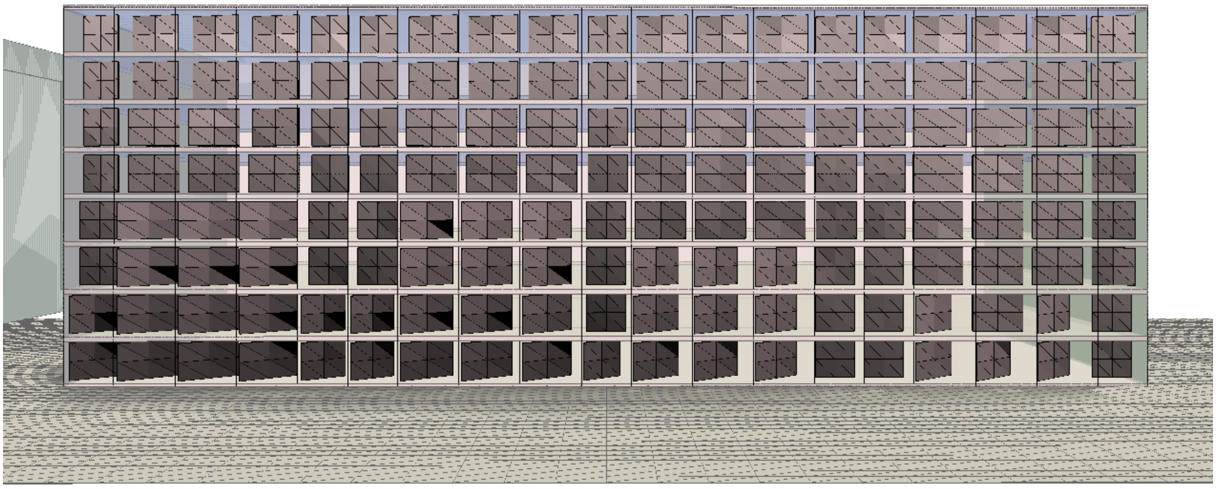

Figure 5: Reconfiguration by rotations manually averaging the energy for the windows.

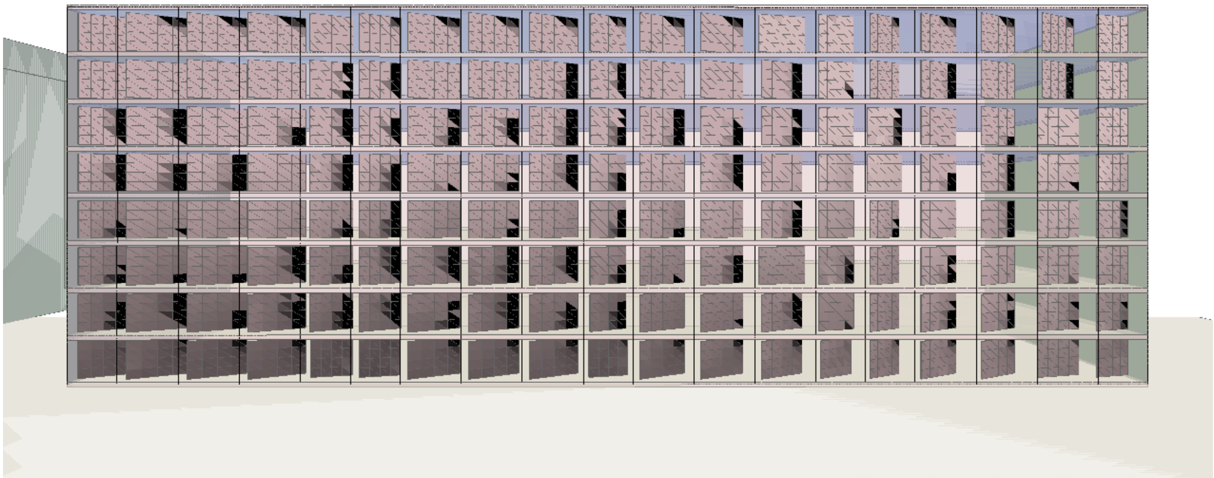

Figure 6: Example of automatic adaptation final distribution seeking maximal energy.

The first example steers the local rotation towards the neighbouring rotation achieving the maximum energy value. After a few iteration the system reaches an quasi steady state, depicted in Figure 6. The second example presents an automatic pendant of Figure 5 by rotating the local rotation towards the rotation of the window element receiving an irradiance value closest to the mean irradiance computed over the neighbourhood. Again after a few iteration, the system reaches a steady state which is potentially different for each run (Figure 7). This final state achieves a less extreme distribution than the initial configuration parallel to the building structure of Figure 3.

These experiments outline the potential of the approach to provide architectural designers with explorative tools that raise their understanding of the physics involved in sustainable construction. The interplay of the scripting parametric framework with the physically realistic simulation engine encompasses different strategies ranging from trial and error to automatic parameter search. If the presented results are limited to a crude assessment of solar radiation, not requiring comparable level of details as other simulation contexts (e.g. thermal or airflow), the approach will be extended to encompass additional dimensions of the sustainable building as well as structural considerations. The context of the competition entry also provided strict constraints on the overall design, while further work will be more explorative.

Figure 7: Example of automatic adaptation final distribution seeking averaging energy.

Acknowledgements

This work was possible thanks to the help of Jérôme Kaempf from LESO-PB, EPFL, who provided the support for radiance simulations. The case study was proposed by the darius golchan atelier, Geneva (D. Golchan, T. Giorgis & M.B.Wang), for an invited competition entry. The research is supported by the Swiss NSF grant K-12K1-118078. The authors would also like to thank the P*rocessing.org* community for the collective effort.

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SOFTWARE

METEONORM Version 6.1		***Available languages*** ☒ **Français** ☒ **English** ☒ **Deutsch** ☒ **Spanish** ☒ **Italiano** ☐ **……….**
Editor **Meteotest** **Fabrikstrasse 14** **3012 Bern, Switzerland**	***Distributor*** **Meteotest** **www.meteonorm.com**	***Price*** **CHF 650.—** **Updates: CHF 150 – 350.—**

Description

METEONORM has been proofed as a worthwhile tool for many people dealing with solar energy since 24 years. In December 2008 the version 6.1 of the software has been published. The most important features are described here:

Climatological Database:

The database has been extended to over 8'000 stations. A complete set of 8 basic parameters (global radiation, temperature, dewpoint temperature, rain, days with rain, sunshine duration, wind speed and direction) is available. It contains mainly global radiation data of Global Energy Balance Archive and other parameters of Climatological Normals of 1961-90 of WMO. Two new databases allow to switch between two recent periods of 1961-90 and 1996-2005 and to see the observed changes of climate during the last decades. With help of interpolation tools the ground data is usable for the whole globe

Generation of extreme conditions (temperature, humidity) for building simulation

Meteonorm data generation has been made originally for simulation of solar energy production. Therefore the values have been trimmed for mean conditions. Nowadays many people use Meteonorm also for building simulation (climate systems, heating). For the design of these systems also extreme conditions are needed. That's why version 6 has been extended with a generation mode, which delivers 10-year hourly minima and maxima of temperature and humidity.

Generation for changed climate

METEONORM includes a mode which allows calculating typical years for the end of this century. As input the output of Hadley CM3 model (seasonal values of temperature, precipitation) is used.

Software:

The latest update included a new map interface to choose the sites and the inclusion of sia Merkblatt 2028 data for Switzerland and 25 test reference years of the USA.

Technical Data

Operating System		***Processor*** **Pentium II**
☐ **Windows 95/98** ☐ **Windows NT4** ☒ **Windows 2000/XP** ☒ **Windows Vista**	☐ **Mac OS/X** ☐ **Mac + SoftWindows** ☐ **LINUX**	***Required memory*** **512 MB**
☐ **Others ………………………………………………………**		***Required disk space*** ***1 GB***

COMPARISON OF TEST REFERENCE YEARS TO STOCHASTICALLY GENERATED TIME SERIES

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INTRODUCTION

Test reference years (TRY) as well a stochastically generated time series can be used for simulation of buildings. In this report both type of data are compared.

DATA

TRY are available at certain sites only, as they are based on long term measurements. In Switzerland 40 sites are available from sia (“Merkblatt 2028”, www.energycodes.ch), in Germany 10 sites (www.dwd.de) and in the USA 1020 sites (http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/). Swiss and German data are based on the European norm CEN 15927-4. For Swiss stations there exists also heating and cooling design temperatures directly calculated from long term measurements. These values are used as reference in this paper.

Stochastically generated time series are calculated with Meteonorm version 6.1 (www.meteonorm.com). In output format “PHPP” the option with 5 different runs was chosen and the statistical correction was used.

METHOD

Two different aspects have been examined:

- Calculation of the design temperatures (heating and cooling) according PHPP format. For this comparison the mean bias error (mbe) and the root mean squared error (rmse) were used.
- Qualitative examination of the local variation of the mountain shadows.

RESULTS

Design temperatures

The uncertainty of the generated data is in the range of 1-2°C. The generation of 5 different runs and the correction enhances the quality especially for heating loads for cloudy situations, which are underestimated without correction. If the design temperatures are calculated based on TRY datasets the uncertainty is the same or even larger as for design temperatures based on stochastically generated time series.

The errors of 1-2°C have to be set in relation to the representativeness of the sites:
The uncertainty of TRY according the yearly means of temperatures is 1.0°C in Switzerland, 2.2°C in Germany and 1.1°C in the USA (cross correlation analysis). For Meteonorm data this value comes to 0.8°C in Switzerland and 1.1°C in Germany and 1.0°C in the USA (due to a larger number of sites and enhanced interpolation methods).

Local variations of mountain shadows

Houses with glass facades or passive houses react strongly on solar radiation. In alpine areas the shadow situation can vary locally to a great extent. This means, that the use of fix station data like TRY has big disadvantages in mountainous regions.

Looking at the global radiation on a south façade in January and December there is a portion of 19% of Swiss surface which has more than 25% reduction of radiation due to shadowing.

CONCLUSIONS

With stochastically generated data design temperatures can be calculated with an uncertainty of 1-2°C, what corresponds to the uncertainty of the official design temperatures. In regions with a high density of TRY the uncertainty of TRY are better than for generated data. The uncertainty for design temperatures calculated directly from TRY datasets is equal and partly even higher as for values based on stochastically generated time series.

In approx. 20% of the area of Switzerland the effect of mountain shadowing is that big and the horizons vary locally so much, that TRY datasets are valid only in a very small area. For these areas stochastically generated data (and correction to local horizon) deliver more realistic results.

Simulation Tool for Architects
Optimization of Active and Passive Solar Use

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Abstract

The presented work offers an improved planning tool as a response to the demand for active and passive solar architecture. An integral solution is presented for the design of solar assisted heating systems and decentralized electricity production using photovoltaics (PV) on building roof-tops and facades. The tools are applicable in the early stage of architectural planning and the underlying simulation is consistently usable throughout all further steps. In particular, this solution offers a number of sensible approximations at the beginning of the planning process and allows refining the input data at a later stage.

The two software programs Lesosai and Polysun form the basis for the project. In a first step, a software interface is created which provides access to the simulation kernel of Polysun through the graphical user interface of Lesosai. Consequently, the architects do not have to install and learn to handle additional software next to Lesosai. Furthermore, no data has to be entered twice and the consistency of all simulation results is guaranteed by the software package. In a second project step, Lesosai's front-end is optimized with respect to the architects' needs.

1. Introduction

It is a general goal to reduce the impact of the buildings to the environment. In particular, the energy efficiency of the buildings should be enhanced, non-renewable energy for heating and cooling should be substituted and potentially a house could be part of decentralized energy production.

On the one hand, the shift towards green energy ideals generates a genuine motivation to educate the building industry and provide appropriate tools for the planning process. On the other hand, the awareness of environmental issues has caused energy topics to become the architects' daily challenge (or routine) and therefore produced a demand for improved planning tools. Solar energy, in particular, has become a central topic because it is affecting the envelope and the general appearance of the building [1].

It is important to make the best use of all forms of solar energy, namely passive solar, active solar-thermal and photovoltaics (PV). Furthermore, other heating and cooling systems including geothermal and heat-pump applications have to be included. Despite their very different technology backgrounds and impacts, these forms of renewable energy sources are all inter-related.

Since the course for solar buildings is set in an early project state it is important that tools for early assessments are provided. This paper describes a new approach to make easy-to-use tools available to builders and architects and to follow a new methodology based on consistent simulation results throughout the entire workflow.

2. METHODOLOGY

With the goal to improve solar use in buildings, a systematic *requirements engineering* [2] approach shall be followed. In a concise user and task analysis, the following questions have to be answered:

- What are the planning processes and the workflows?
- Who are the people involved in the planning process?
- What tools do these people use?
- Who are the users of today's tools?
- Who are potential users of improved tools?
- Who are the decision makers?

Planning process

Analyzing the planning processes, two main categories have to be distinguished: The planning process for new building and the one for building renovation.

In ***new building planning***, involved parties related to the energy topic are the building owner, the architect, an energy planner (may not be present for smaller objects) and the installer. In some regions of Europe (including Switzerland), the energy provider also plays a more and more active role. In summary, it is typically the architect's plans that are followed and ideally, the active or passive use of solar energy is reflected in the main setup of the object.

In ***building renovation***, by contrast, the starting point is often the near end-of-life of the installed heating system which initiates energy related planning. The regulatory framework requires a certain standard of building insulation, which brings an indirect interdependency with the building envelope. In general, passive solar use is more complicated to improve than active solar heating systems, while the use of a heat pump is typically the solution causing hardly any interaction with the building.

The planning of PV systems typically does not follow any of the above mentioned and often there is no architect involved in the planning. The result might be of poor esthetical quality and it would be beneficial if architects are more often involved in PV planning.

Improvements proposed by this project

It is recognized that the decision makers in the early planning stage require one single easy-to-handle tool. As there is more input to be entered for the building envelope, all data will be entered in *Lesosai*. A new module specific to the active solar thermal elements is added and the results specific to the active solar are displayed in new graphics. In the resulting package, the *Polysun Plugin* is completely integrated and the architect does not have to install and learn to handle another tool. In the simplified approach to the design of active solar systems, a number of parameters have to be pre-defined. It is an important task of the project to define these default values and to ensure robust simulation and sensible system results.

3. TOOLS

State-of-the-art in planning

Computer tools to simulate the thermal behavior of buildings today include passive solar gains but have crude or none implementation of active solar thermal (such as SIA380/1 tools, or the hourly tools for SIA380/4 or EN ISO 13790). On the other hand solar thermal system simulation tools are very specialized and accurate, but not well linked to building models. Both tools are mostly used by engineers and thermal energy experts either to check the compliance with (SIA) Norms or to dimension the solar thermal system.

Polysun

The simulation software Polysun offers a broad range of functionality required for the analysis and design of domestic energy systems ranging from solar thermal to heat pump and PV systems. The stand-alone version has a broad world-wide customer base. *Polysun Designer* offers full flexibility in system design by its unique graphical editing capability.

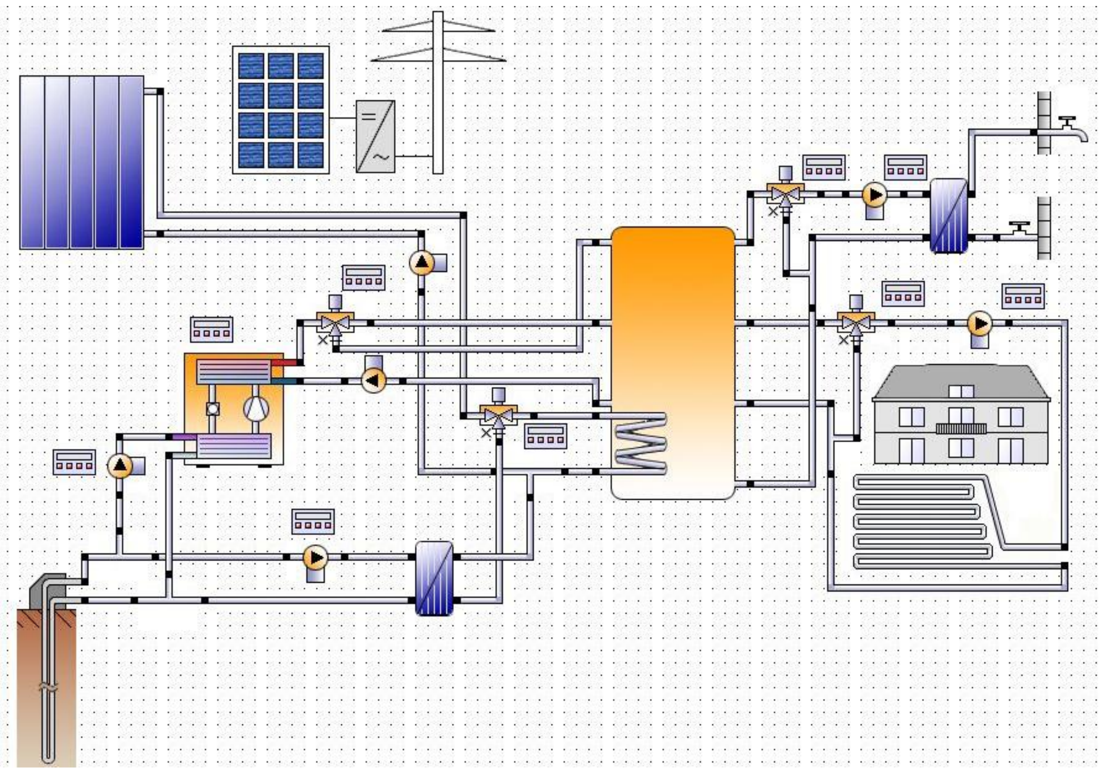

Figure 1: Polysun planning tool including solar thermal, geothermal/heatpump, and photovoltaics in one tool. Furthermore, all details of the heating system, such as radiators/floor heating, controllers and pumps are modeled with their physical behavior.

In the Polysun catalogues, a broad range of components are stored with all characteristic data necessary for the hydronic and thermal analysis of heating systems and the analysis and design of PV applications (including comprehensive PV module and inverter data).

Polysun is shipped with a large number of system templates with established heating and PV concepts and calculates all relevant system parameters related to heating and electricity production. It also comprises the calculations for amortization and the data required for subsidy applications. The target users of the stand-alone version of Polysun are the installers and planners.

Lesosai

The software *Lesosai* is a well-established software tool for the thermal energy calculation and certification of buildings. It can handle one or several heated or cooled zones. Typical results are shown in Figure 2.

Lesosai is designed primarily for building and thermal engineers and architects. It allows the calculation of environmental impacts of energy consumption, taking into account the energy used, but also considering the construction materials of the building.

The graphical user interface is optimized to handle complex buildings in sufficient detail for the building certification. From this data, all required parameter for the dynamic simulation are extracted and passed to the Polysun simulation kernel by an internal software interface. The selection of system templates is based on the Polysun template database.

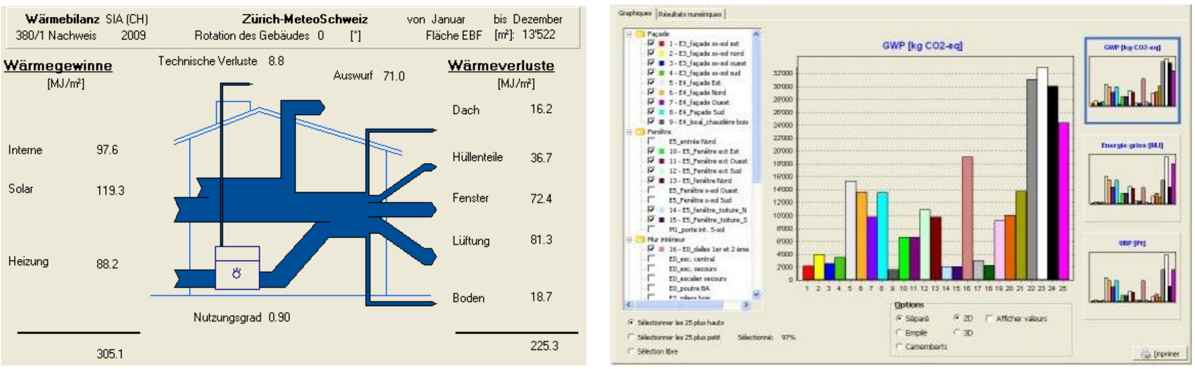

Figure 2: Typical output generated by Lesosai include Sankey diagrams (left) and detailed environmental impact calculations (right).

4. IMPLEMENTATION

Polysun is implemented in the Java programming language. The goal of the *Polysun Plugin* is that selected third party software programs have a direct access to the Polysun simulation kernel and the Polysun databases. The interface has been designed with the premises to offer maximum flexibility and an efficient data exchange. While Polysun is implemented in the Java programming language, it does not matter which language or programming environment the calling software is based on.

Software interface

The general setup of the software interface between *Lesosai* and *Polysun* is summarized in Figure 3. The XML data exchange between the tools is separated from the function call in order to provide a concise interface structure. XML is chosen to provide the flexibility and, in particular, to be able to re-use the interface allowing also other programs to connect to the *Polysun* simulation kernel through the *Polysun* software interface.

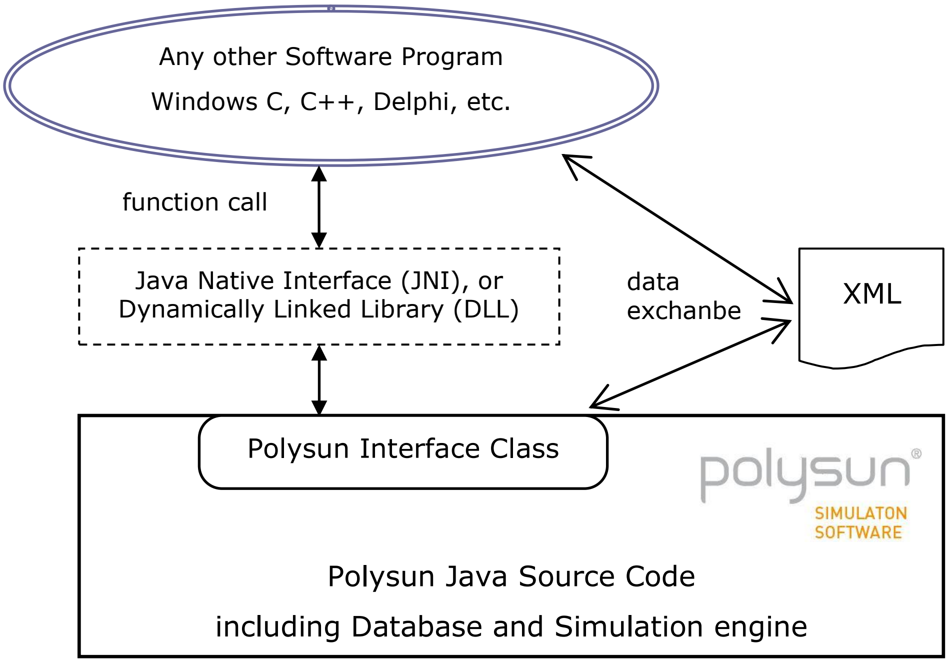

Figure 3: Concept of the software interface to the Polysun kernel.

Weather data

The calculations rely on statistical weather data in several ways, both in the building simulation part of Lesosai and in the heating system analysis of *Polysun* (solar collector, air-water heat pump, swimming pool simulation, etc). Lesosai and *Polysun* both rely on the world-wide weather data and the interpolation scheme of Meteotest/Meteonorm [3].

The consistency of the weather data is crucial in the joint simulation scheme between *Polysun* and *Lesosai* and has been specially addressed when designing the software interface.

5. RESULTS

The approach presented in this paper is generally applicable and has already been implemented with several partners. Two examples are discussed in the following, where the Polysun-Plugin is integrated in existing software.

Lesosai Polysun Inside

As a result of the presented work, *Lesosai* provides a one-tool combination of the building energy model and an accurate energy simulation of all passive and active solar gains. *Lesosai Polysun Inside* empowers architects to consider solar systems in an early planning stage, based on automatic performance calculation of the solar system through *Polysun*. The *Polysun* simulation kernel is working invisibly behind the *Lesosai* interface.

plan4[solar] Polysun Inside

In the software *plan4[solar] Polysun Inside*, Vela Solaris offers the *Polysun* simulation kernel trough the Plugin-Interface for *rooftop configuration* together with its partner Gascad [4], see screen shot in Figure 4. In this application, Polysun simulates yearly PV earnings and assists the choice of PV modules and inverters in a first step. Future extensions will include heating and cooling systems applying various renewable energy sources such as solar thermal and geothermal. The main advantages of *plan4[solar] Polysun Inside* are the 3D object visualization and the generation of a parts list.

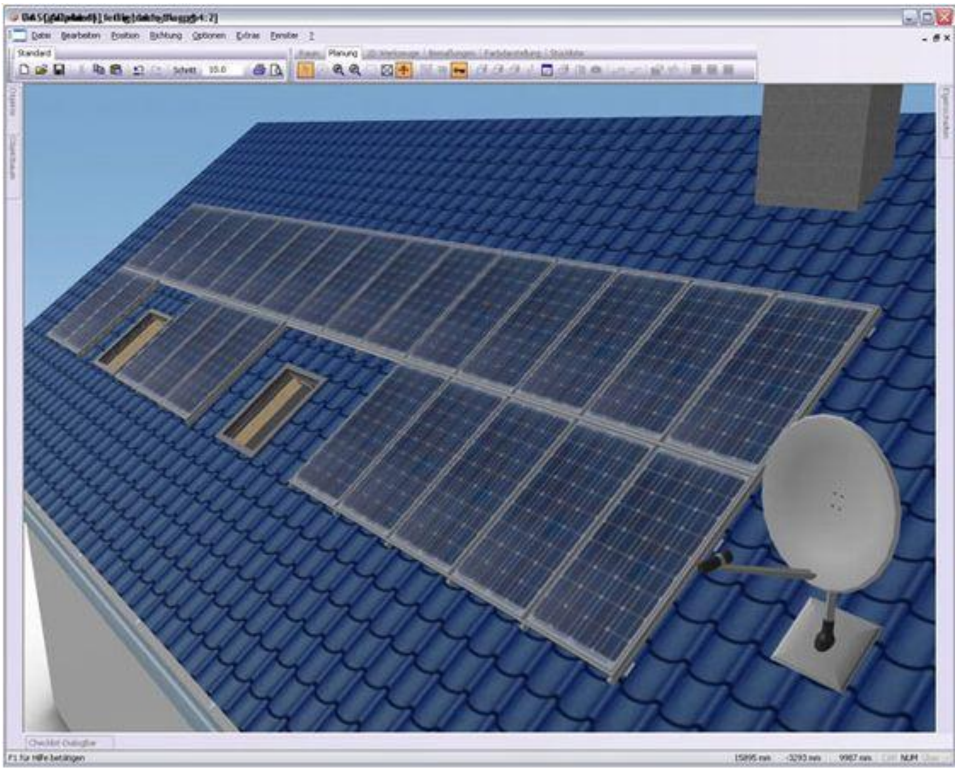

Figure 4: 3D visualization as one of the key results of plan4[solar] Polysun Inside.

6. CONCLUSION AND OUTLOOK

The presented work offers an integral solution for the design of active and passive solar architecture. It is applicable in the early planning stage and is consistently usable throughout the planning process.

Subsequently to providing the active solar calculation engine for all users of the *Lesosai* program, it is intended to simplify the Lesosai user interface and optimize it for its use by architects. The complexity of the data input is reduced by providing smart default values for solar systems and building elements, to broaden the use of this tool in the architects' community. At the same time, it is still possible to use the dynamic simulation kernel of *Polysun* which is more accurate than other simulation schemes and which allows using the simulation projects in a later stage in the workflow with the standalone version of *Polysun*.

ACKNOWLEDGMENT

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SERVICE LIFE PREDICTION OF CONSTRUCTION ELEMENTS - MODELLING AGING BEHAVIOUR OF CONSTRUCTION MATERIALS

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ABSTRACT

Designing new buildings according to sustainable criteria requires tools that enable verification of the durability of the different elements of a construction. In this context, it is necessary to be able to estimate the service life of a building or parts of it. The recent publication of the standard series ISO 15686 - Buildings and constructed assets – Service life planning (Parts 1 to 10) redefines the importance of this issue. Part 2 of this standard defines service life prediction procedures based on the factor method.

The objective of the work presented herein is to simulate the aging behaviour of multi-layer construction elements such as roofs, facades, walls, etc. that are exposed to environmental loads like sunlight, variation of temperature, rain, frost, humidity, mechanical shocks, etc.

The applied method is based on a model in which the behaviour of each layer material is modelled individually. The whole element-model is built by interconnecting these material-models. Even if this kind of simulation works according to simple rules, the challenge is that one must know each used material's behaviour under environmental stress. By iteration over time steps, the model computes the degradation of the performances of each layer. At the same time, it identifies abnormal behaviour and dysfunctions. The end of service life can be considered reached when a performance is lower then a predefined quality-level.

KEYWORDS

Service life prediction, simulation, construction materials, degradation

1. INTRODUCTION

This paper presents the results of research carried out in the Laboratoire de Construction et de Conservation (LCC) of the Ecole polytechnique Fédérale de Lausanne (EPFL) with the objective of developing a method and a tool for service life prediction that can be applied to multi-layer construction elements exposed to various types of agents.

In a building, each part of the construction such as a facade, a roof, a foundation etc. needs to have specific characteristics to ensure stability, durability and interior comfort. Depending on its function, it must perform against various requirements such as air and water tightness, thermal insulation and visual criteria (colour, texture etc.). To guarantee these multiple characteristics, elements, in most cases, consist of several layers of different materials. In this way, each material meets one or more of the demands placed on the element.

From the example of a facade with external insulation and cladding (fig. 1), one can intuitively understand that, as long as the cladding is in good condition, the insulation will be well protected against the rain. However, when the cladding shell weakens with age the insulation will suck up water and deteriorate. In this case, after a "certain" period, the thermal insulation property decreases and the facade element will no longer play its insulating role.

Following this example, the presented method is an attempt to model the different phenomena created in a multi-layer element when it is exposed to environment conditions.

2. METHOD

The method is based on the finding that aging processes are dependent on two vectors. On one hand, there are the characteristics and properties of the different construction materials called *"performances"*, on the other hand, are the factors and agents causing the modification of the material properties called *"constraints"* (fig. 1 and 2).

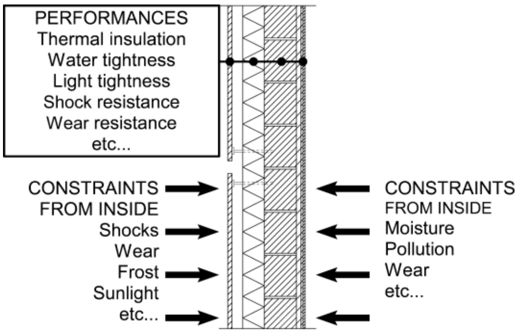

Figure 1: Multi-layer Facade Element - Constraints affecting the element performances

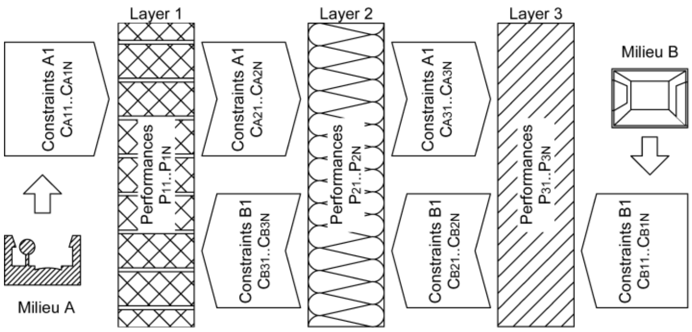

Figure 2: Constraints affect the element from both sides

2.1. CONSTRAINTS

From the agents influencing buildings, as presented in ISO standard 6241:1984, some constraints have been selected for their direct or indirect role in the processes of material degradation. Table 1 shows these constraints with the associated agents.

Agent type	Agents	Constraint	Scale
1. Mechanical	Hail, moving actions	Shocks	0..10
	Moving actions, internal and external shocks	Stabs	0..10
	Abrasion, friction	Mechanical wear	0..10
	Running water	Wash out	0..10
	Wind	Air speed / wind	0..10
2. Electromagnetic	Sun	Solar radiation	0..10
3. Thermal	Warming, thermo-shock	Temperature	°C
	Frost	Frost	0..10
4. Chemical	Precipitation, surface water, ground water, projected water, water infiltration	Wetness	0..10
	Air humidity, condensation	Moisture	Pa
	Acids, bases, concrete medium	pH	pH
	Carbon dioxide	CO_2	0..10
	Dust, soot	Pollutants	0..10

Table 1: Constraints, provoking material modification, selected for the model.

In quantifying the different parameters and integrate them into the computer model, several constraints can be expressed with a conventional scale. For other constraints, an ad hoc scale with a range from 0 to 10 was defined. This is necessary because either no known physical value can describe them or because large differences between intensities are better expressed on a scale with a logarithmic character. The last column in table 1 indicates the selected scales.

Value	Typical stress	Typical location
0	None	
1	Touch	Ceilings
2	Punch	Walls in non occupied rooms
3	Walking	Floors in non occupied rooms, office walls
4	Rare jumps	Walls living room, flat roof non accessible
5	Frequent jumps	Walls of workshop
6	Hail	Floor living room
7	Fall of vessel	Floor bath room
8	Fall of bottles	Floor gymnastic room, balcony
9	Fall of hammers	Public stairs, floor class room
10	Fall of machine pieces	External floor, industrial floor

Table 2: Example of ad hoc constraint scale - shocks and stabs.

2.2 PERFORMANCES

Material properties that are necessary to meet the required element qualities are grouped under the denomination *performances*.

Table 3 shows basic performances that apply to all construction materials and are necessary for the propagation of the constraint values (see chapter 2.3). These basic performances are, if necessary, complemented by other performances specific to a material or a family of materials, for instance "carbonation speed" for concrete based materials or "frost resistance" for stone materials.

Like the constraints, the performances are also expressed either in real physical values or on an ad hoc scale from 0 to 10.

Performance	scale
Thickness / width	mm
Shock-absorption	0..10
Static strength	0..10
Wear Resistance	0..10
Resistance to shocks	0..10
Resistance to stabs	0..10
Resistance to corrosion	0..10
Resistance to wash out	0..10
Water tightness	0..10
Air tightness	0..10
CO_2-Tightness	0..10
Light tightness	0..10
Surface appearance	0..10
Surface flatness	0..10
Thermal conductivity	W / m K
Moisture conductivity	mg / h m Pa
pH-Value (Alkalinity)	pH

Table 3: Basic performances with their scales.

Water tightness performance

Value	Permeability	Typical material
0-1	Very high	Air
2-3	High	Light textiles, materials in bulk
4-5	Medium	Fibre materials, dense textiles
6-7	Low	Hardwood parquet, wooden panelling
8-9	Very low	Masonry
10	Tight	Metals, glass

Table 4: Example of performance scale

2.3 CONSTRAINTS - PERFORMANCES INTERACTION

For the material aging simulation of a multi-layer construction element, the interaction between constraints and performances is caused by two types of relations.

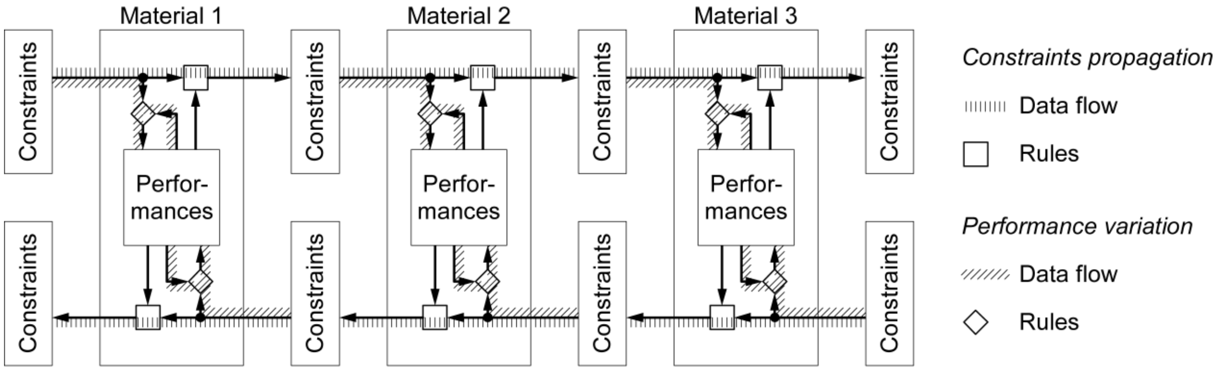

Figure 3: Illustration of Constraints-Performance Interaction.

The first type is the *constraints propagation*: the rules that define how environmental loads are transmitted or reduced by the different layers.

The constraint scales and the performance scales have been chosen to allow computation of the propagation by simple subtraction (1) (see fig. 4)

$$constr_{n+1} = constr_n - perf_n \tag{1}$$

where:
$constr_n$: constraint acting on the material
$constr_{n+1}$: propagated constraint
$perf_n$: corresponding performance of the material (see fig. 4)

The second type of relation is the *performances variation*. This means the rules describing in which way and in which proportion the performances of each material are modified depending on an intensity of a constraint. The variation is computed as follows:

$$perf_{t+1} = perf_t - \Delta perf \tag{2}$$

where $\Delta perf$ is computed from the maximal variation $\Delta perf_{n\_max}$ and the constraints

$$\Delta perf = \sum_n \left(\frac{contr_n}{100}\right)^2 \cdot \Delta perf_{n\_max} \cdot \Delta t \tag{3}$$

where:
$\Delta perf$: performance variation
$\Delta perf_{n\_max}$: performance variation for a maximal constraint
Δt : time step duration in years

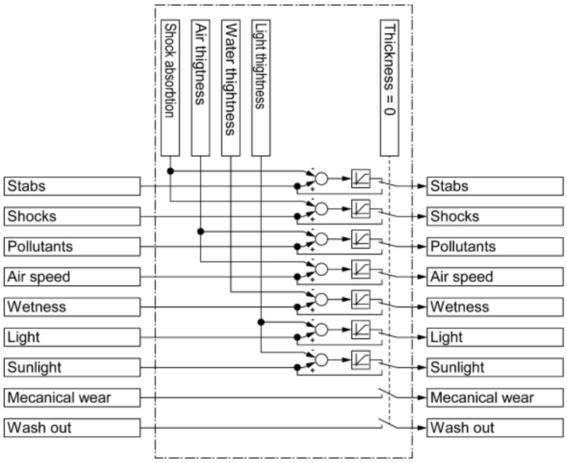

Figure 4: Illustration of constraints propagation

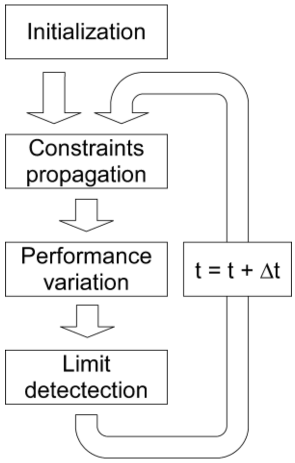

Figure 5: Iteration loop

In an iterative loop alternating constraint propagation, performance variation and increasing simulation time, the evolution of the layer-performances and the global performances is computed (figure 5).

3. FAILURE CRITERIA

To extract service life information from these simulation results, one must define failure criteria. This means the state of degradation one considers to be the end of service life - when the construction element cannot fulfil the role for which it was designed – must be determined. There are a number of different criteria for these limits. They can be functional, such as the loss of thermal insulation or tightness They can also be aesthetic, for example when the visual aspects are too much deteriorated by discolouration, loss of brightness or surface alterations of natural wood, etc.

In the model, these criteria have been introduced as levels. If one of the key performances drops below its failure level, an alarm signal appears with an age indication corresponding with the end of service life.

4. PROBABILISTIC APPROACH

In fact, the different model parameters (constraints, performances and performance variations) can only be determined approximately. This is because currently scientific or experimental confirmed values are not available and must therefore be estimated, and because of the incertitude of the factors influencing a construction element's life.

By introducing these parameters as probability density functions, it has been possible, with a Monte Carlo simulation, to obtain results in the form of probability density functions as well. This allows to take into account the incertitude of the parameters and to give more realistic predictions, with probability indications, about the duration of service life.

5. CONCLUSION AND OUTLOOK

The need for service life prediction has been pointed out by Hovde [3]. It appears that the current knowledge of aging processes is mostly qualitative and rarely quantitative. To be able to make predictions more reliable and precise, important research and experimental investigations need to be carried out in order to determine the dose-response functions of different loads on material characteristics.

The prediction of construction element service life has some similarities with meteorological prediction. They have both a large number of influencing factors, very complex relationships between these factors and the uncertainty of several parameters. But in both cases one can have the same motto: *"It is better to have a prediction with low reliability than to have no prediction at all"*. The presented method attempts to approach the question of material aging in a global way, being conscious that the simplifications are significant and that the reliability is currently not very good. On the other hand, it offers the advantage of being flexible and capable of evolving because the rules for constraints propagation and performance variation can easily be adapted for each material. From this point of view, the potential to increase the reliability of predictions or to include different materials is very good, but this requires a significant research investment.

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"*SMÉO FIL ROUGE POUR LA CONSTRUCTION DURABLE*" A TOOL FOR BUILDING DESIGN ACCORDING TO SUSTAINABLE DEVELOPMENT PRINCIPLES

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ABSTRACT

In building and infrastructure processes, the earliest decisions have the largest effect on the project, offer the widest freedom but are often taken without much information on their effects. Therefore the state of Vaud & the city of Lausanne have put their efforts together to develop a guideline to help project management and authorities to find the optimal way for design & realization from the earliest to the last project stages.

Based on a multi-criteria analysis method, this new computer tool "SméO, Fil rouge pour la construction durable" is developed for the Web under Open Source license. It intends to qualify building and/or quarter projects according to a comprehensive set of sustainable development criteria through the life cycle analysis all along the design and realization processes.

At the genesis of a project, the tool evaluates the needs, the available resources, the site and architecture, the financial resources, the social context and enquiry as well as conformity to local requirements. When materializing the project, the tools helps in looking at its impact on the land and landscape, infrastructures, building design and material choice, building management and investment costs. It evaluates the viability, safety, comfort, and health of the future building as well as its uses of energy and water resources and exploitation costs. It helps in predicting the resources needed for maintenance and finally deconstruction and recycling.

At each design step, the tool takes advantage of other existing specialized tools and new knowledge to evaluate the project and to take the optimal decisions.

INTRODUCTION

Several years ago, the State of Vaud and the City of Lausanne launched a sustainable development policy. In order to assess the sustainability of their buildings, they developed a tool, SméO, which "*addresses all the stakes of sustainable development along the whole life cycle of the building, and adapts its references to the phases of the project, to its dimension and to the type of intervention*"[1].

An important aspect of this assessment and decision support method is to be flexible and adaptable to be applied to constructive operation of extremely variable nature and (temporal and spatial) scales. The State and the City wanted to link this adaptability to a great ease of use, in order to enable it to drive as many construction projects as possible towards the principles of sustainable development.

The main challenge of this tool is to be simple for sharing knowledge and present results, while integrating the complexity of the information resulting from the holistic, systemic and dynamic approach of the problems that SméO should handle.

A GLOBAL APPROACH

To apprehend SméO, it is essential to understand the underlying global approach to its design. The full life cycle of a construction is divided into five basic steps: the genesis, the materialisation, the use, the maintenance and finally, the deconstruction at the end-of-life[1].

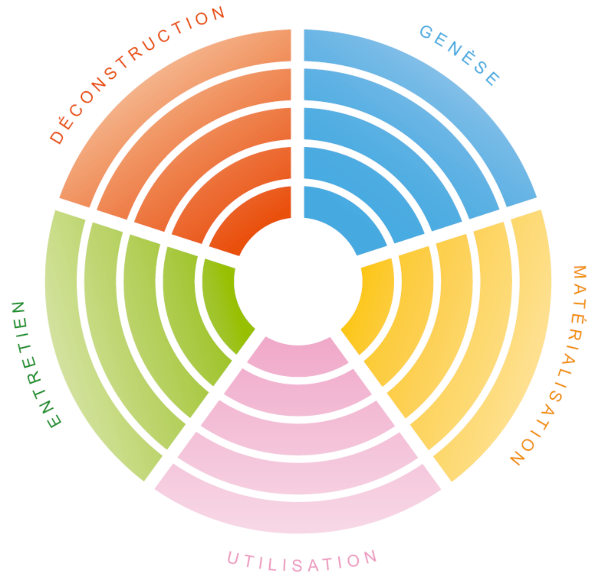

Figure 1: The steps along the life cycle.

1: Genesis 

This step poses criteria linked to the foundations of the construction project and its correspondence to the context in which it is established. To evaluate all aspects of this step, decisive for the good success of a project, the user should be able, among others, to answer the following questions: is the project balanced from a socio-demographic perspective? Is it integrated into the site? Are the administrative constraints evaluated? Did natural hazards be taken into consideration? Are financial, material and energy resources available?

The interest of this step is to confront the initial information and the perimeter of the future building to its actual impact in terms of sustainability, long before laying the first stone. The Genesis ensures solid bases to the project and identifies the possible difficulties to which it could be confronted in a long term vision.

2: Materialisation 

Materialisation occurs once the initial step is confirmed. This second step is based on a more precise assessment of the criteria linked to the achievement - respectively transformation or refurbishment - work. Therefore, the tool analyzes and qualifies the socio-economic and

[1] « Outil pour la planification et la construction selon les principes du développement durable », Roulet Yves, 2ème symposium sur les Énergies Renouvelables et l'Environnement dans le bâtiment, Yverdon, 9 et 10 octobre 2008

environmental impacts of the constructive concept, the chosen materials, the energy resources; the products used or even the recycling ability of the various elements. Thus, the materialisation step reinterprets the project in terms of full life-cycle, from planning up to the dismantlement and elimination of various building elements.

3. Utilisation

This step considers the optimisation of the use of the building(s) once occupied. It passes through all using issues (energy, waste, social relations, etc.) while promoting a good financial performance in the long term.

4. Maintenance

The purpose of the maintenance is to keep the building value at its sustainable and optimal level. This essential not only for keeping everything functioning in the long term, but also for ensuring a good comfort and well being of the occupants.

5. Deconstruction

Finally, the deconstruction step aims to limit the environmental impacts at the end of the building life by skilfully valorising the materials (recycling), or even to reconvert areas to other assignments, like transforming a former factory into apartment building. Such possible reconversions and recycling should be cared of when starting a project, so that future generations can take advantage of constructs carried out by their predecessors.

Thank to this approach based on the full life cycle of a building, SméO users take advantage of a decision support and systemic analysis tool.

METHODS

The Hermione evaluation tool

The Hermione multi-criteria evaluation tool [2] is used in SméO. The method was chosen for its qualities, including its ability to provide tangible and easily understandable results and to be free of "*weights on stakes and criteria, weights that are difficult to establish with accuracy and relevance*"[2]. To ensure a correct analysis and a relevant diagnosis of the problem, this multi-criteria analysis method relies on three fundamental principles to be absolutely respected when designing the list of criteria:

1. This list should be exhaustive: all stakes should be represented by a criterion.
2. It should not be redundant: no stake should be represented more than once by a criterion.
3. At each evaluation level, the criteria should have the same importance. If necessary, an important criterion is placed at a higher evaluation level, together with other equivalent criteria. This is necessary to avoid weighting the criteria, thus to ensure a relevant and credible analysis.

It also helps if the list is coherent: each criterion should be expressed in such a way that the performance is improved if a criterion is improved.

These principles were respected when defining the list of criteria and sub-criteria and their evaluation levels.

The evaluation uses a four level scale: according to each criterion, the evaluated object (in this case the building design) is either satisfying or acceptable (green), or inacceptable or not satisfying (red). A yellow mark is given when the result is unknown or uncertain, and a veto mark (black) is given if the result is so poor that it cannot be compensated by other good results.

To evaluate the qualitative criteria, qualities are assigned on the basis of arguments. "*Behind each colour, there is a quality and the assessor must be able to convincingly justify its judgment* [2]." As to the quantitative criteria, it is necessary to establish two or even three thresholds. The first sets the upper limit of not satisfactory, the second the lower limit of of satisfactory, and the last, if applicable, the veto limit.

Based on the Condorcet principle[2], Hermione evaluates the criteria at each hierarchic level (criteria, sub-criteria, etc.) and reflects the specific results by using the mentioned colour code. Then it aggregates all of these partial assessments according to majority rules to provide the user an overall assessment of the relevance of the scenario, a snapshot of its sustainability.

DEVELOPMENT MODE: OPEN SOURCE SOFTWARE

The open source software mode was chosen to develop the tool, since it appears to be especially adapted to the tool's philosophy and to the principles of sharing knowledge and continuous improvement desired for SméO.

The ergonomic virtual interface ensures not only a clear reporting of the results of the project analysis during its life cycle, but also makes easier the overall apprehension of strengths and weaknesses of the assessed project. It is essential that the use of the tool be simple and exciting to make it recognized as a real decision support tool, effective and useful to the optimization of projects. Moreover, as open source software, SméO will be improved by the users experience returns.

FUNCTIONS OF THE TOOL

When the users logs in, a personal projects library is created for storing the data and evaluation results. Once his project registered, the user defines the size and purpose (affectation) of his project, the type of works, the analysis starting point as well as the concerned building trade.

Then SméO proposes an adapted and coherent list of criteria for which the user should provide information. Other existing tools (e.g. software computing the energy use) may be proposed when necessary. Indeed, this tool is based on existing standards, documents and tools, such as:

- The service model SIA 112 [3] for defining the phases of the project
- The recommendation SAI 112/1 [4] for the sustainable development criteria
- Several SIA standards such as SIA 380/1[5], 380/4 [6] for energy in buildings
- The Minergie-Eco® [7] and EcoBau [8] references,
- The SNARC [9] method for quick evaluation of project at first stage
- Tools like Albatros [10], PVSyst [11], PolySun[12], EcoBat[13], LesoSai [12, 14], etc.

This step is the most important for an appropriate analysis.

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[2] This principle says that an assessment is globally satisfying when a majority of criteria are satisfying without a strongly dissatisfying minority.

Finally, SméO evaluates the proposed criteria and aggregates these results according to the Hermione method. These results are presented on a wheel (Figure 1), in which each sector represents a step in the building life cycle, the performance being presented along the radii. The user immediately sees the strengths of his project, to be maximised, and the weaknesses that need corrective actions to be optimised. At this step, the user can browse in the tool between synthetic results and assessment details, for example to test the effects of changes in his project.

"SMÉO FIL ROUGE POUR LA CONSTRUCTION DURABLE", A TOOL WITH HIGH ADDED VALUE

SméO is the first tool that performs a scan on several coordinated plans by integrating simultaneously notions of life cycle of the building, stages of the project as well as the three dimensions of sustainability. SméO is not a tool among others because it does not reinvent the wheel but delivers the very substance of existing tools to feed a comprehensive and transversal buildings sustainability evaluation method.

In addition, thanks to the flexibility offered by the chosen modes of development and their pooling, SméO is flexible enough to adapt, for example, to future changes in requirements or contexts, or even at different spatial scales. Meta-tool for sustainable development, SméO is sufficiently universal to handle objects of very different sizes. Aware of gains brought by the flexibility of the tool and its broad application potential, SméO designers intend to give it an enlarged dimension by creating synergies with other current projects: While the first version addresses buildings only, running development will handle also town districts.

It is desirable that the many intrinsic qualities to SméO as well as its ease of use contribute to reach the main objective that is to be useful and appropriate for as many actors as possible and actually lead construction and planning projects towards the principles of sustainable development.

CONCLUSIONS

The evaluation of the sustainability in the field of construction should be constantly adapted to new knowledge, new products, new techniques, and to socio-economic developments. The typology of a construction project must be adapted to its assignment and the analysis should be able to start at any time to help long time planning.

It seems therefore obvious that a tool for evaluating sustainability in this area must be flexible and scalable. This is why SméO is a tool built on a multi-criteria analysis with a structure allowing for a constant evolution of its criteria referential. Thank to this systemic approach, SméO is adapted to various situations not only today but also in the future.

The first version assesses the sustainability at the building level for all types of assignments and all types of work including new construction, small renovation or heavy transformation. In its future development, the same tool will allow the analysis and evaluation at the district or even region including other appropriate macroeconomic, social and environmental criteria, always with an approach oriented towards the whole life cycle of the addressed objects.

The tool **"SméO Fil rouge pour la construction durable"** is now available in French on **www.smeo.ch.**

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SOLARCHVISION

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For a better understanding of this paper, please refer to the colour illustrations of the digital version of the proceedings. [Ed.]

ABSTRACT

Considering the importance of paying attention to the local properties of each site and due to the insufficiencies in the existing tools and methods of solar analysis especially in architectural and urban design process, a basic research was needed to help the architects, urban planners, clients and the others. SOLARCHVISION is the computer program based on the thesis of first author of this paper entitled "From the Sun to the Architect" which defines a new method in architectural solar analysis. SOLARCHVISION brings a brand new vision for discovering the advantages and disadvantages of design decisions about kind and unkind faces of the sun in each location and through any period of the time. In this vision, the points are rated from red in the most undesirable situation to blue in the most desirable situation, while the middle values are displayed in colours such as yellow and cyan. However it is easy for the designer to use SOLARCHVISION through the whole process of design; different local parameters affect the results of this analysis such as sun path, direct/diffused radiation, changes in outdoor temperature, the geometry of the building and its surroundings.

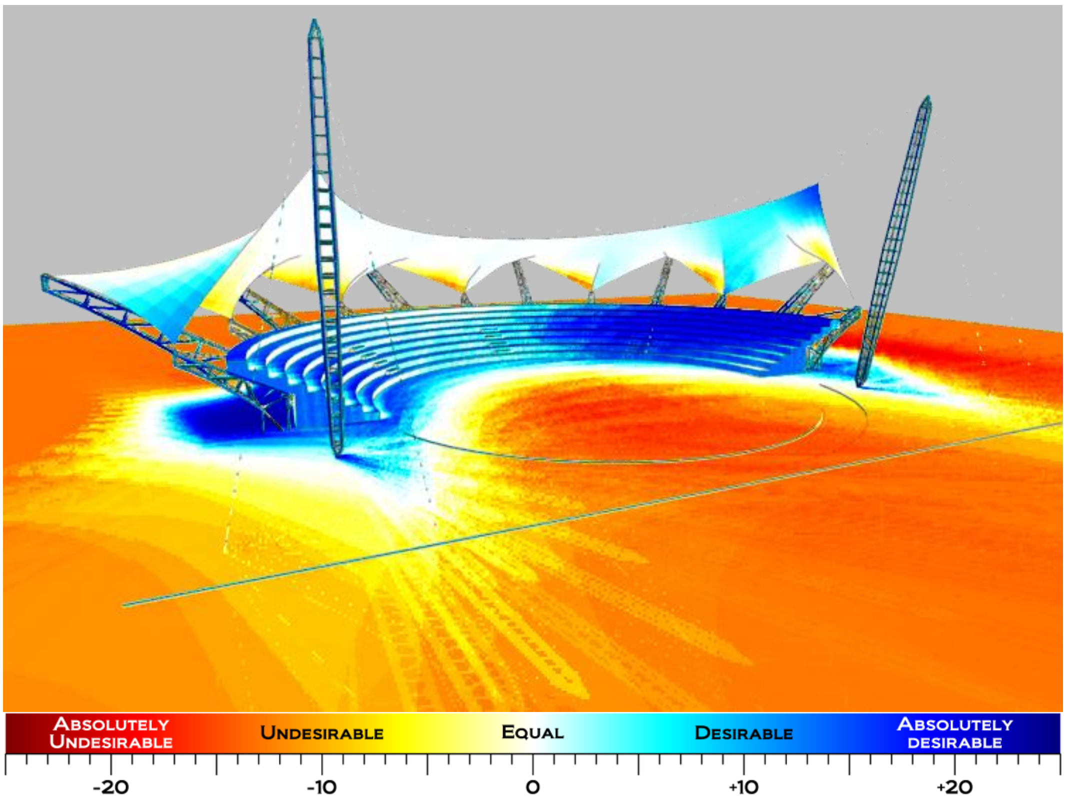

Figure 1: SOLARCHVISION yearly solar analysis diagram in the climate of Tehran.

INTRODUCTION

To answer the main architectural and urban design questions about proper building form, proper building orientation, proper shape of opening in each direction, proper shape of shading devices and proper material assignment and also the proper layout of building masses beside each other, it is necessary to be aware of the kind and unkind faces of the sun in each location.

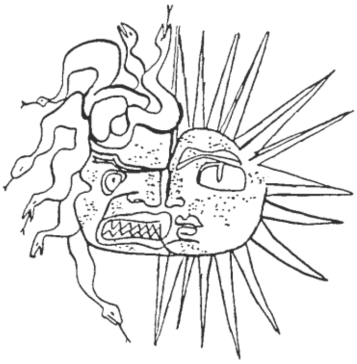

Figure 2: 1948 Le Corbusier painting of the sun [3]

METHOD

"The kind and unkind faces of the sun in each moment depend on different basic parameters such as:

1st, the intensity of direct and diffused solar radiation.

2nd, the amount of need to shade or shine." [1, 61-91] & [2, 303]

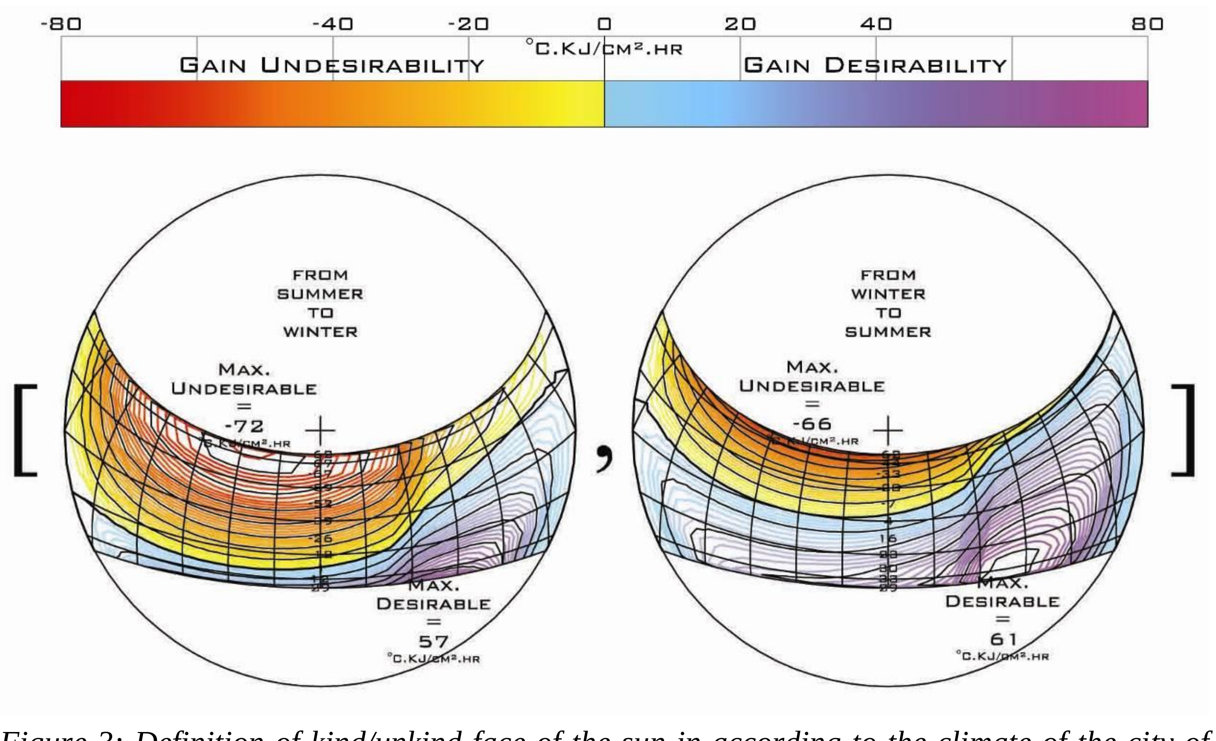

Figure 3: Definition of kind/unkind face of the sun in according to the climate of the city of Yazd (located on 31.5N, 54.2E) using direct radiation and 21°C as the base temperature.

Sensitive Building Skin Hypothesis

There are many similarities between human body and his architecture:

1st, the normal temperature of human body is the constant value of 37°C and the changes more than 2°C make unhealthy state; also the normal temperature of his place would better be about 21°C.

2nd, the role of human activity in the metabolism of the body is similar to the role of building internal gains from people, devices and etc. in according to its function.

3rd, the role of canopy, balcony, porch and etc. in protecting building skin is similar to the role of hat and dress in protecting human skin.

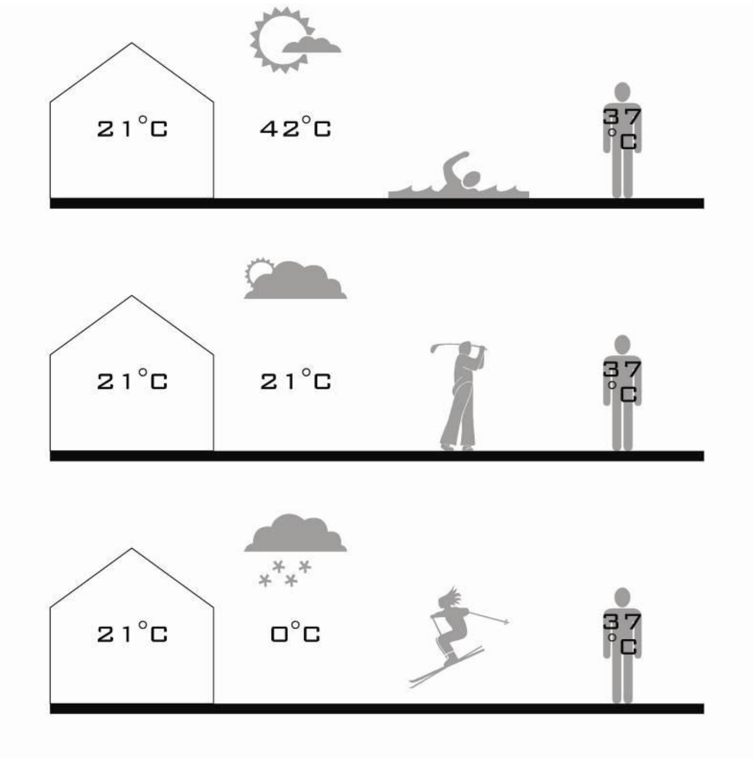

Figure 4: Man and man-made similarities [1, 67]

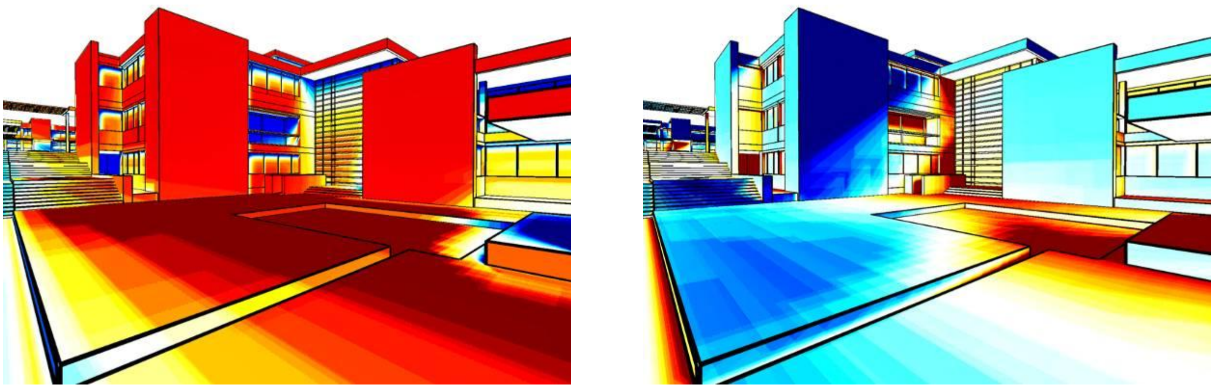

Figure 5: SOLARCHVISION summer analysis (left) and winter analysis (right)

According to sensitive building skin hypothesis, SOLARCHVISION display shade/shine hazards in red and yellow colours and shade/shine opportunities in blue and cyan.

RESULTS

SOLARCHVISION is a diagram which shows the situation of the building skin under the kind and unkind faces of the sun. It brings a brand new vision to the architects, urban planners and landscape architects to discover the advantages and disadvantages of their decisions about the sun in each location through the design process.

The user defines the properties of building location by selecting a city from the list or entering the available data of a location such as latitude, elevation, turbidity, monthly average of minimum and maximum temperatures. The architect or urban planner could use his favourite and suitable CAD software to model everything needed and then import. Next the date and time of analysis should be set up. Finally by selecting output cameras SOLARCHVISION diagram is resulted.

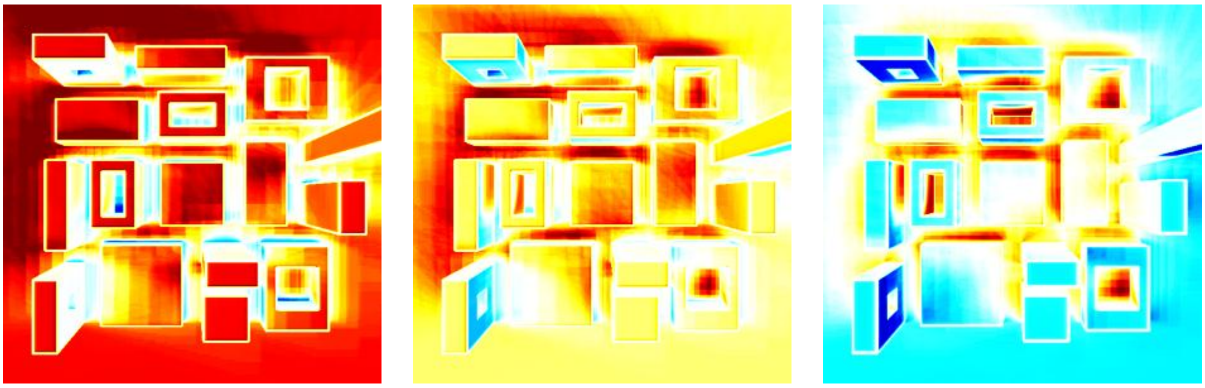

Figure 6: SOLARCHVISION yearly top view analysis of the building complex in different cities of Iran: Tabas{33.6N, 56.9E} (left), Shiraz {29.7N, 53E} (middle) and Hamedan {34.8N, 48.6E} (right).[attention: North direction is above]

The above diagrams display different range of climates of Iran. It is obvious that Hamedan has a cold climate and Tabas has a hot climate; however they are almost on the same latitude. The most important thing in the hot climate like Tabas is to maximize shades in hot hours of the day; but in the cold climate like Hamedan the shades are real hazards. Furthermore Shiraz has both hot and cold conditions; in this case the solar analysis is more complex. That's because in half cycle of the year shade is needed and in the other times shine is needed.

CASE STUDY: NAJAF, IRAQ

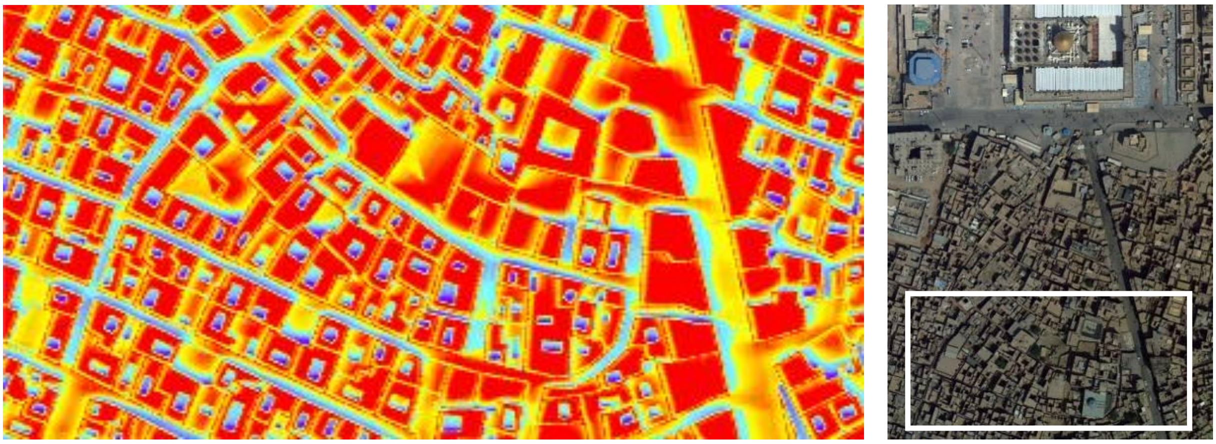

Figure 7: SOLARCHVISION yearly top view analysis of the old town of Najaf which shows the suitable proportion of courts and alleys.

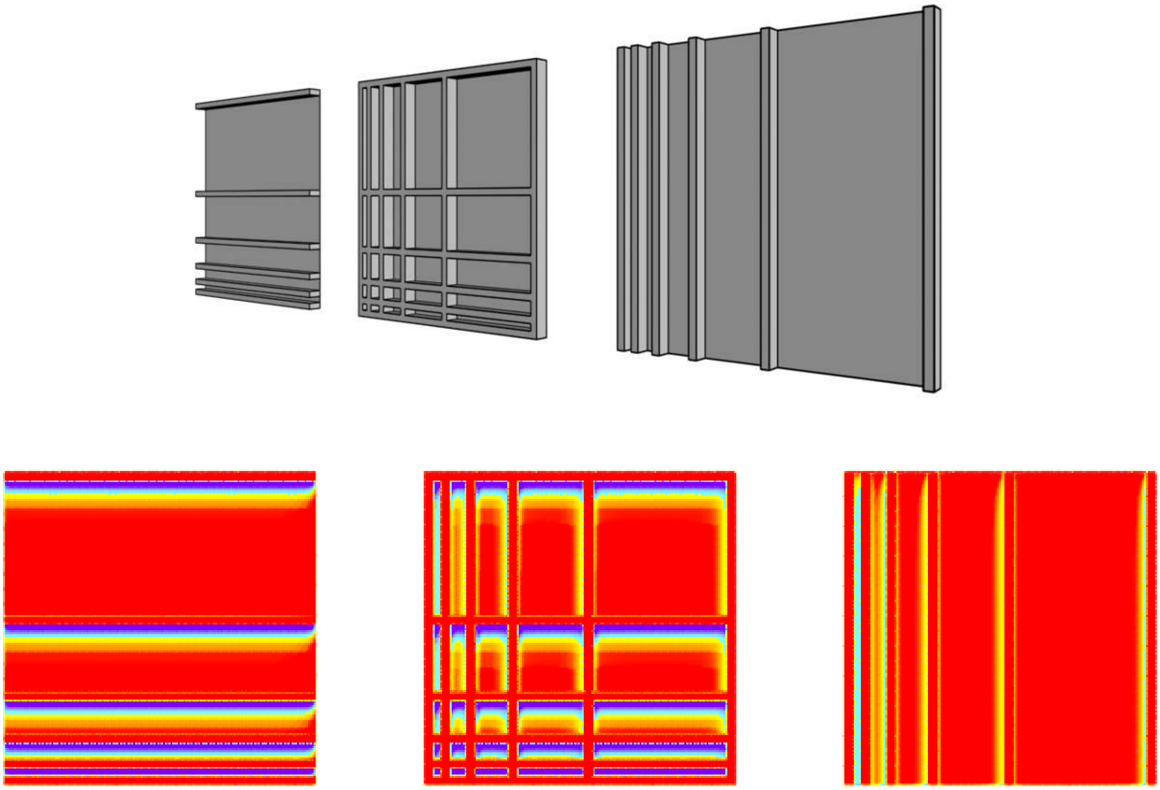

*Figure 8: SOLARCHVISION front view analysis for west facade in Najaf which shows the suitable type (horizontal) and proportion (depth = 2 * height) of louvers.*

Figure 9: SOLARCHVISION yearly perspective view analysis of Imam Ali holy shrine extension complex which shows the proper effect of porch and trees in this climate.

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SOFTWARE

		Available languages
		☐ **Français** ☒ **English** ☐ **Deutsch** ☐ **……….** ☐ **Italiano** ☐ **……….**
Editor **Mojtaba Samimi**	***Distributor*** **Raz Mehr Mehraz solarch studio**	***Price*** **-**

Description

SOLARCHVISION brings a brand new vision for discovering the advantages and disadvantages of design decisions about kind and unkind faces of the sun in each location and through any period of the time. In this vision, the points are rated from red in the most undesirable situation to blue in the most desirable situation, while the middle values are displayed in colours such as yellow and cyan. However it is easy for the designer to use SOLARCHVISION through the whole process of design; different local parameters affect the results of this analysis such as sun path, direct/diffused radiation, changes in outdoor temperature, the geometry of the building and its surroundings.
The user defines the properties of building location by selecting a city from the list or entering the available data of a location such as latitude, elevation, turbidity, monthly average of minimum and maximum temperatures. The architect or urban planner could use his favourite and suitable CAD software to model everything needed and then import. Next the date and time of analysis should be set up. Finally by selecting output cameras SOLARCHVISION diagram is resulted.

Technical Data

Operating System	***Processor*** **2GHz**
☐ **Windows 95/98** ☐ **Mac OS/X** ☐ **Windows NT4** ☐ **Mac + SoftWindows** ☒ **Windows 2000/XP** ☒ **Windows Vista** ☐ **LINUX** ☐ **Others ……………………………………………………**	***Required memory*** **2GB** ***Required disk space*** **2GB**

A METHOD TO USE DISCRETE ONLINE WEATHER FORECASTS FOR BUILDING SERVICES APPLICATIONS AND LOAD MANAGEMENT

Dr. Axel Seerig[1]; Carina Sagerschnig[1]

1: Gruner AG, Basel, Switzerland

ABSTRACT

In general for predictive building controls, subscription based weather-forecasts based on current values and forecasts of a national meteorological service are used. The data for the respective location is then processed as a piece of information technology via the Central Control System of a building.

The internet, however, bears the possibility to retrieve the required data from online weather forecast providers free of charge and for most locations. These forecasts are usually available for a period of 5-9 days in advance for the maximum and minimum values, e.g. outside temperature. The problem, however, arises in that the data is not provided in the necessary resolution. For most applications in the building and energy field, hourly or quarter-hourly values are needed.

The objective of this study is to define a method to generate forecast values in variable resolutions of time, based on free online forecasts and to discuss on the one hand the quality of the retrieved input data and on the other hand the method to inter- and extrapolate target data.

In the study various analytical methods to generate outside air temperature patterns are examined. Only methods which meet the requirements of predictive controls in the building and energy field have been used. In order to inter- and extrapolate target data for variable target resolutions an independent discrete model is developed.

ONLINE DATA AQUISITION

The internet allows the retrieval of weather forecasts from various providers free of charge and for most locations. These forecasts indicate the daily maximum and minimum temperatures for the days to follow. Online weather data has the advantage of being up-to-date and instantly available without having to negotiate with federal offices of meteorology first, and still offers accurate enough data for many applications in building technology [1, 2, 3].

Data is acquired through an automated internet query (fig. 1) which directly feeds into a spreadsheet programme (e.g. MS Excel), thus tables (stand-alone or embedded in other tables) from the internet are directly imported into the programme. The weather homepages can be accessed as regularly as needed to keep the data up-to-date.

The standard web query used in this study is suitable for acquisitions of online-data from tables and texts. Forecasts, embedded in a graphic or flash application have to be converted through OCR.

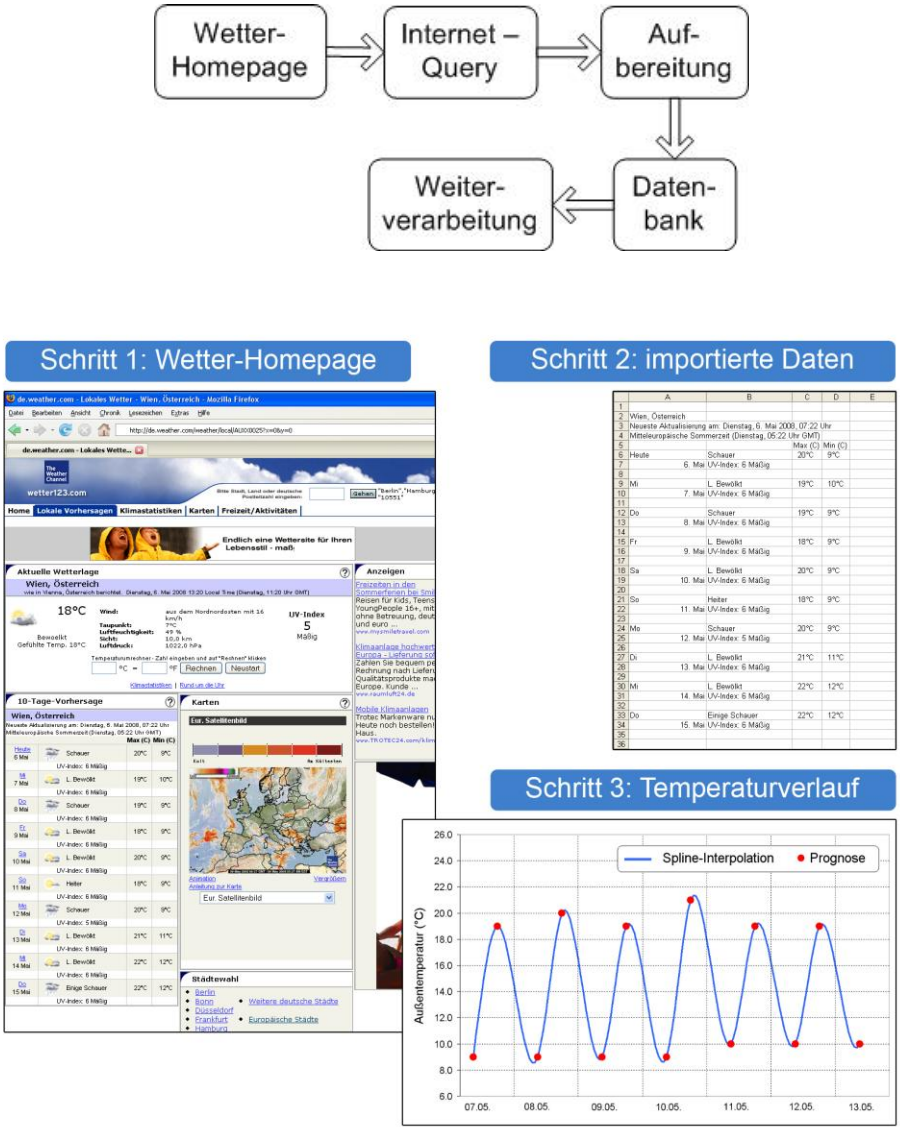

Figure 1: Online data acquisition

The acquired data is then processed in a spreadsheet programme and ready to be used further as a stream of data. Weather forecasts are usually available for a period of 5-9 days in advance for the maximum and minimum values, e.g. outside temperature.

In order to be able to use online forecasts for weather predictive control, an hourly temperature curve has to be generated from the predicted minimum and maximum temperature for a day. In this study weather forecasts by the provider http://de.weather.com [4] were used.

METHOD

In literature various approaches to the generation of weather data have been discussed for different applications/ input data and levels of complexity of the calculated data [5, 6, 7]. This paper examines suitable models for the generation of outside temperature curves which are of high enough quality to be used in standard weather predictive building control and which can be easily implemented. Of the two methods presented for data generation one depends on the location and the other is location independent.

Spline-Interpolation

One simple method for spreading/unrolling discrete online forecast values on an hourly temperature curve is spline interpolation. Spline curves are functions which are made of polynoms which pass through given points. If weather data is generated by splines, the daily maximum and minimum values are the given points in the coordinate system, which are connected by spline curves.

A preferred method for the interpolation of daily temperature curves is the approximation by splines of higher order. Thus, higher oscillations can be avoided. In this study cubic splines, polynomial functions of third order, are used, they tend to mildly overshoot but within acceptable limits. Because of this model-based disadvantage, spline curves can not be recommended completely for weather data generation. Due to possible overshoot, maxima and minima of the spline curve may not match the original data.

Time-factor method

By using a synthetic function which is similar to a sinusoidal function the disadvantage of overshooting can be avoided.

This method, referred to in this paper as “time-factor method”, is based on qualitative modelling of a typical daily temperature curve progression at a specific location. The connection between forecast highs and lows and the daily mean curve is described by specific time factors, based on previously measured or statistic hourly temperature values.

The time factor f is determined by the ratio between the present spread of temperature and maximum daily spread (equation 1):

$$f = \frac{t_i - t_{\min}}{t_{\max} - t_{\min}} \qquad (1)$$

f time factor [-]

t_{min} daily minimum temperature [°C]

t_{max} daily maximum temperature [°C]

t_i temperature at given time i [°C]

Thus, the time factor can assume values between 0 and 1. For the daily minimum (t_{min}) the time factor f=0, for the daily maximum (t_{max}) the time factor f=1.

For the calculation of mean time factors daily values or values of lower resolution of outside temperature for a specific location are necessary. As input data, measurement or statistic data of a full year can be used. The time factor is calculated from the hourly median value of outside temperature.

Fig. 2 shows the time factors, which were calculated from the median of a yearly temperature curve progression with measured data on the one hand and statistic data from the simulation programs BLAST and EnergyPlus on the other [8, 9, 10].

A comparison between the spline and time factor method is shown in fig. 3.

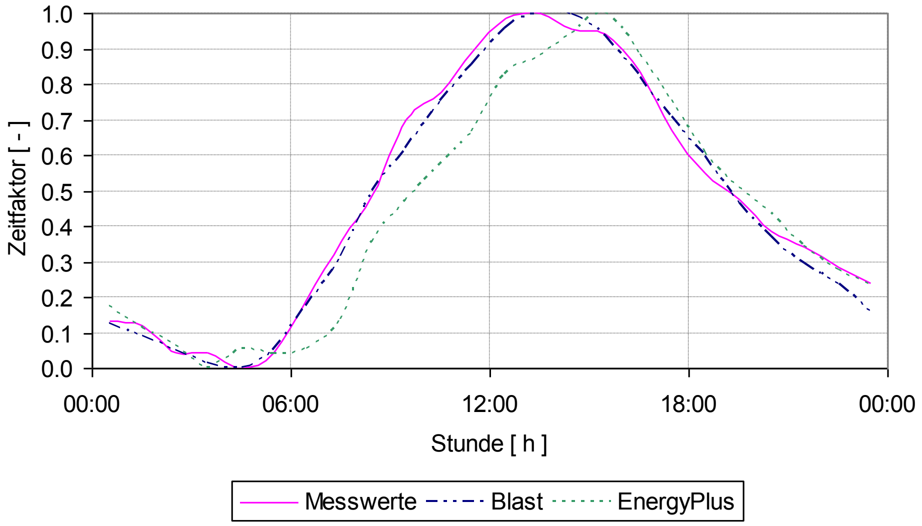

Figure 2: Comparison of time coefficients derived from different data sources

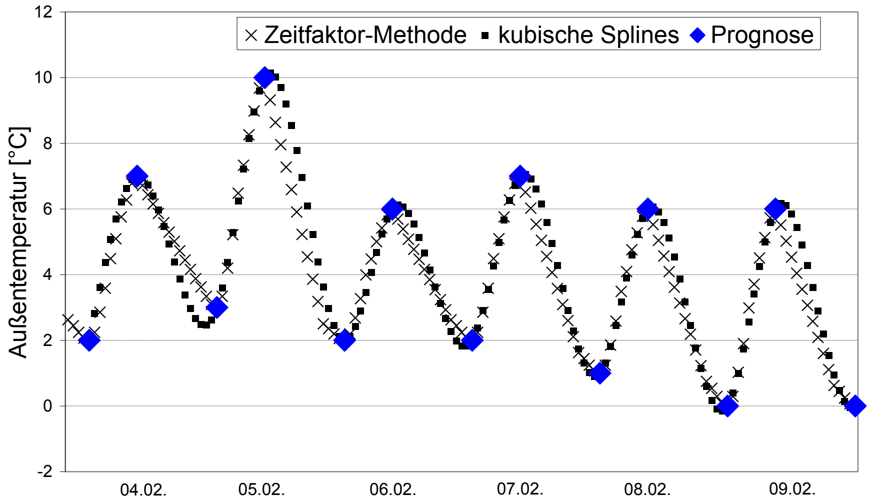

Figure 3: Comparison of inter- and extrapolation methods

APPLICATION

For applications in building and energy technology the retrieved synthetic weather data further processed and coupled with a physical building model using transfer functions. As seen in figure 4, the prediction of electrical load, by the described method, shows a high accuracy for an example case.

For further improvement of forecast accuracy, free forecast values for sun, wind and rain can be integrated. With this step, new areas of application could open up e.g. optimization of solar collectors (forecast sun) or wind turbines feeding into the grid (forecast wind). Moreover, since November 2006 radio-controlled time signals also transmit weather forecasts for many locations in Europe (Switzerland: radio station HBG, Prangins; Germany: radio station DCF, Mainflingen). Thus the method described is facilitated even without an internet connection, and provides quick access to forecasts without a time difference.

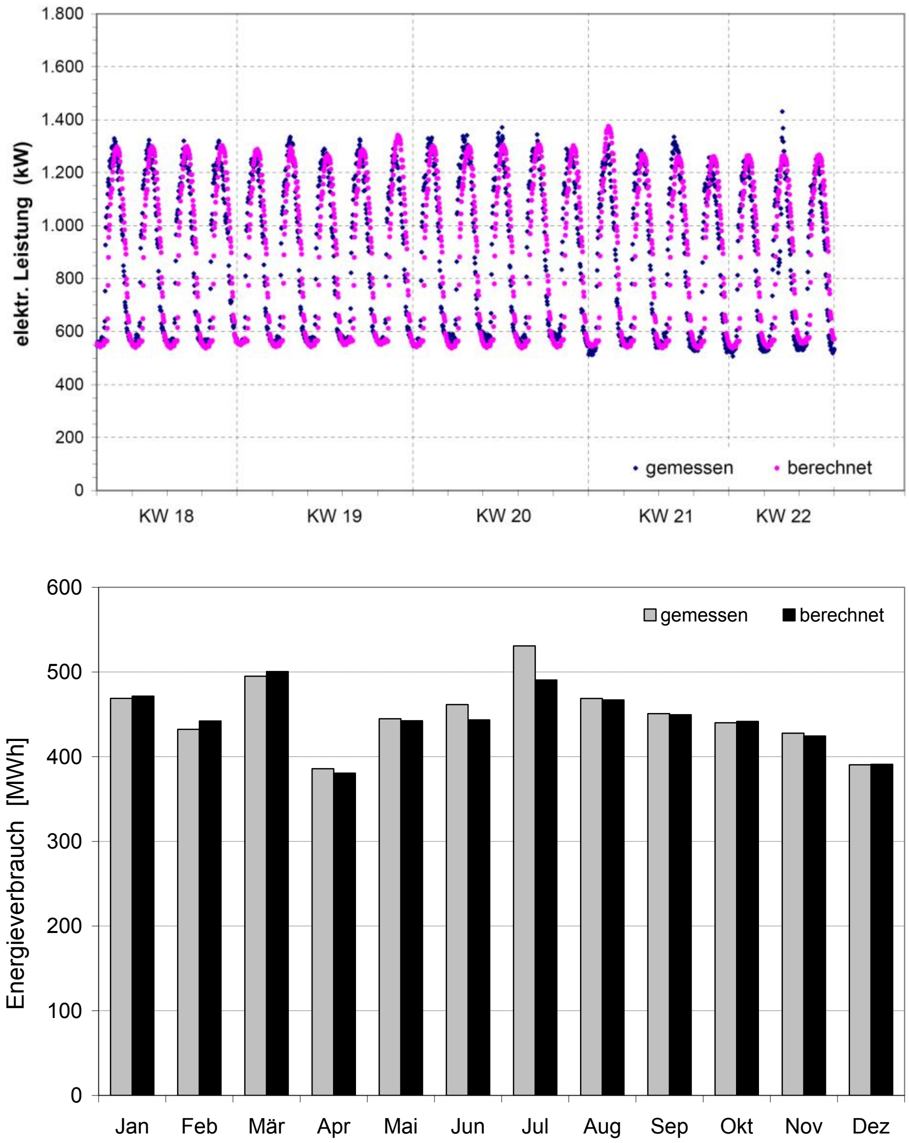

Figure 4: Comparison of measurement data and load prediction (above: hourly power values, below: monthly consumption)

CONCLUSION

Free online forecasts can be used for a wide variety of weather predictive controls, delivering results of sufficient accuracy for energy and building control. Online forecasts are flexible in application and easily accessible independent of location and time. In collaboration with a university and a market leader in building controls, the development of integrated applications within the Central Control System of a building is currently in progress.

Using these online forecasts a method was developed to predict future building behaviour in terms of energy loads/temperatures. Forecasts are acquired through an automated internet query which directly feeds into a spreadsheet program from where the data can be processed further. Various methods (spline interpolation, time-factors) are employed to generate daily temperature curves from the discrete forecast values for daily maximum and minimum temperatures. The generated temperature curves are then used in weather predictive building control. Here hourly predictive temperatures are linked by building transfer functions to estimate building behaviour in terms of energy loads/temperatures.

In order to further improve the forecast accuracy, free forecast values for sun, wind and rain can be integrated. Moreover, radio-controlled time signals are available also transmitting weather forecasts for many locations in Europe. The method described is thus facilitated even without an internet connection, and provides quick access to forecasts without a time difference.

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AUTOMATED MONITORING AND PREDICTION OF HEATING ENERGY CONSUMPTION IN BUILDINGS

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ABSTRACT

In winter 08/09 a prototype service was developed to measure and evaluate the heating energy consumption in buildings in an automated, cost-efficient way. The service consists of a low cost hardware and an internet portal which visualises and evaluates the data. The project was financially supported by the Federal Office for Energy and the building programme of the Climate Cent foundation [1].

The hardware was installed in 10 buildings taking part in the building program of the Climate Cent foundation. It measured heating energy consumption and daily sent this data via GPRS to a central server in Berne. Additionally, information about local air temperature and solar irradiation were gathered from weather satellites and stored together with the measurement data on the central server. A customized software analysed the data and visualized them. All data, graphs and results were stored in a password protected area, accessible via internet.

Measurement data between Jan. and April 09 were correlated in a multiple linear regression with the daily average ambient temperature and irradiation. The correlation coefficient R^2 was above 90% for 5 of the buildings (above 65% for 9 buildings). Yearly heating energy consumption in a standard year was estimated by applying the regression parameters to the daily values of ambient temperatures and irradiations for one year in Meteonorm [2]. For some buildings the measured values were substantially higher than the expected energy consumption. A part of the deviations results from uncertainties in the regression and the assessment of circulation losses and consumption of warm water. But our data show also that the expected values seem to be wrong in some cases.

For building owners, architects, heating planners and energy experts, a similar service as applied in our study could be useful for several purposes:

- Determine and visualise the real energy consumption and energy index of a building
- Measure if the energy consumption of a certain building meets the expectations / calculations
- Verification of the success of a renovation
- Detect energy leakages / energy saving potential in buildings
- Optimize heating regulation of buildings
- Gather information for planned renovation of a building (insulation or heating renewal)

The project participants will improve the existing prototype and start a second measurement campaign with more buildings in winter 09/10.

INTRODUCTION

In Switzerland exist about 1 million buildings with a gas or oil heating, accounting for about 25% of the total Swiss energy consumption. More than 80% of the buildings are older than 30 years. With a proper renovation, their energy consumption could be reduced by a factor of two at least. The Swiss government and the cantons have started to recognise this high potential for energy savings and financially reward better insulation of buildings. From 2010 to 2020 the Swiss Government will spend 200 million CHF per year for the renewal of buildings [3].

A problematic aspect in the context of building renovations is, that often only approximate values about the real energy consumption of the buildings exist. A detailed analysis of the energy consumption behaviour would help to plan the renovation as well as to optimise the heating regulation and check the success of an insulation. Up to now, such analyses are carried out only for a very small percentage of buildings because they need expensive measurement devices, a long measurement time and specialists analysing the data.

In the project "Egon energy in buildings" which was financially supported by the building programme of the Climate Cent foundation and the Swiss Federal Office for Energy, a system was developed which shall allow to assess the yearly energy consumption of buildings with a measurement time of a few weeks, low cost hardware and a fully automated analysis.

Objective of this system are the following goals:

- Determine the real energy consumption and energy index of a building
- Measure if the energy consumption of a certain building meets the expectations / calculations
- Verification of the success of a renovation
- Detect energy leakages / energy saving potential in buildings
- Optimize heating regulation of buildings
- Gather information for planned renovation of a building (insulation or heating renewal)

METHOD

The system was applied to oil and gas heating systems. A hardware was installed at the heating system of the building. It measures heating energy consumption and daily sends the measurement data via GPRS to a central server in Berne. Additionally, information about local air temperature and solar irradiation are gathered from weather satellites and stored together with the measurement data on the central server. A special software analyses the data and visualizes them. All data, graphs and results are stored in a password protected area and permanently accessible for the building owner via internet.

Hardware

At the heating system, an oil volume meter (from Satronic) or a reed contact for the gas meter (from GFW) were installed. Both devices generate digital output signals proportional to the amount of oil resp. gas used. With the data logger Barionet (from Barix AG) and a customized software the digital signals were counted and stored as hourly sums. Every night, the data logger sent these data via internet to the central server in Berne. Because we didn't have access to the LAN network of the building owners we used a GPRS router (from Siemens) to connect the Barionet with the internet.

Total hardware costs were at about CHF 1'000.- per building. Installation time was approximately 1 hour.

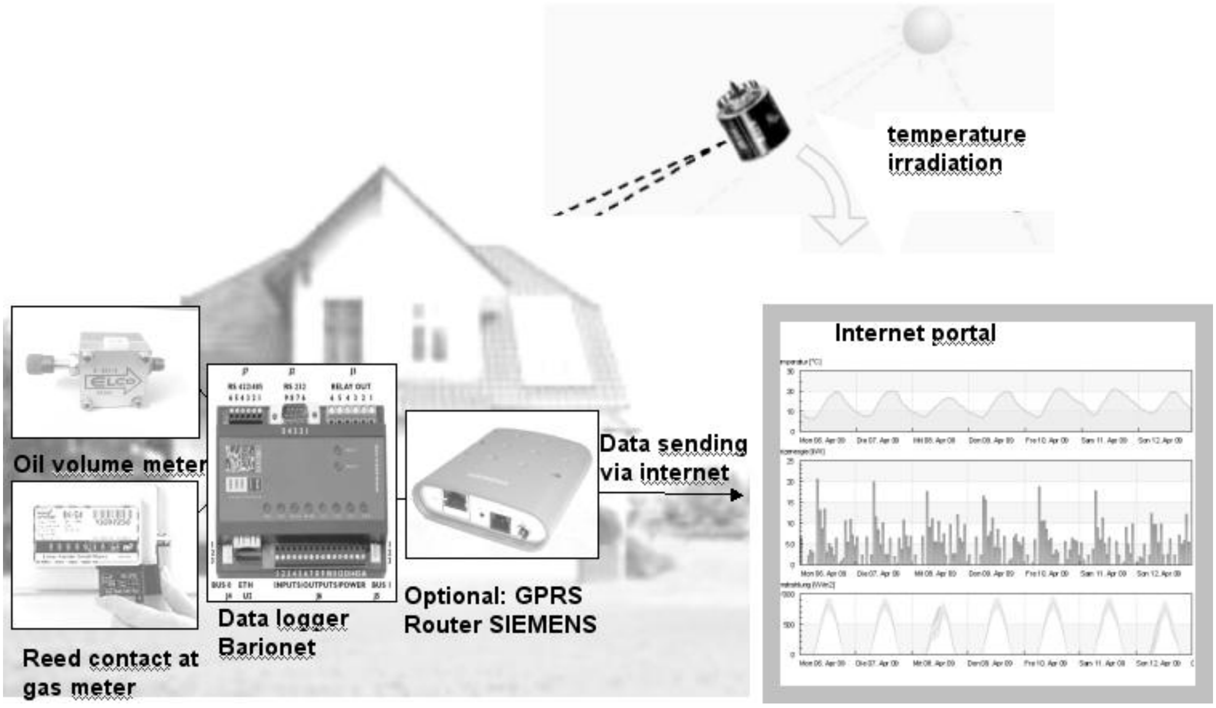

Figure 1: Principle of the system, including hardware on-site and a central internet portal

Software

All measurement data were sent daily to a central server in Berne and stored in a SQL data base together with temperature and irradiation data in hourly resolution. The real time meteorological data were automatically fetched from weather satellites and weather models.

For further analysis of the data, only daily averages of heating power and temperature and sums of irradiation were used.

In a multiple linear regression, the heating power of the building was correlated with ambient temperature and irradiation:

$$P = b_0 + b_1 \text{ x Temp} + b_2 \text{ x Irr} \qquad (1)$$

Where

P :average daily heating power [W]
Temp: average daily ambient temperature [°C]
Irr: daily sum of global irradiation [Wh/m2]
$b_{0,}$ b_1, b_2: regression parameters

To assess the yearly energy consumption of the building, daily values of temperature and irradiation in a standard year were derived from the software Meteonorm [2]. Using the regression parameters, energy consumption for every day of the standard year was calculated and summed up.

Internet portal

An internet portal (www.egonline.ch) was built up, where all data were accessible in a password protected area. Measurement data as well as the results are presented as graphs and available as CSV-files for download.

Measurement at 10 buildings

The hardware was installed at 10 buildings in the region of Zurich which took part in the building program of the Climate Cent foundation. Besides from building Nr. 7704 all buildings had already been renovated or were renovated during the measurement phase (building nr. 8279). The following tables gives an overview on the size, type and heating system of the buildings.

building ID	heated surface (m2)	heating system	type of building	measurement period
392	337	gas	apartment building	10.12.2008 to 20.5.09
634	2650	oil	office building	16.12.08 to 20.5.09
675	682	oil	apartment building	10.12.2008 to 20.5.09
1176	963	gas	office building	15.01.09 to 20.5.09
1441	224	oil	apartment building	27.01.2009 to 26.3.09
2985	474	oil	apartment + clinic	03.07.2008 to 1.3.09
4706	1614	gas	apartment building	22.01.2009 to 20.5.09
5073	141	oil	apartment building	06.02.2009 to 7.5.09
7704	335	oil	apartment building	16.12.2008 to 27.2.09
8279	1567	gas	apartment building	15.3.09 to 6.5.09

Figure 3: overview on the buildings

RESULTS

The following results were calculated for each building:

- regression parameters b_0, b_1, b_2
- R2 of the regression, including graph with all measurement data and the corresponding regression value of heating power
- Estimated energy consumption of the heating system during heating season in kWh and MJ/m2
- Estimation of the circulation losses and warm water consumption in kWh per year
- Estimated energy consumption of the heating system during a complete year (including circulation losses and warm water consumption) in kWh and MJ/m2

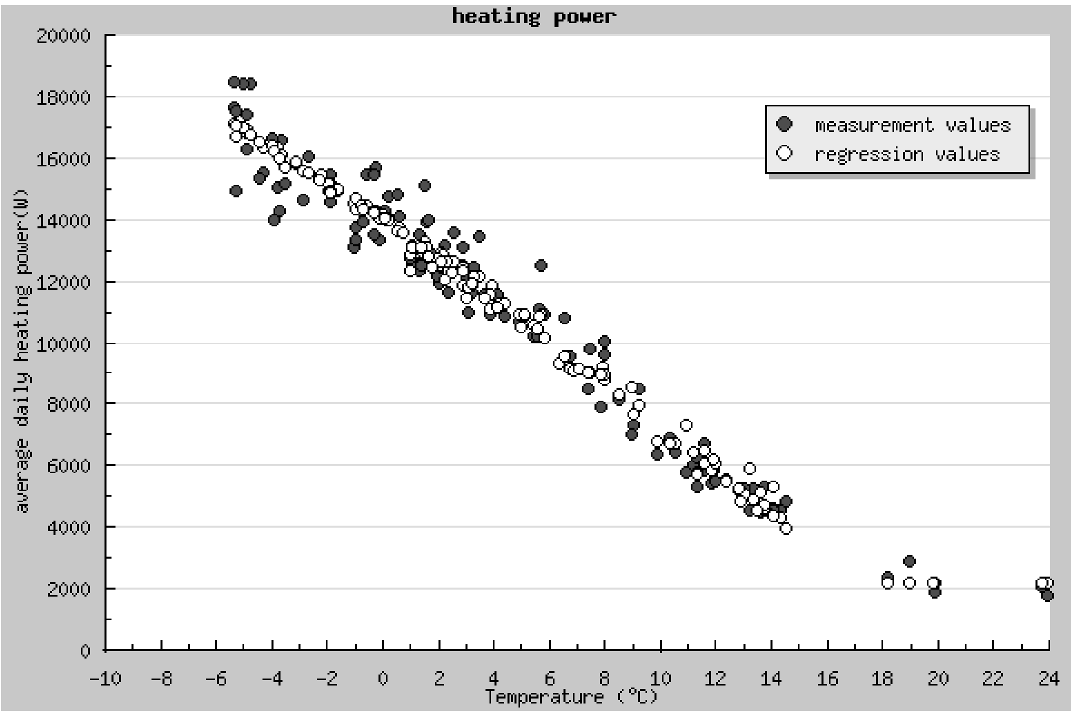

Figure 2: correlation of average daily heating power with temperature and irradiation

For each building the expected energy consumption of the heating system during heating season had been calculated by the Climate Cent foundation with a simulation tool. We used these calculated values as a benchmark for our estimated energy consumption values.

DISCUSSION

Figure 2 shows as a typical example for all buildings the regression for building nr. 634. It can be seen that heating power decreases with increasing ambient temperature until temperature reaches ca. 14°C. In contrast to a simple linear regression, regression values do not represent a straight line, because in addition to the temperature effect also the effect of irradiation was taken into account. This heating curve shows how the building reacts to changes in temperature and irradiation.

At temperatures above 14°C heating power is constantly at about 2000 W per day, which corresponds to the circulation losses and hot water consumption. For building nr. 634 these losses therefore amount up to ca. 40% of the yearly energy consumption. (rough calculation: on an average heating day, a heating power of 10’000W is necessary. Circulation losses and hot water use are necessary during 365 days per year, heating power is used during approximately half of the year). For all buildings estimated hot water consumption and circulation losses varied between 15 and 77% (average of 40%).

Although it is often assumed that buildings are not heated any more if ambient daily temperature increases above 12°C, 8 of the 10 buildings were heated also at days with an average ambient temperature of 15°C or even higher.

The correlation coefficient R^2 for the linear regression is between 93 and 99% for 5 of the buildings. For the other buildings it is lower, but data are not cleared yet from outliers. The estimated yearly energy consumption deviates in many cases substantially from the expected energy consumption (in average by 34%). There is no correlation between the quality of the regression and the deviation between estimated and expected energy consumption. A part of the deviations results from the difficulty to accurately estimate the start and end of the heating period and the exact determination of the height of circulation losses and consumption of hot water. Finally, expected values (i.e. yearly energy consumption according to the Energiesparrechner of the Stiftung Klimarappen) seem to be wrong for at least some of the buildings. Further reasons for the deviations are still under investigation. The complete system, including hard- and software will be developed further. In winter 09/10 a second measurement campaign is planned.

ACKNOWLEDGEMENTS

The project members gratefully thank the expert group Marco Berg from the Climate Cent foundation, Thomas Nordmann from TNC Consulting AG, Charles Filleux from Basler and Hofmann and Charles Weinmann from Weinmann Energies for their competent advice and supervision of the project.

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SOFTWARE

Automated Monitoring and Prediction of Heating Energy Consumption in Buildings		*Available languages* ☐ **Français** ☐ **English** ☒ **Deutsch** ☐ **……….** ☐ **Italiano** ☐ **……….**
Editor Enecolo AG: info@enecolo.ch Meteotest: office@meteotest.ch www.egonline.ch	***Distributor*** Still in development phase. Not available on the market.	***Price*** Not available on the market.

Description

With a combination of hard- and software, it shall become possible to measure and evaluate the heating energy consumption in buildings in an automated, cost-efficient way.

Goals

- Determine and visualise the real energy consumption and energy index of a building
- Measure if the energy consumption of a certain building meets the expectations / calculations
- Verification of the success of a renovation
- Detect energy leakages / energy saving potential in buildings
- Optimize heating regulation of buildings
- Gather information for planned renovation of a building (insulation or heating system renewal)

Principle

A hardware is installed at the heating system of the building. It measures heating energy consumption and daily sends the measurement data via GPRS to a central server in Berne. Additionally, information about local air temperature and solar irradiation are gathered from weather satellites and stored together with the measurement data on the central server. A special software analyses the data and visualizes them. All data, graphs and results are stored in a password protected area and permanently accessible for the building owner via internet.

Features of the hardware

- easy and fast installation of measurement hardware (ca. 1 hour installation time)
- can be installed in any gas or oil heating system

Features of the software

- real time temperature and irradiation data from weather satellites – no on-site measurement devices necessary
- correlation of energy consumption with temperature and irradiation data
- estimation of yearly heating energy consumption
- visualisation of results with predefined graphs in password protected area, accessible via internet
- storage of all data, permanent access to all past and actual data

Hard- and software are in a prototype-phase. The first 10 buildings were measured in winter 08/09. In winter 09/10 a second measurement sequence is planned.

Technical Data

Operating System	*Processor*
☐ **Windows 95/98** ☐ **Mac OS/X** ☐ **Windows NT4** ☐ **Mac + SoftWindows** ☐ **Windows 2000/XP** ☐ **Windows Vista** ☐ **LINUX**	*Required memory*
☒ **Others:** software runs on a central server, not for distribution	*Required disk space*

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ACKNOWLEDGEMENTS

CISBAT 2009 would not have been possible without the efficient contribution of the secretariat of the Solar Energy and Building Physics Laboratory as well as that of our scientific and technical staff.

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CISBAT can only exist thanks to the financial support of the Swiss Federal Office of Energy. We are very grateful for their continuing support.

Finally, we cordially thank all speakers, authors and participants from the five continents who have brought CISBAT 2009 to life.

Prof. J.-L. Scartezzini