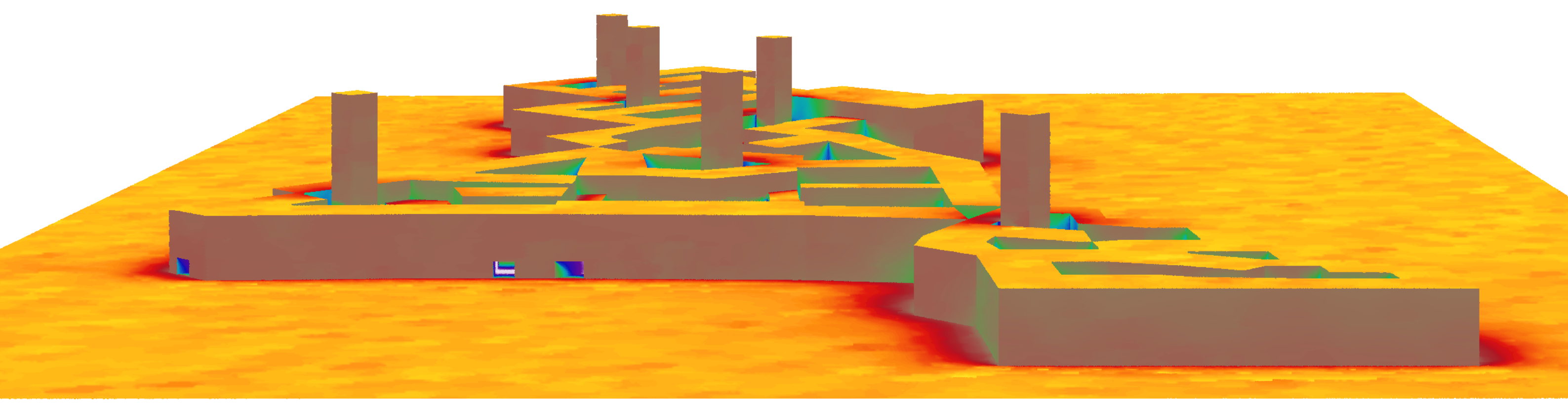
A Bioclimatic approach to design and optimize a hypothetical Masterplan for the new EPFL Research Centre in Ras al Khaimah

Silvia Coccolo
Prof. Jean-Louis Scartezzini
Dr Jérôme Henri Kämpf
Prof. Riccardo Bedrone

March 2012



INDEX

1.1 United Arab emirates

The United Arab Emirates (دولةالإماراتالعربيةالمتحـــــــــــدة) is a constitutional federation of seven emirates: Abu Dhabi, Dubai, Sharjah, Ajman, Umm al- Qaiwain, Ras al-Khaimah and Fujairah; the UAE were established on 2nd December 1971.The capital is Abu Dhabi, that's the political, industrial and cultural centre of the state; every emirate is governed by a hereditary emir.

UAE are situated between 22°30' and 26°10' North latitude and between 51° and 56°25' East longitude. Located in the southeast of the Arabian Peninsula, on the Persian Gulf, they have a common border with Oman, and Saudi Arabia, and share the sea borders with Iraq, Kuwait, Bahrain, Qatar, and Iran.

The UAE coast stretches for more than 650 [km] along the southern shore of the Persian Gulf, and the confederation occupies a total area of 83,600 [km²]. The total population consist, as an estimation of 2010[4], in 8,264,070 people, of which the biggest part are immigrant, in 2010 the total population consist in 7,316,070 immigrant and 947,997 Arab. The 60.5 [%] of the immigration is from South Asia, India, Pakistan, Bangladesh, China, Philippine and Thailand. The biggest part of the population is in the emirate of Abu Dhabi, with 404,546 people; indeed Ras Al Khaimah has a population of 97,529 people.

		Arab population (2010)		
Emirate	Men	Women	Total	Percentage
Abu Dhabi	204,108	200,438	404,546	43
Dubai	84,245	83,784	168,029	18
Sharjah	78,818	74,547	153,365	16
Ajman	21,600	20,586	42,186	4
Umm Al-Quwain	8,671	8,811	17,482	2
Ras Al Khaimah	49,181	48,348	97,529	10
Fujairah	32,486	32,374	64,860	7
Total	479,109	468,888	947,997	100

Table 1 Arab population in UAE. National Bureau of Statistic, 2010

		Population in UAE (2010)		
Nationality	Men	Women	Total	Percentage
Arab	479,109	468,888	947,997	11
Immigrant	5,682,711	1,633,362	7,316,073	89
Total	6,161,820	2,102,250	8,264,070	100

Table 2 Population in UAE. National Bureau of Statistic, 2010

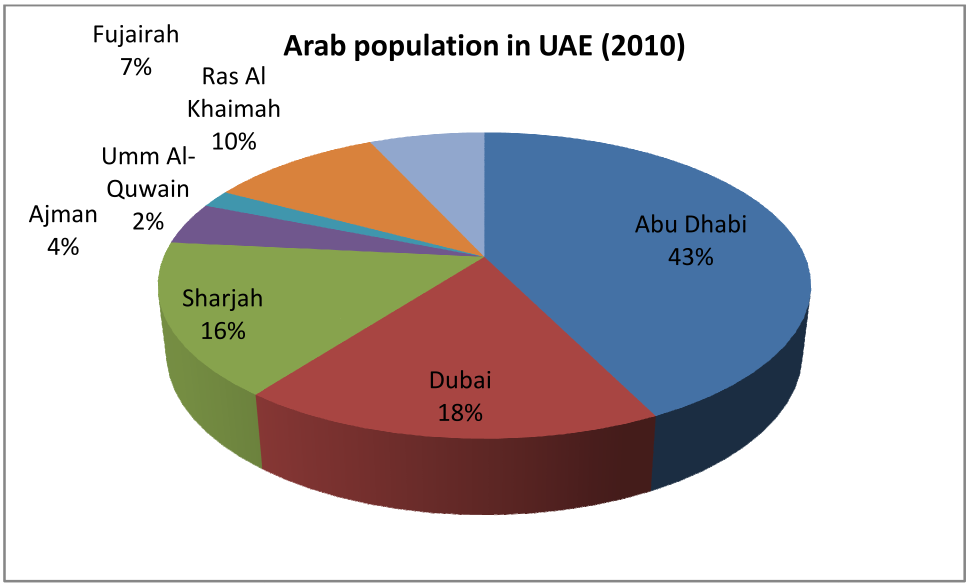


Figure 1 Arab population in UAE

The official religion is Islam, but other religions are allowed. The official language is Arabic.

The region is flat, but in the East side there are the Oman Mountains, that rise to an altitude of over 2000 meters. The maximum dimensions are 8 [km] from East to West, and 18 [km] from North to South. The sand desert covers the largest portion of UAE, and it's called Rub Al Khali Desert.

Figure 2 Map of United Arab Emirates[5]

1.1.1 CLIMATE

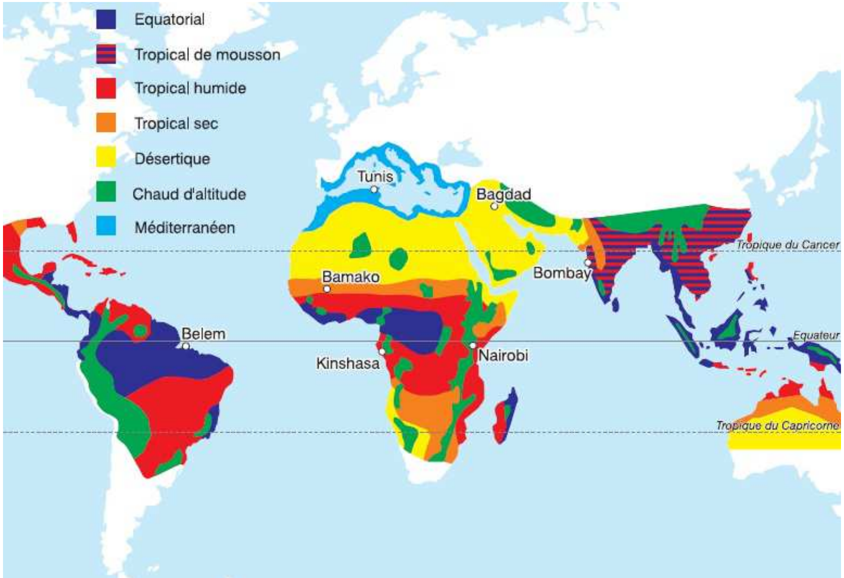


Figure 3 World's map indicating the different climates zones [2]

As we can see in the Figure 3, Ras Al Khaimah has a desert climate, characterized by highs temperatures in summer, and a high difference between day and night temperatures. In summer, during the day, temperatures reach 43° to 49 [°C], and during the night get as low as 24 [°C]. The annual difference between daytime and night temperature is included between 11[°C] and 17[°C]. Precipitations are irregulars and between 50- 250 [mm/year].

Winds are strong, with a dominance direction from West and North West (52%), but also from South- East (28%)[6].

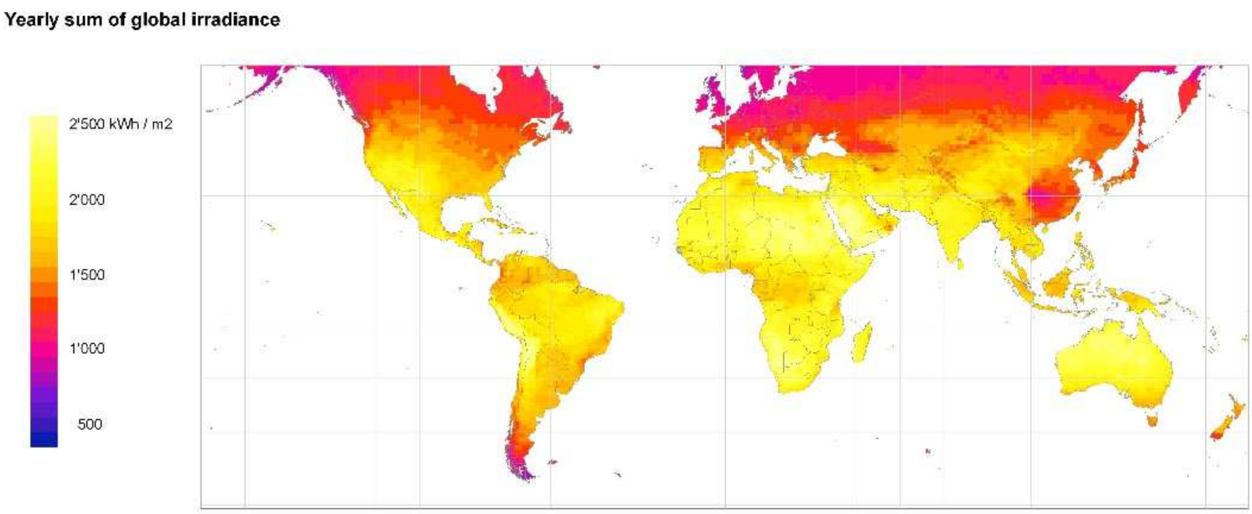


Figure 4 Yearly sum of global irradiance. Meteonorm

From the Figure 4 it can be noticed that the global radiation in Ras Al Khaimah is more than 2,150.00 [kWh/m²], for reference the maximum in Switzerland is around 1800[kWh/m²]. The average annual rainfall is different, between the coast and the mountains. The rain occurs, mostly during the winter. As we can see in the picture below, the mean rainfall is of 110 [mm/ year], with a minimum of 7[mm] in 1999/2000, and a maximum of 382.8 [mm] in 1995/ 1996.

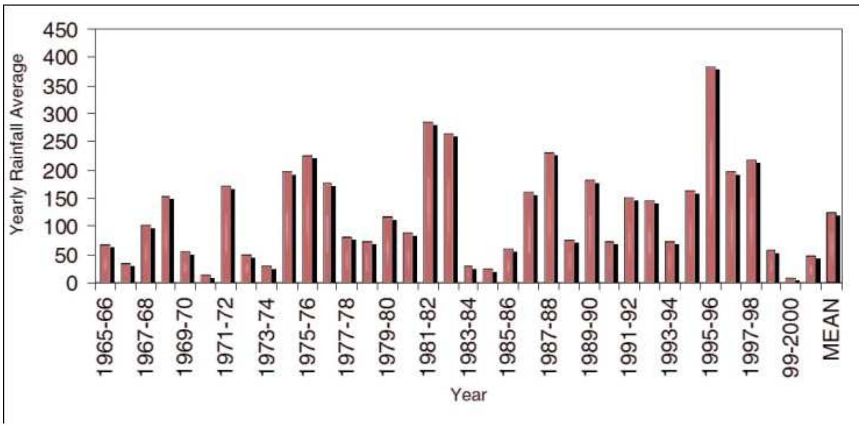


Figure 5 Average annual rainfall in the UAE, 1965- 2001[7]

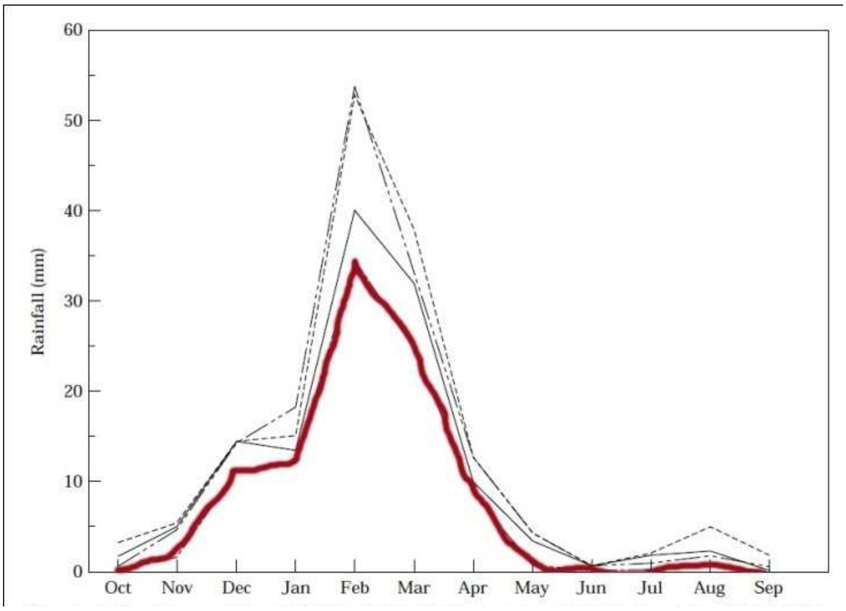


Figure 6 Average monthly rainfall totals for the four geomorphological regions of the UAE (1967- 1992). In red the west coast[8]

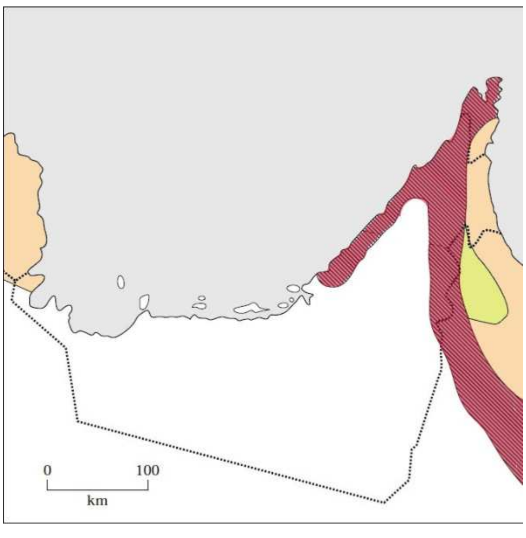


Figure 7 Bioclimatic zone of the UAE. Orange: sub humid. Yellow: semi-arid. Red: arid. White: hyper- arid[8]

1.1.2 Flora and Fauna

The northern area of the UAE is part of the eco-region of the *"Gulf of Oman desert and semi desert area",* for the WWF classification, and as we can see in the image below.

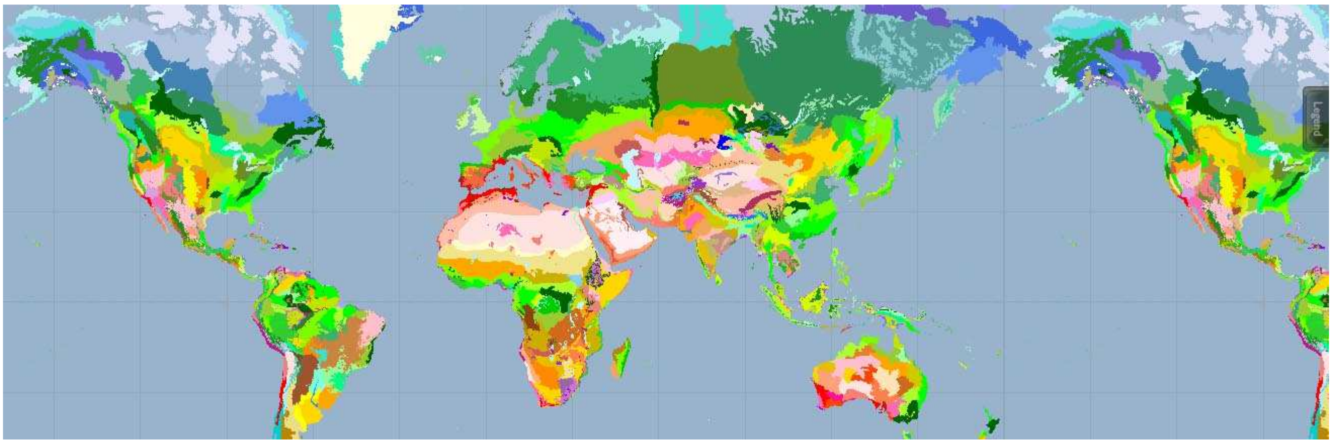


Figure 8 Ecoregion WWF [9]

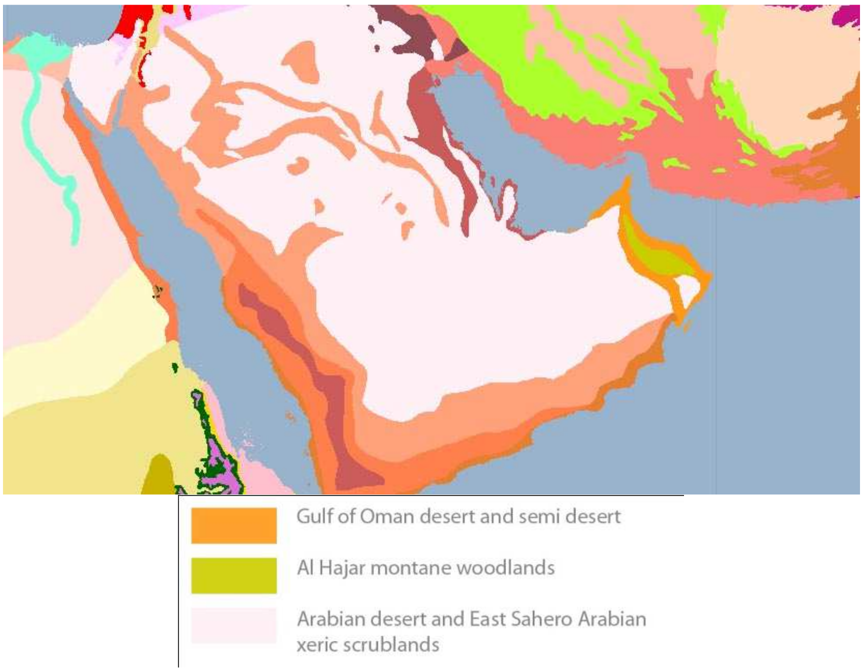


Figure 9 Ecoregion WWF. Arabian peninsula[9]

The main part of the territory is desert, but there are some oasis, characterized by date palms, acacia and eucalyptus tree. The desert vegetation consists largely of shrubs, bushes and trees, like Ghaf Trees (Prosopis cineraria), Acacias (Acacia albida) and the Desert thorns (Lycium L.). But the desert is also a home to many plants such as Desert ephemerals, Hyacinths and Thumbs, which flourish mainly during the winter and spring season giving the desert an amazing look.

During the winter, after rains, a lot of plants emerge from the sand, as Senna plants, Desert Sqashes, Eyelash plants and Blepharis. These plants have developed ways to survive in the arid conditions: some of them store the water in succulent leaves, or absorb water from the humid air; a few have seeds that can survive long dry periods, while others release seeds only after the rainfall.[10]. The fauna in plain was destructed by hunting, but from the conservation program in 1970, some species were protected, as Arabian Oryx, leopard. Fish, near the coast, consist in mackerel, perch, tuna, sharks and whales.

1.1.3 Sandstorms and Dust storms

In desert regions sand storms and dust storms are a natural force that affects climate conditions. Every year, sandstorms move hundreds of millions of tons of sand, creating dunes. Dunes are "*moundhill of sand, which rises to a single summit. Dunes may exist alone or attached to one another in colonies or dune chains*"[1]. They can reach 300 [m] height, and 16- 24 [km] long.

Dust storms are creating when, after a period of calm weather, comes a strong wind, and the air became full of small particles. On the other side in sandstorms the air is composed, for the first hour of dust and sand, but then just of sand, creating a sand cloud above the ground, of an higher about 2[m] above. The erosion by the flow of sand is greater at ground level and unimportant at 50 [cm].

Is important to notice that there is a difference between the direction of the air and the direction of the sand, because the air can change rapidly its direction, but the sand tends to continue straight on. Deposit can create sand shadows behind the obstacle, or sand drifts between obstacles. As we can see in the picture below, the sand is deviated by the obstacle, creating an elliptic shadow behind it.

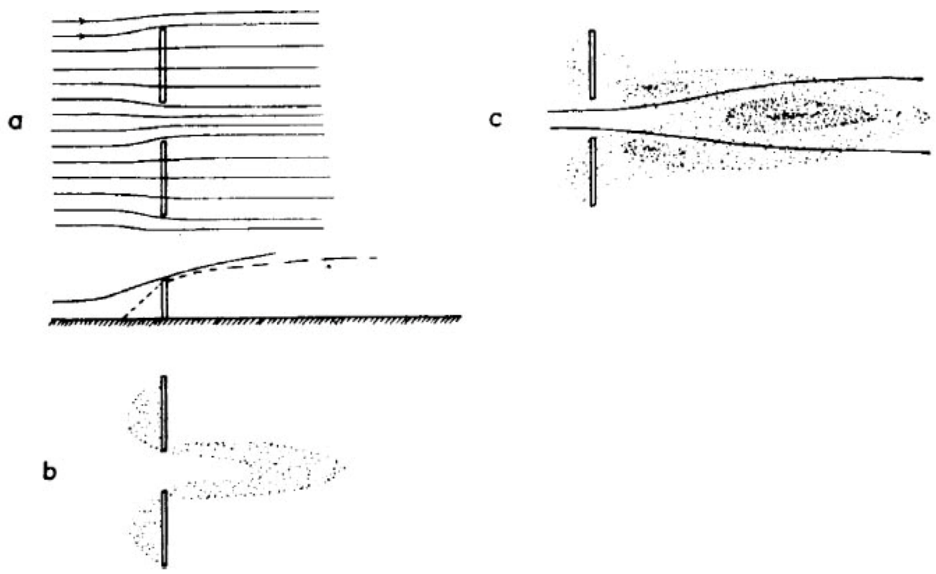


Figure 10 A sand drift formed behind a gap[9]

There are four kinds of dunes, as we can see in the image below. The Barchans dunes are crescent-shaped dunes that are concave downwind; they form in places where there is limited sand and a constant wind direction. The Parabolic dune is a crescent shaped dune that is concave upwind and forms in areas in which there is some vegetation and a good supply of sand. The Longitudinal dune is a linear dune that is parallel to the direction of the wind and forms in areas in which the wind direction is not constant and the supply of sand is moderate to good. It can be kilometres in length; they are formed in areas in which there is a desert pavement and variable winds. Transverse dunes are linear dunes that are perpendicular to the direction of the wind; they form in areas with abundant sand and little vegetation.[12]

[1]11. Alghamdi, A.A.A. and M. Akyurt (2001) *On sandstorms and energy recovery from sandstorms*. Energy Conversion & Management **42**, 1143- 1156.

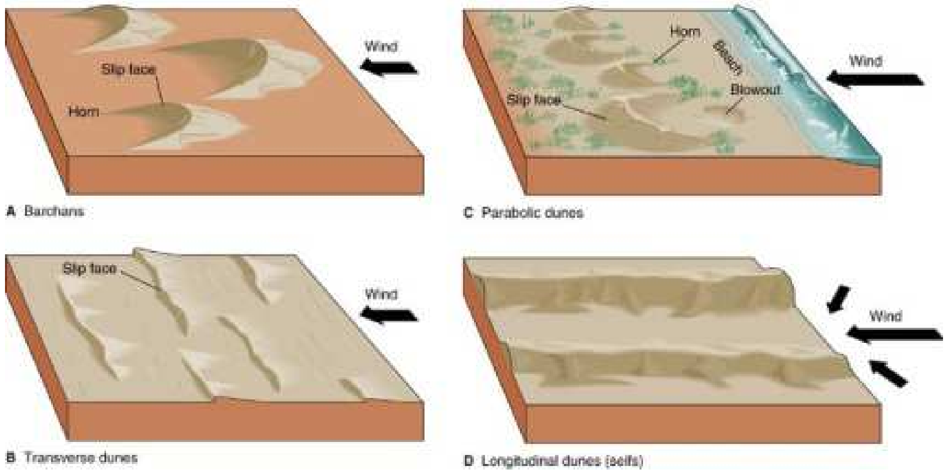


Figure 11 Dunes origins[10]

Another way to classify the dunes is connected with their displacement: there are three kinds of dunes: the immobile dune stabilized by vegetation; the partly active dune one partly covered with vegetation; and the fully active one that is wind-driven.

To complete the description of the dunes, we can say that the dunes are composed of two sides, the longer one, on the windward side, and the shorter slip face in the lee of the wind; the valley between dunes is called a slack. The movement of the wind, with the sand, can be divided in four levels:

- The creep, where the sand erode the ground.
- The saltation, where the sand moves with a circular path, falling with a constant angle of 15°.
- The suspension.
- The wind current.

As we can see from the topographic plan of the site of the Masterplan, there are two kinds of dunes: the dunes transversal to the wind from the North- West, and the dunes transversal to the wind from the South. The hypothesis is confirmed by the article "*Desert loess in Ras Al Khaimah, United Arab Emirates*" [6], where the sand movement is connected with the wind regime, as "*The wind regime is complex. Just under 52%of sand-moving winds blow from the West and North-West, but just under 28% blow from the South-East.".*

The sand displacement is connected to the wind speed: the speed augment exponentially from the wind speed of 6 [m/s]. In the case of the area of the Masterplan, we can say that the wind from South, in August, hasn't got a high speed, and as we can see in the graph below: the sand movement is limited, because of a wind speed of average 4.57 [m/s]. We have reduced the analysis to the month of August, because is the only month with a high presence of the South wind.

Figure 12 Dunes in the Masterplan. Perpendicular to the North- West wind (orange), and to the South wind (yellow).

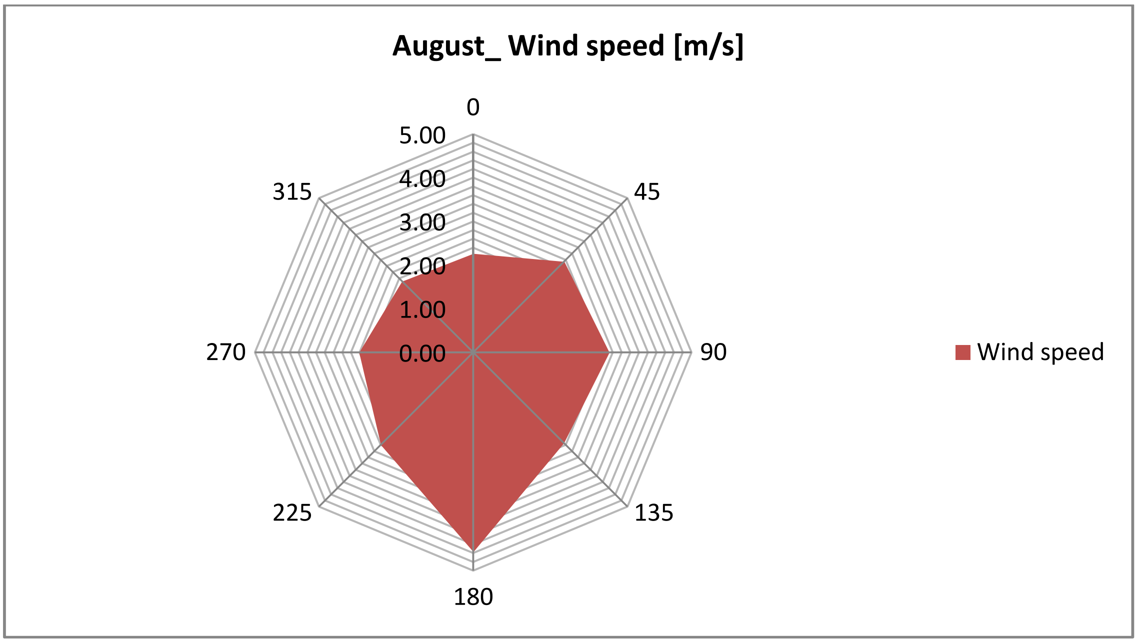


Figure 13 August. Wind speed [m/s]

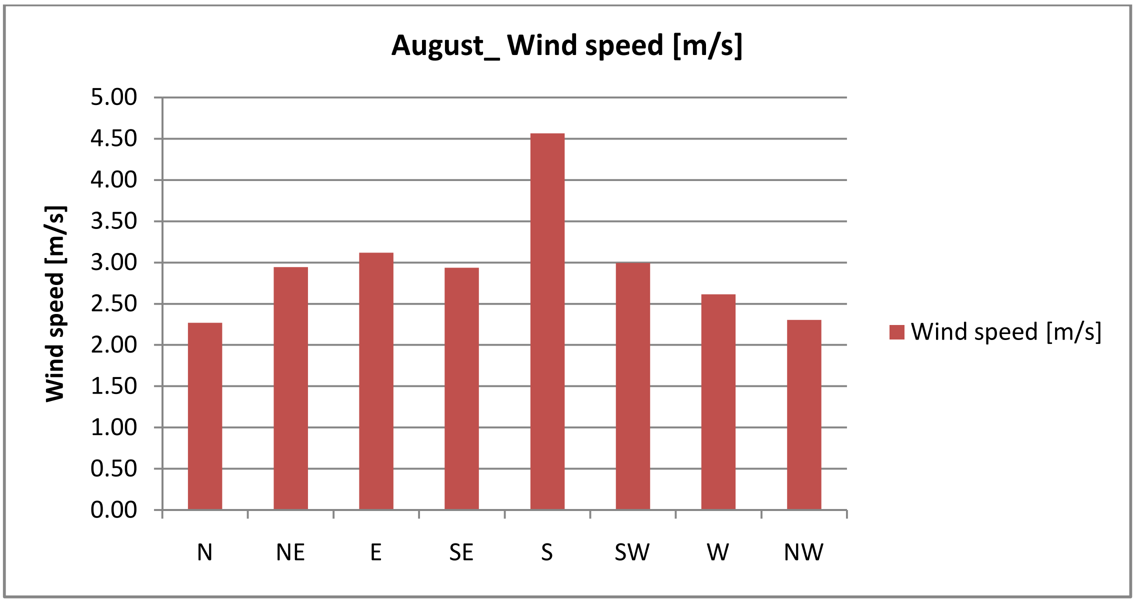


Figure 14 August. Wind speed [m/s]

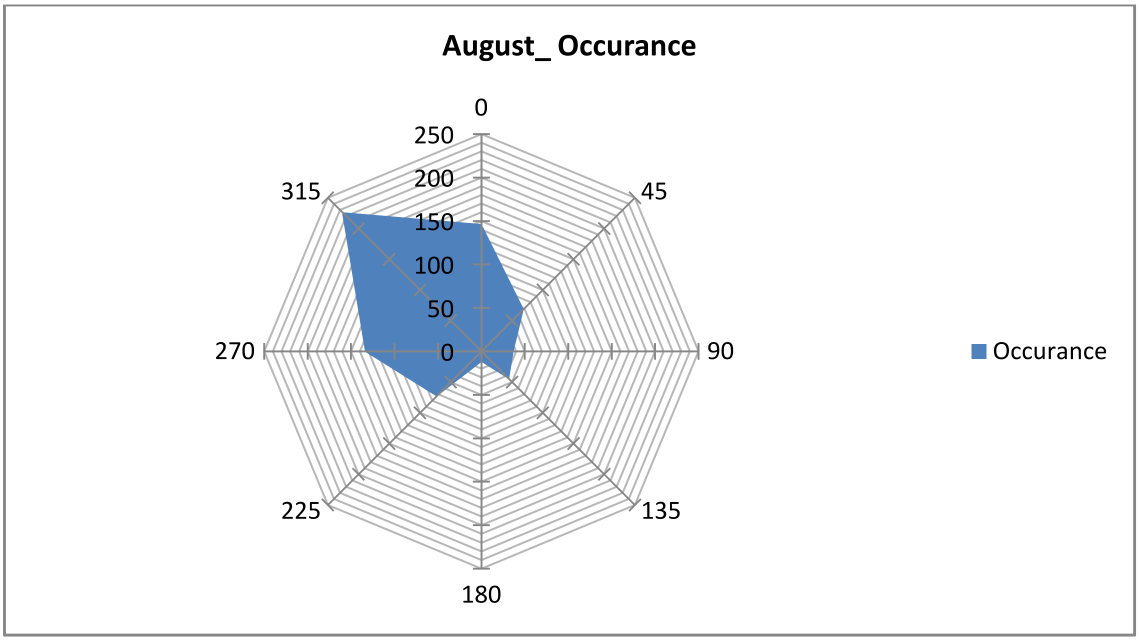


Figure 15 August. Occurance

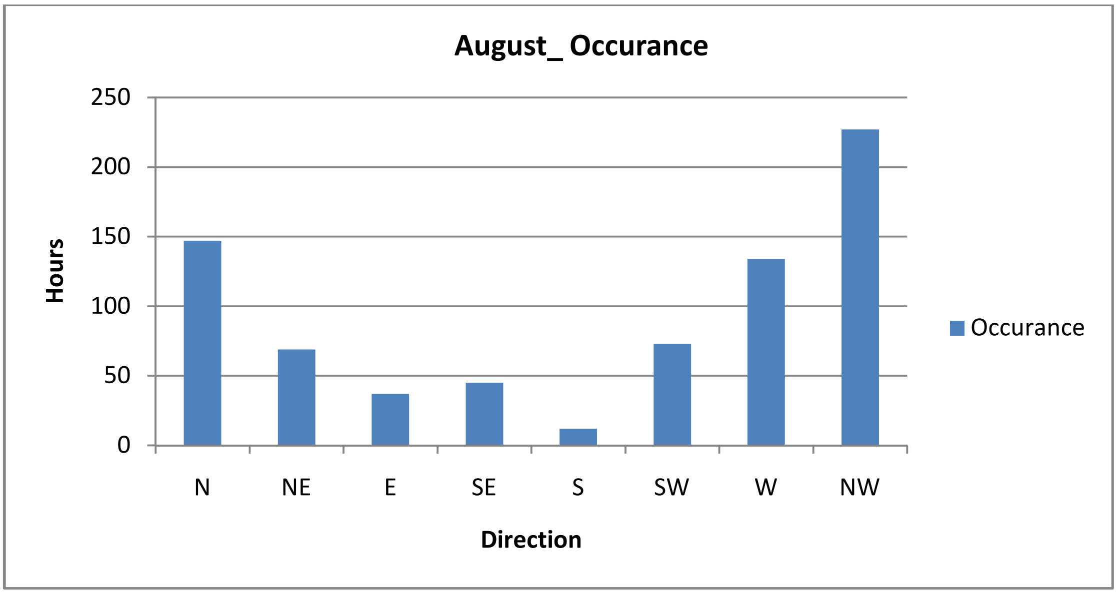


Figure 16 August. Occurance

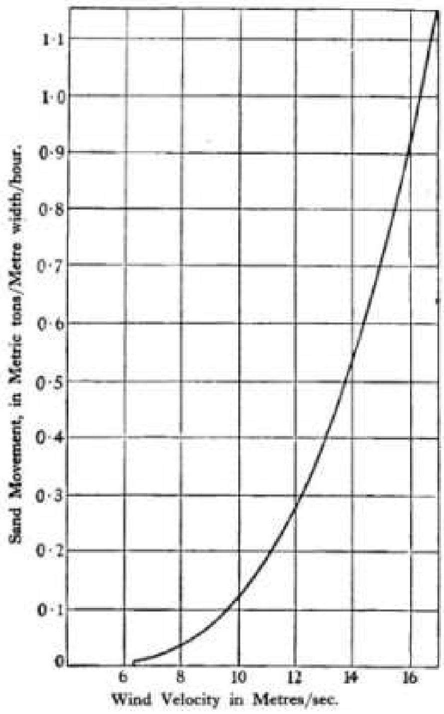


Figure 17 Wind velocity compared with the sand movement[11]

1.1.4 WATER RESOURCES

The main problem in United Arab Emirates is the water supply. Indeed the Arab peninsula is characterized by an arid climate; furthermore the population had increased during the last decade, creating a higher water demand, that can't be satisfied by natural water resource. During the past, the groundwater was the only source, but with the actual increasing water use, for agriculture, people needs etc. conventional is not enough, as we can see in the table below.

Year	Domestic	Agriculture	Industrial
1985	229[b]	–	–
1990	513[a]	950[a]	27[a]
1995	540[c]	1,300[c]	95[c]
2000	555[c]	1,400[a]	100[c]
2005	570[c]	–	105[c]
2010	911[c]	1,545[c]	110[c]
2025	1,100[a]	2,050[a]	115[c]

[a] Uitto and Schneider 1997
[b] Al-Mugrin 2000
[c] FAO 2000

Figure 18 Past and projected water demand [million m³] in the United Arab Emirates [5]

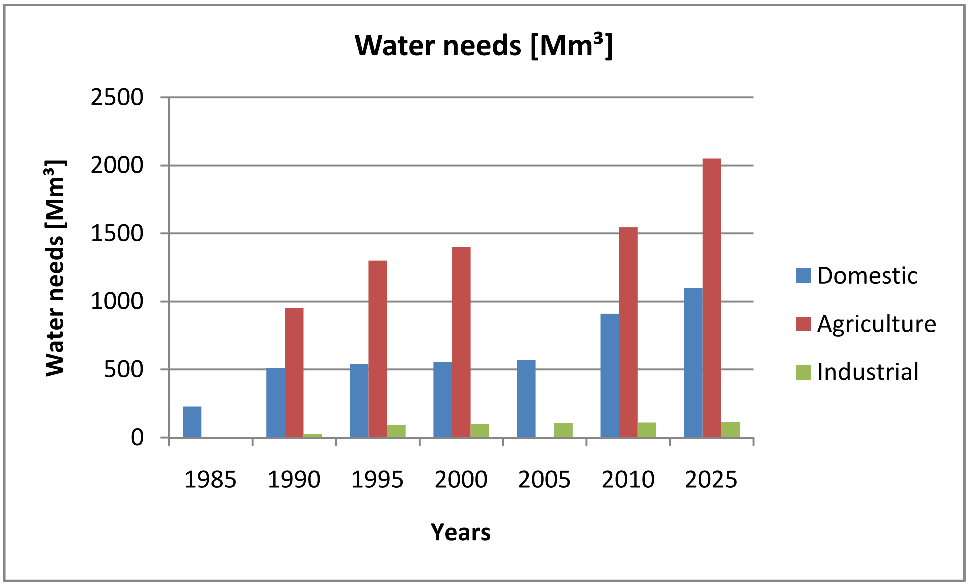


Figure 19 Water needs [Mm³]

The main water resource can be divided in: conventional (surface and groundwater) and non-conventional (desalinated and recycled water).

CONVENTIONAL

Surface water can be **seasonal floods** from Oman's mountains. Another way is the **springs**, characterized by high temperature, and therapeutic value, as Khatt in Ras al Khaimah.

Another way is the **falaja**, with a use of 20 [Mm^3/y], a man- made channel that intercepts the groundwater flow. Actually there are 150 falaja in UAE, but just 50 are still active.

Groundwater is constituted of renewable, shallow resources and non-renewable resource as deep aquifer. As we can see in the Figure below, there are five kinds of aquifers: limestone aquifer, Ophiolite aquifer, eastern and western gravel aquifer, sand dune aquifer and the coastal sabkhas.Sand dune aquifer are an important source of water, and as can be noticed in the picture below, in the area near the city of Ras Al Khaimah water can be find at 10 meters above the sea level.

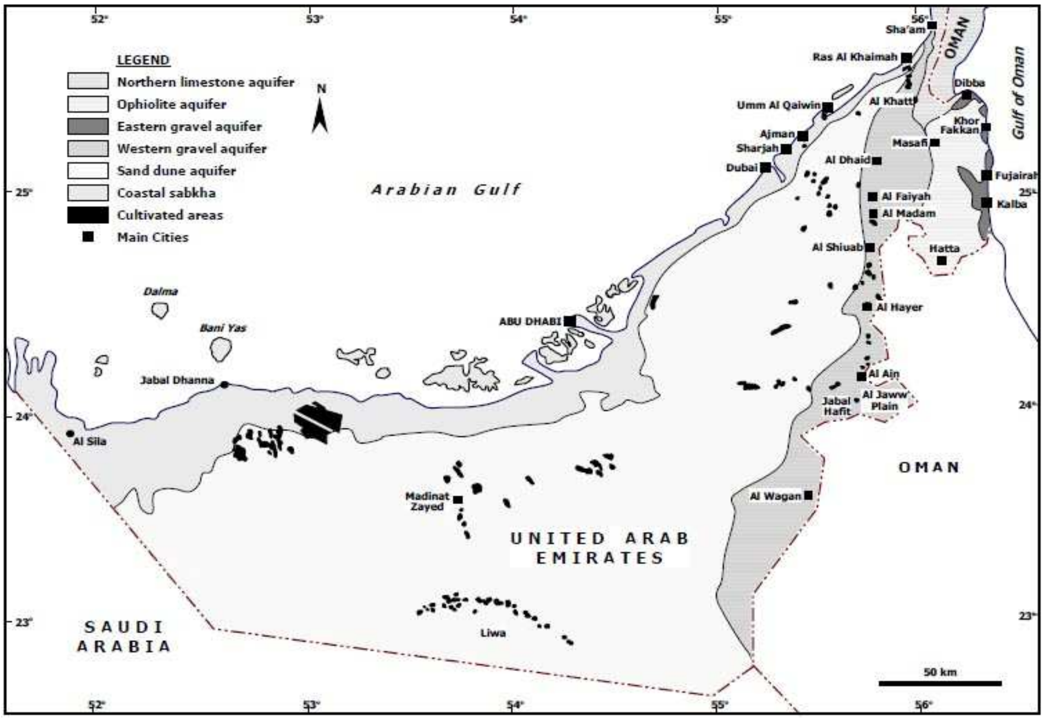


Figure 20 The main aquifers in the UAE[13]

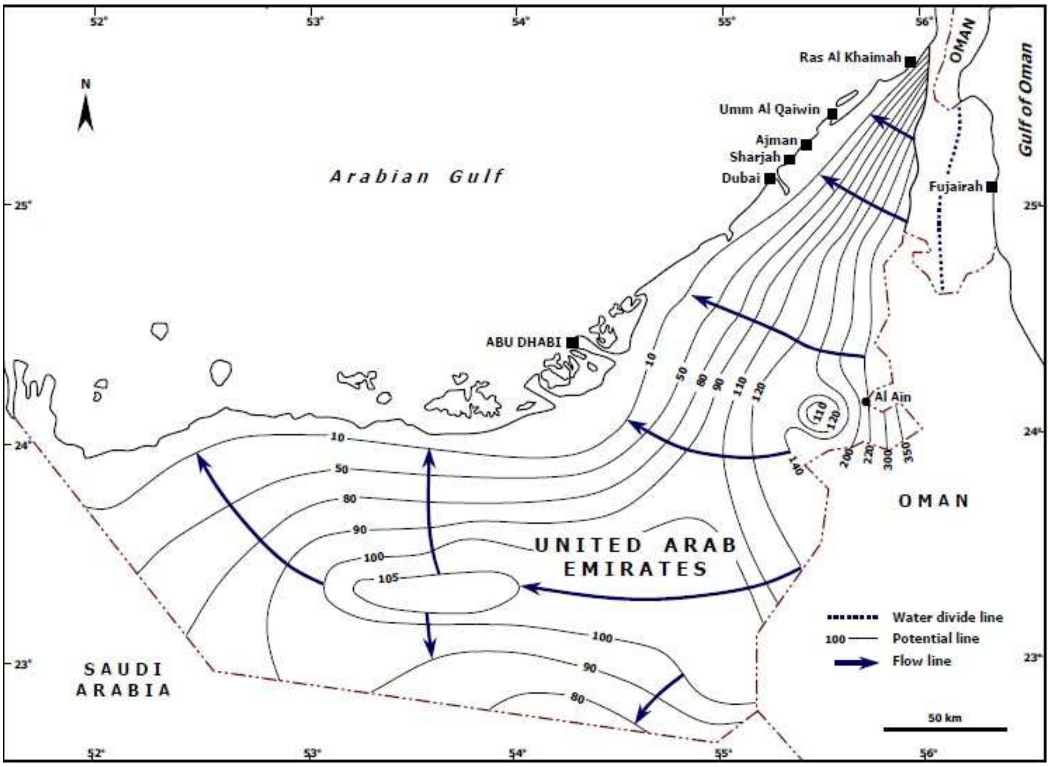


Figure 21Hydraulic head map, in meters above sea level, for the sand and gravel aquifer, 1995, United Arab Emirates (modified from US Geological Survey-Groundwater Research Project, 1996; Hutchinson, 1996).[13]

NON CONVENTIONAL

Desalinization water is one of the most important water resources in UAE: with a use of 694 [Mm^3/y];but the utilization of the sea water is creating great problems in the local flora and fauna, because of the augmenting of salinization of the sea. Reading the article *"The Golf, a young sea in decline"*[14], we can say that the impact of desalinisation is higher: the water that is put back in the sea, is brine, hotter that the natural water, and contains biocide. The last water resource comes from the recycling, with a use of 150 [Mm³/y]: machine can treat the waste water, and the water produced is used for garden irrigation. There are four sewage treatment plants in the United Arab Emirates, located in Abu Dhabi, Dubai, Al Ain, and Al Sharjah.

Resource	Existing	Potential	In use	Source
Conventional Resources[Mm³/y]				
Seasonal floods	125	125	125	Al Asam, 1996
Perennial springs	3	6	3	Rizk and El-Etr, 1997
Seasonal springs	22	40	---	Ministry of Agriculture and Fisheries, 1993
Falajes	20	40	20	Rizk, 1998
Aquifer recharge	120	120	120	Khalifa, 1995
Groundwater	---	---	880	Ministry of Agriculture and Fisheries, 1993
Non-ConventionalResources[Mm³/y],				
Desalinated water	----	----	694	Ministry of Electricity and Water, 1998
Reclaimed water	150	----	150	Hamouda, 1995

Table 3Summary of conventional and non-conventional water resources in the United Arab Emirates [13]

The high use of water in UAE create a lot of problem, for example the depletion of groundwater resource: the authors Z. S. Rizk and A. S. Alsharhan estimated that the annual recharge for groundwater in the UAE is 21.8 to 32.7 [Mm³/y], while groundwater abstraction is 880 [Mm³/y].The water demand had increased during the last 20 years, mainly for agriculture, with an increase of 47 [%], from 1999 to 2000. In conclusion we can say that's important to reduce the water demand by taking actions as minimizing the water use for agricultural practices, controlling the leakage in water distribution system, reducing the personnel consumption and raising the awareness on the importance of water.[7]

1.1.5 Oasis

Oasis is living space, characterized by vegetation and water, in the middle of desert. Normally they can exist thanks to groundwater, created by bedrock that collects rain water. The water is near the surface and can be collected by people. The main oasis in Rub Al Khali Desert is Liwa oasis, of proximally 100 [km] long. This oasis has a semi-circular form, and around it small cities have been developed. Another oasis is Al Ain, at 60 kilometres east of the Abu Dhabi capital; his name means "spring", in Arabian. At 25 [km] South of Ras Al Khaimah there is Khatt Springs, a famous oasis with three hot springs of sulphuric water that comes out from the base of the mountains, from a depth of around 28 [m], and a water temperature of 40 [^{o}C].

Figure 22 Liwa Oasis. Google Earth

Figure 23 Al Ain Oasis. Source Wikipedia

1.2 THE ARAB CITY

"Urban research on pre-modern towns depicted the socio- spatial and material fragmentation of urban patterns in small and distinct quarters as one of the most typical characteristics of Arab cities."[15]

The Arab city is characterised by the fragmentation; the quarters are an extension of the private space, as a *"material expression of the retreat from the public sphere, that is, for the intimacy and seclusion of family life"[15]*and every quarter have a high degree of autonomy, and self- governed themselves.

1.2.1 BIOCLIMATIC PATTERN

Many features coming from the bioclimatic aspects, can explain the urban landscape in Arabia, from the past to the present.

First of all the necessity of finding **water.** In Arab city there are many examples of this, as the *foggaras,* an underground water network to conduce water over long distances, thanks to the gravity force, for irrigation and human use. Obviously there are other ways to move the water, as hydraulic force or hydraulic pumps. Water is a need, but also a way to celebrate richness, for examples with beautiful gardens.

Protection and exploitation of **natural elements,** as water, sun, wind, land. For example in the cities near the sea, the buildings are turn to the sea, for benefits of sea breeze and shade. In the other side the city look like closed in the side of the desert, protecting buildings from the sand storm.

Maximization of interior volume of a building, and **minimization of the exterior surfaces**. As it happens in urban space, with covered street, providing shelter, shadow and ventilation. As it happens in houses, where the inhabitable spaces are distributed around a patio, which provides natural illumination, ventilation, thermal regulation. During the summer provides shades; it absorb the coolness of the night, creating an air current during the morning, by the warm air indoors. The use of **Masherabiya**, can regulate the cross flow of air and luminosity. But also the use of **material,** as terracotta brick, wood and lime, ensure a good isolation of the building.

1.2.2 HUMAN ASPECTS

Many aspects of human behaviour can explain the architecture of a city. In the case of Arab society there are many viewpoints that can be usefully to understand their way to consider the space, and how they live in it. In this context it can be interesting to read this sentence by Mohamed Boughali *"Man only builds upon oppositions and the form that he creates exist only in their opposition to their context, the exterior as opposed to the interior, fullness as opposed to emptiness".*

Man built to find something different from the surrounding, and in the case of Arabian, there are many features that can explain their way. First of all the need of privacy, realized by the **enclosure** of houses.

Another element is the difference between **man and women**. Women are like their house, as symbol of enclosure, privacy. In the other side men are the pathways, moving and creating the city, as a flux, as a movement. This dualism is represented in the urban form: the centre is design with the predominance of the man's network, while the periphery, residential, is created by the women's attitude, as closeness and privacy.

Houses in Arabian state sare characterized by family dynasty, indeed district originate from the original family house, creating a hierarchic structure. The Arabic city can be imagined as a structure of successive enclosing entities, from women- private- space to the main men- network.

Interaction between the physical features in the environment, and the sociable behaviour of people.

The last element concern the difference between European city and Arabian city: from the first European colonisation started the “destruction” of the ancient Medina. Indeed the mean feature that characterizes the European city is the street- communication form: the square and the buildings form come from the street network. Indeed Arabian city starts from the courtyard house, from the relationship between families. As we can see in many northern Africa cities, there is a dualism between the ancient Medina, symbol of closeness and family relationship, and the new city, with large streets cutting the ancient urban tissue.

1.2.3 ARCHITECTURE

The main features that characterize the pre-industrial Middle Eastern city are: the citadel, the palace, the mosque-bazaar complex and courtyard houses.

In UAE, before the petrol- development, there were some town near the coast, as Ras Al Khaimah and Fujairah, in the other side in the desert lived just community of Bedouins; cities were characterized by defence systems, as forts and towers and they were generally constructed of sun dried mud brick, except for Ras al Khaimah where, thanks to the Hajar mountains, the major part of buildings were built with rock.

1.2.4 CASE STUDIES

In this paragraph we’d like to analyse, by Figures, the main patterns of the Arab city, with three examples of cities in south-western Saudi Arabia. In the Figures below are noticed the main features of an Islamic city, that are: the residential quarters, the mosque, and the watch and defence towers.

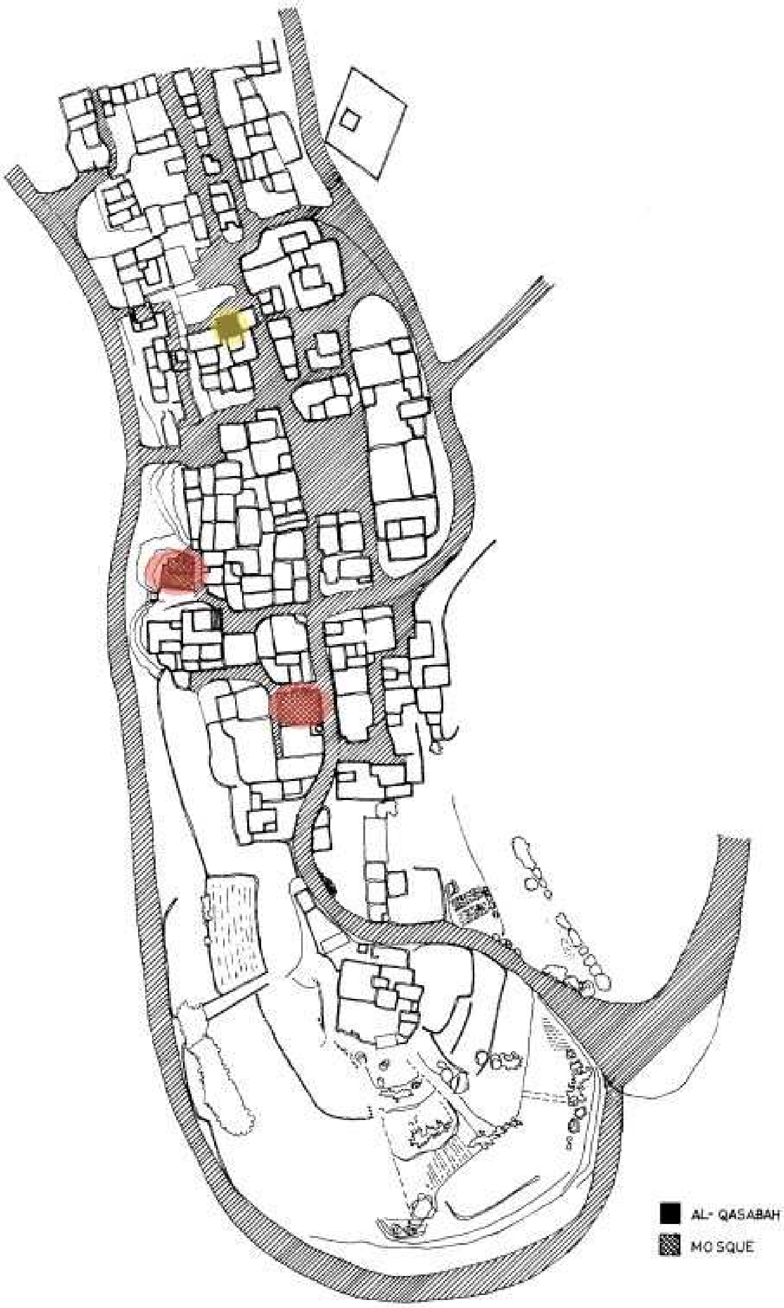


Figure 24 Site plan of Al Kas. Saudi Arabia. In red the mosque, in yellow the defense tower, white the residence.[16]

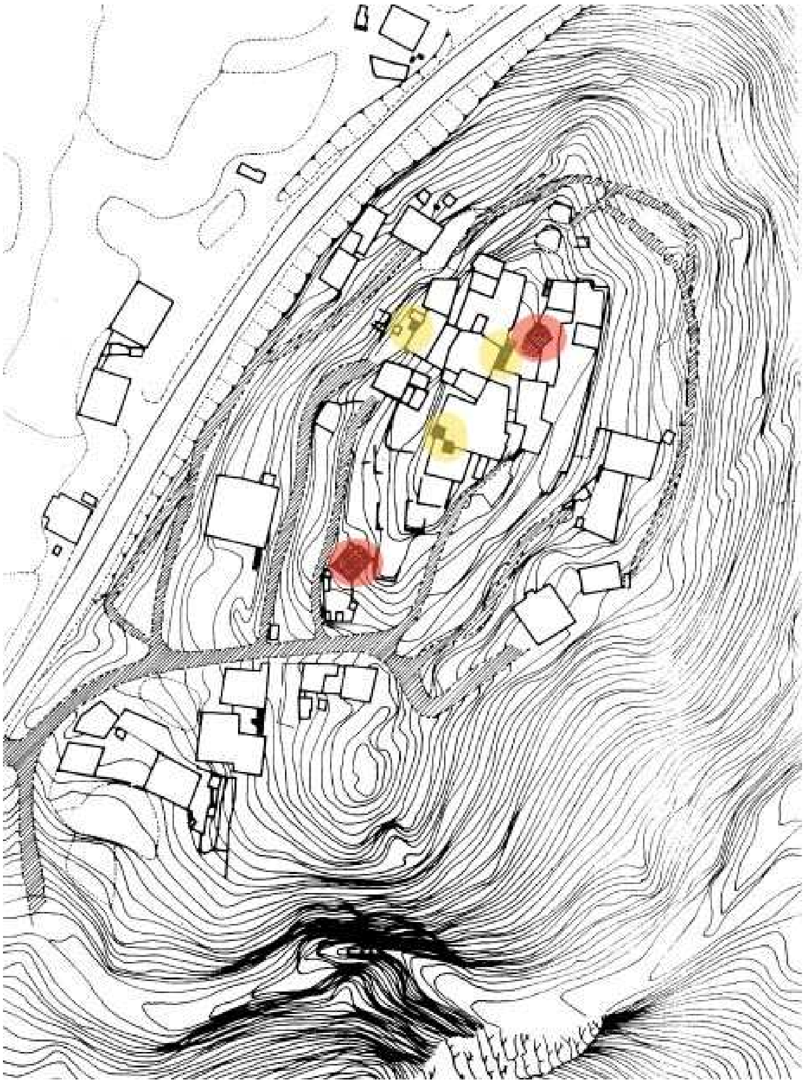


Figure 25 Site plan of Al- Malad, Saudi Arabia. In red the mosque, in yellow the defense tower, white the residence. [16]

Figure 26 Site plan of Al- Alkhalaf. Saudi Arabia. In red the mosque, in yellow the defense tower, black the residence [16]

1.3 Urban development

1.3.1People fluxes

A city in no longer conceived as the lifeless inert structure that supports life, as does the sum of buildings, technologies and district isolated elements; on the contrary, it is an evolutionary organism that constantly interacts with people; it is customized by people and customizes human behaviours.[17]

A city is not a simple composition of different elements; it must be seen as a complex interaction between the elements, creating a unity. People moved around the cities, creating an energy flux that creates itself the city. Projecting a city, a quarter, can't be seen as a simple analyse of different elements, it is important to create a network, as says Himmelb(l)au:

"*The development of a city is nothing else but the three dimensional system of our brain. How we think can be compared with the development of even a mega-city. That means that if all the synapses are connected, every district is connected with every district, every person is connected with every person. That's not the way our brain works. On the other hand, it doesn't work like high-rack system, like a diamond - it's a system in between, it's perfect to connect with the city planning issue.*"[2]

We need to think at a city as collective properties, not just as a sum of individuals. And this is the research (made at MIT SENSEable City Laboratory in Cambridge, MA, in collaboration with the Department of Chemical and Bio systems Science of the University Of Siena, Italy), studying people movements, around the city, by analysing the location data from personal mobile device in Milan, and from the GPS position in Amsterdam.

In the Figure below it's clear the way of people movements around the city of Milan, in an area of 20*20 [Km²], from the periphery to the centre. Indeed a lot of people live in the periphery of Milan, and work in the city centre.

[2]Interview, Wolf D. Prix, Coop Himmelb(l)au. www.floornature.com

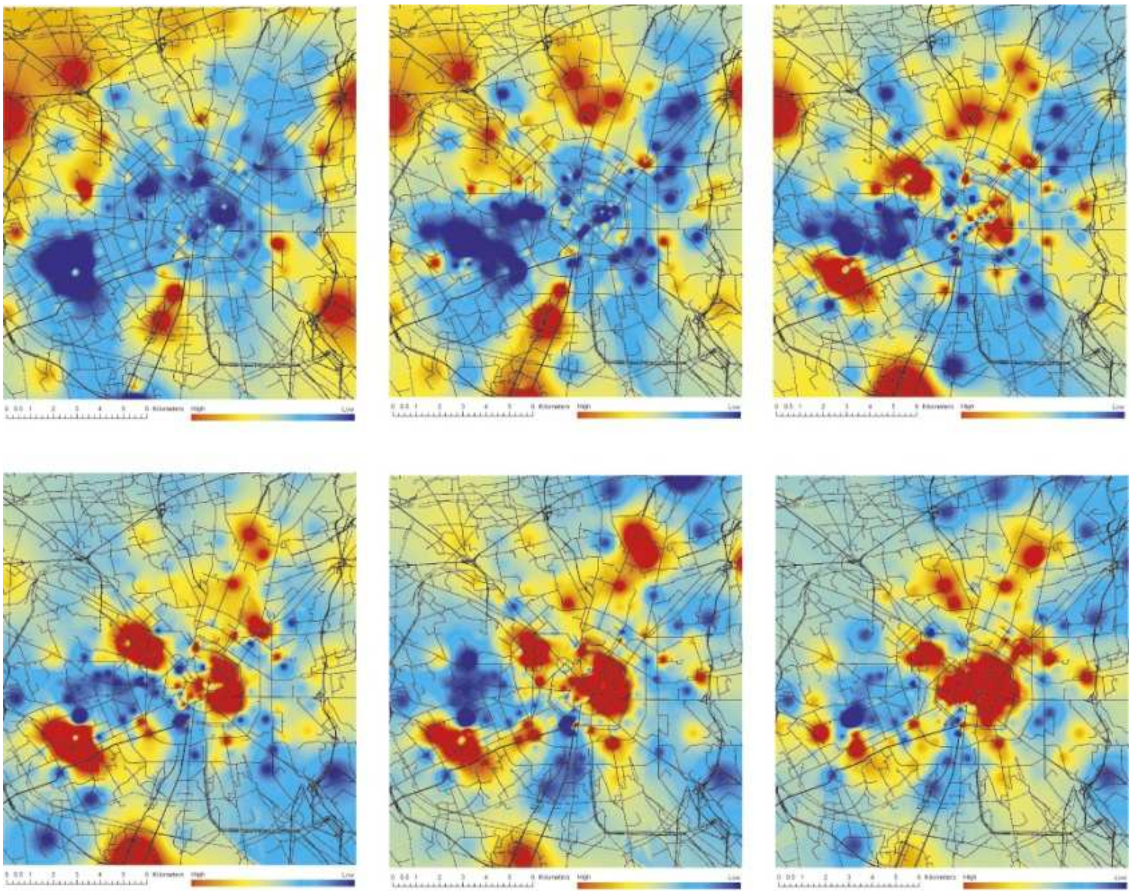


Figure 27Maps showing areas with different cell phone call density in the metropolitan region of Milan, from 9.00 am to 1 pm[18]

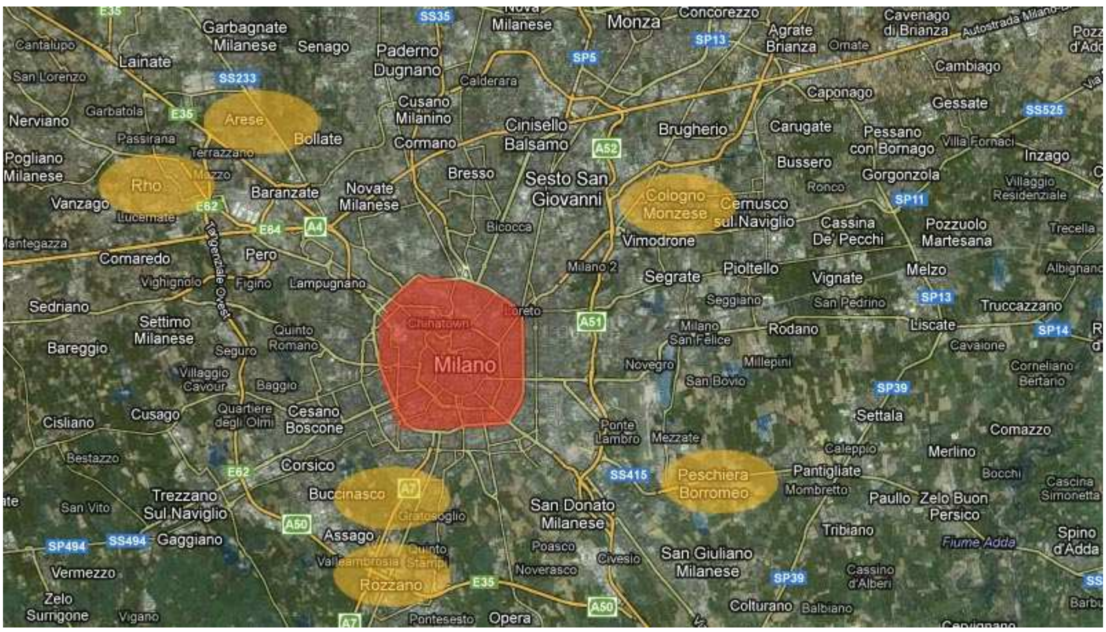


Figure 28 Milan. Google Earth. In red Milan, in yellow the external cities

As we can see in the map of Milan taken from Google Earth, people leave in the main external cities around Milan, as Rho, Arese, Cologno Monzese, Buccinasco, Rozzano and Peschiera Borromeo. These cities had a great demographic grow from 1980, when the doubled the population thanks to their proximity to Milan.

Another interesting project is "The Amsterdam Real Time project" that reveals that every citizen of Amsterdam, and generally of every city, has a mental map of the city, that conduce himself to different ways, in different time and dates. This project was developed in two months, in 2002, and every Amsterdam's residents were equipped with a GPS. The dates were organized, creating a city map, from people fluxes.

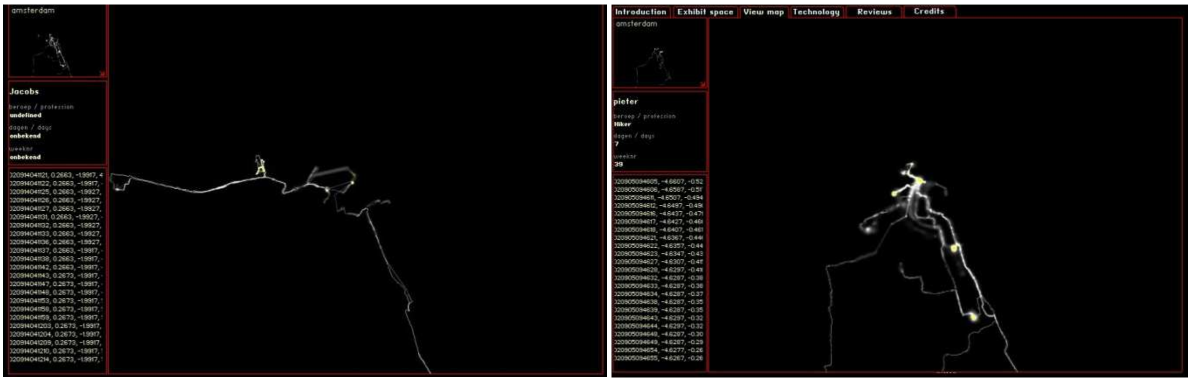


Figure 29Peter's and Jacob's map[19]

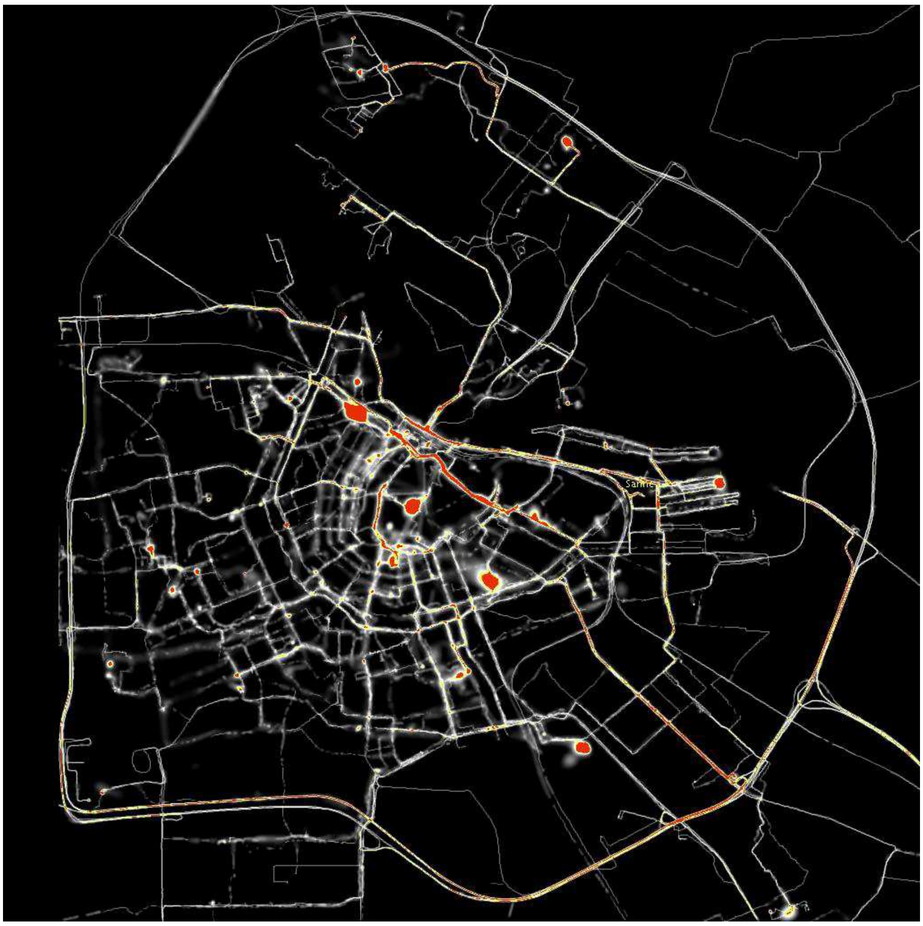


Figure 30 Amsterdam real time[19]

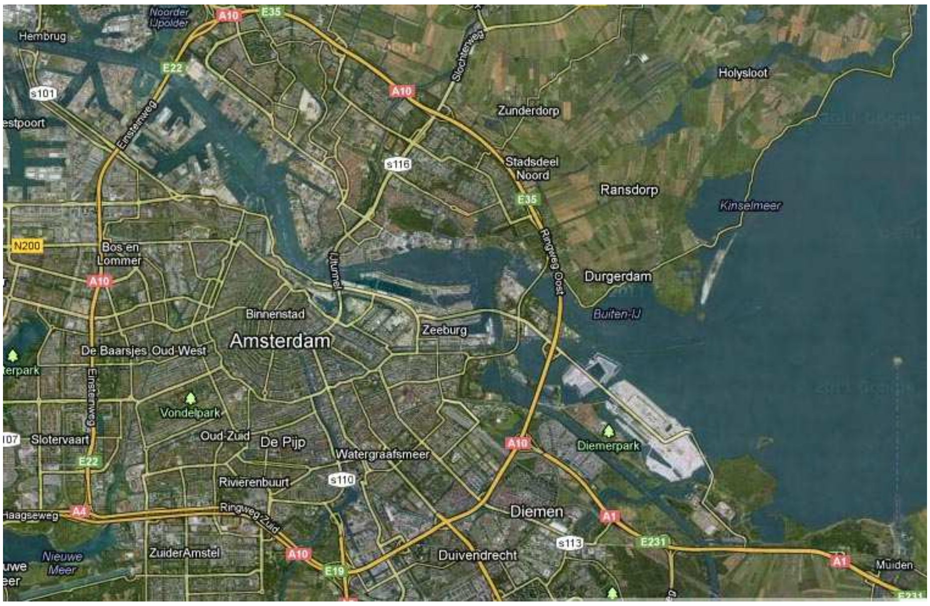


Figure 31 Amsterdam Google Earth

The study evidenced the necessity of a new approach to urban development, not only from the morphology, but something connected with fluxes, the dynamic movement of people. As for Amsterdam the new map, created by people's movement, reveal the use of the external high street, the A10, as the best way to displace. And then that the people are mostly moving near the city centre, in three focal point.

1.3.2 Urban design guideline

Hot dry climate have not suitable characters for living, this is why is important to define some guideline, that can improve the condition living, as clarify by Dr Baruch Givoni[3]. In hot dry climate Dr Givoni, define two main directions lines: first of all to design a building minimizing energy need for archive the comfort, secondly improving existent energy sources, as solar energy for heating, and natural ventilation for cooling.

The guideline are:

- Choosing locations with the most favourable climate.
- Minimizing the urban temperature.
- Improving urban ventilation, by building design.
- Providing shades during the warmer days, in streets and open spaces.
- Minimizing the dust level.
- Minimizing glare in street and open space.
- Providing protections from sandstorms.

Another element to analyse is the people stress, caused by the climate. In this case we can define three kind of stress:

- Heat stress, caused by solar radiation and high air temperature.
- High glare, from direct and indirect sunlight.
- Sandstorm or high intensity wind.

[3] Baruch Givoni is Israeli Architect, one of the most recognize specialists in bio-climatic architecture.

To ameliorate these conditions, is important to guarantee shade and ventilation in streets and social places, by buildings position and vegetation.

Defining the position of building, can be interesting to know that's it's better to guarantee opening windows, for glare and ventilation, in North- South axes, than in East- West axes. Starting from this concept, we can agree in saying that's better to have a small distance, relative to his high, between buildings in the East- West axes, decreasing the solar radiation and increasing shades.

The main objective is to create a city, where the daytime temperature is lower, than in rural areas, this can be achieved by urban density, buildings height and reducing the albedo. In an urban space, the albedo can be absorbed by the building's white roof, minimizing the radiation component in streets and opens spaces. Also the tree can help in reducing the temperature, because of leave's attitude of producing humidity, which in dry climate can ameliorate the comfort.

Wind in dry region is higher during the day and lower during the evening and night. For this reason it can be difficult to assure the correct ventilation of buildings. The main elements to create good ventilation are:

- Creating family units from the top to the bottom of buildings: wind is stronger at roof level, and lower at street level. To assure good ventilation, is important that every unit have a roof.
- Using wind catcher or wind tower, to canalize the air flow from the top to the bottom of the house.
- The buildings most assure each other a reasonable distance, to permit a good ventilation.
- Any building must be positioned perpendicular to the wind direction, creating wall- isolation to the flow.

To reduce the solar gain, but to guarantee correct ventilation, is important to distinguish from North- South axes and East- West axes on building position. Indeed building can have a small distance in East- West axe, in a proportion of 1:5 [distance- height], instead they need a proportion of 2:1 [distance- height] in North- South axe.

There is a contrast for the definition of streets: in one way, to guarantee the minimum solar radiation, an East- West orientation in better than a North- South orientation, also with wide street. But the North- South orientation reduces the wind penetration in the urban area, while the wind comes from the West direction.

1.3.3 Green open areas

How can the green space influence the urban climatology? Urban park influence people behaviours, people's feelings and perception of the city, but also the urban climatology.

Parks effect physical environments, social behaviours and ecological functions:

- Reducing psychologically, the noise levels, originated from traffic, social activities.
- Reducing air pollution, from transports, industry, house's heating and cooling.
- Creating a place for social activities.
- Developing social aesthetic and perception of the city.
- Territorial separations, as quarters and functions.
- Incrementing sustainable mobility.
- Protecting flora and fauna.
- Flood control and retention of rain water.
- Creating shades and protecting from wind and hot temperatures.

Parks also influence the urban climate, because:

- Plats have a low heat capacity and thermal conductivities.

- Leaves absorb the solar radiation, so the reflected radiation is small, low albedo.
- Higher evaporation rate, because the water is absorbed by the earth and leaves.
- Plants and leaves filter pollution and dust from the air.
- Plants reduce the wind speed and fluctuation near the ground.

1.3.4 CASE STUDIES

We'd like to define some examples of urban planning in hot dry climates, from history to actual models, to evidence the main concrete aspects in projections, and the application of Givoni's criteria, as the case study of Kashan. In the other side there are examples of urban project, which comes from the foreign tradition, as the case of Lebanon and Riyadh, with any interest in urban climatology.

KASHAN, IRAN

The city of Kashan is situated in desert region of Iran, with pre- historical origins. The authors of the article "*Energy efficient architectural design strategies in hot dry area of Iran: Kashan*."[20], analyse the city from macro to micro scale factors and the design strategies for the climate.

MACRO CLIMATE DESIGN STRATEGIES

- High external walls, to guarantee shadows to street walkers, and privacy to inhabitants;
- External wall to protect the city, from enemies attach, and sand storm;
- Streets are narrow, and facing the direction of the wind; their irregularity decrease the wind force.

Figure 32The city of Kashan (Iran) [21]

MEDIUMCLIMATE DESIGN STRATEGIES

- Courtyard houses are the main typologies adopted. First of all in courtyard there are normally a pool and some trees that augment humidity and cooling of the air. Secondly the courtyard is, for the main part of the day, shaded, creating a comforting space. Third courtyards create convective natural ventilation around the building.
- Minimization of the external surface of building, protecting from solar radiation.

- Traditional buildings were made by mud and it's derivate, that have a strongly resistance to sun radiation, thanks to his thermal inertia.
- Use of white colours for external surfaces.
- Minimization of the glass surface, and construction of the windows at high level.
- Providing natural ventilation, especially during the evening and the night.

MICROCLIMATE DESIGN STRATEGIES

- Atrium, as a progressive separation between external and internal.
- Wind- catcher, functioning as a chimney, but conducting the air in the underground, in contact with cold water. The flux of ventilation change during the daytime and the night, as we can see in the picture below.

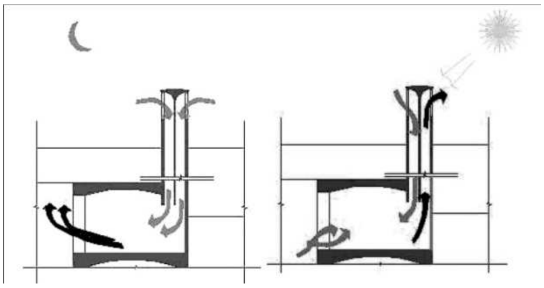


Figure 33Wind catcher function, during day and night[20]

As a resume of the topics, it's interesting to view the table below, where are summarize the main elements for a sustainable architecture in arid climate.

Scale	Past Climate Responsive Design Strategy(s)	Solution(s) for Future Design
Macro	Distance between buildings; Enclosed urban environment; Narrow and irregular streets	Adopting urban environment with natural elements (such as winds' puff) from urban design point of view
Medium	Building form; Building envelope; Self-Efficiency in materials; Optical and thermophysical properties of the building envelope	Developing shady areas in contemporary designs; Developing methods of using domestic materials in constructions
Micro	Atrium and Courtyard; *Eyvan* and *Revak*; Wind catcher (Air trap)	Revival of some architectural elements and developing for current uses; Inspiration from traditional systems to create energy efficient systems based on local possibilities

Table 4Climatic responsive design strategies[20]

GATED HOUSING INSAUDI ARABIA

An interesting analyse was made by George Glasze and Abdallah Alkhayyal, that analysed the urban development of the city of Lebanon and Riyadh, from the past to the present. They put in evidence the gap between the traditional Arab architecture and the European urban structure; indeed they explain the transformation by social- economics development of the society.

With the term "gated housing" the authors define three typologies: first the new villages built by European immigrants, as cultural enclave or foreign people; secondly the extended family compound and finally the government staff housing. The gate that in the past was the symbol of protection for sedentary people from the nomad attack, now assumes a new definition: as something foreign, averse to the Arab reality.

The gate house as a cultural enclave have occidental's usage, and as said a young Lebanese man: *"I almost feel like I were still in Miami here; there is a basket court, there is a pool, there will be a highway to the city…".[15]*

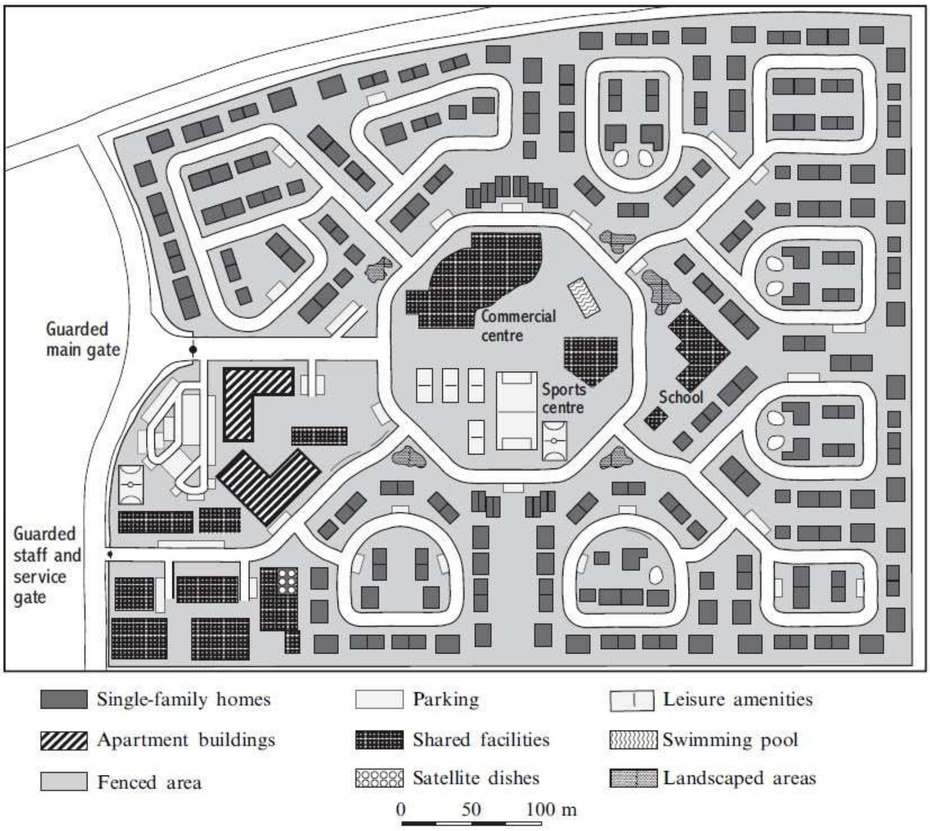


Figure 34 Gate- village in Ar Riyadh

1.4 THE BUILDINGS

1.4.1 MATERIALS

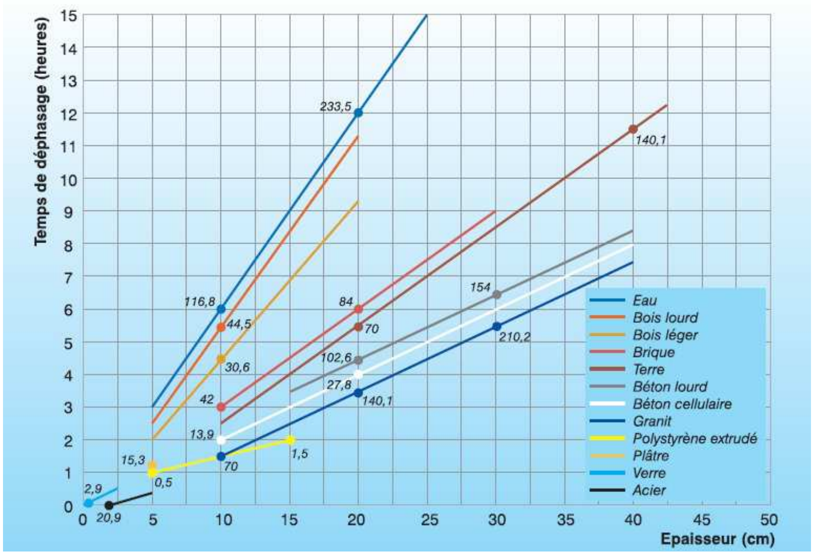


Figure 35Thermal inertia[2]

Givoni in his book "Man, climate and architecture"[22] explains the main elements to project in hot climate, as in Ras al Khaimah. First of all is important to understand the ambient characteristic, as the maximum temperature and the diurnal range. In the other side there are three important elements concerning the building: the orientation and the external colours of the building that are related to the absorbed solar radiation; then the thermal resistance [R] and the heat capacity [Q]. The thermal resistance moderate the heat flow from external to internal surface, and the threshold temperature, to define the necessity of insulation, is 25 [°C].

One of the main parameter to analyse for selecting the material is the **thermal inertia**, that's a scalar quantity, to measure the material's capacity to resist at the temperature's changing. When we have to define a material, is important to understand his properties, to ameliorate the internal comfort of the building. As we can see in the diagrams below, water has the best result of thermal inertia, and glass and steel the worst. The simulation, to obtain these results, was made on a wall, south oriented, in an arid climate.

1.4.2 BUILDING DESIGN

The main topics of the design of buildings in this climate are connected to: building layout, ventilation, windows, external walls and roof, patio and courtyard.

BUILDING'S LAYOUT

- Compact layout, to expose the minimum surface to external radiation and hot air.
- Orientation North South.

VENTILATION

- Reducing of air infiltration during the day, and maximization during the night.
- Efficient ventilation by window's orientation and position.

WINDOWS

- Very small openings.
- Windows need to be positioned with equal area in the windward and in the leeward sides of the building.
- Windows can be large, but they need to be protected by movable insulated shutter, and must be closed during the day.
- Heights solar radiation, during the summer, occurs on the eastern and western wall, indeed during the winter is on the southern wall.

EXTERNAL WALLS AND ROOF

- Flat roof.
- Heavy weight material.
- Wall and roof: high heat capacity concrete wall, with insulating material (as Rockwool or expanded plastic) and covered by waterproofing material. White plaster.
- Roof must be sloop down in the courtyard, during the day it have an high temperature, but during the night air is cooled by the roof, and channelled by the slope into the courtyard.
- Using external windows in the roof, isolating the roof with polyethylene and an air space between the internal surface and the isolation. Windows are closed during the day, and opened during the night, creating vertical flow of hot air from inside to outside.

PATIO AND COURTYARD

- Patios and internal courtyard to create ventilation by pressure gradient.
- Patios can be equipped with closable insulated shutters along the external walls: they can be open, and create ventilation, but they can be also closed to protect the building.
- Patio and courtyard need to be shaded by trees, pergolas or canvas screen.

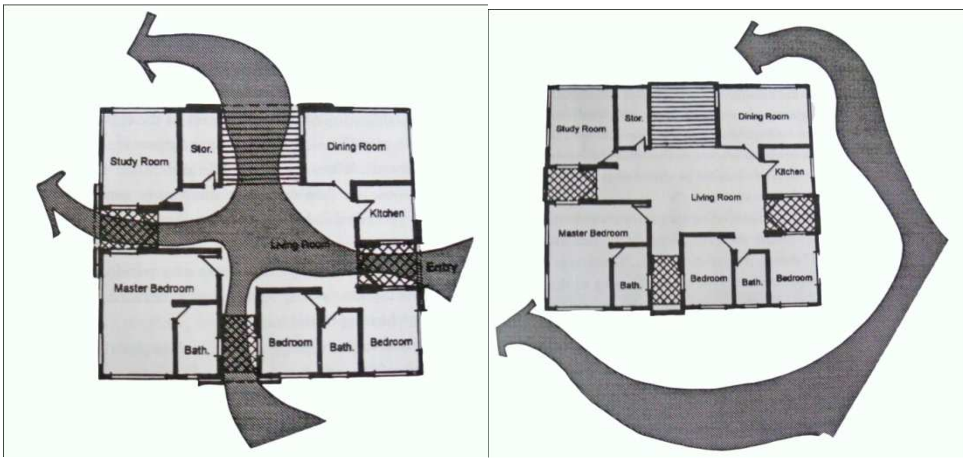


Figure 36Scheme of porches[23]

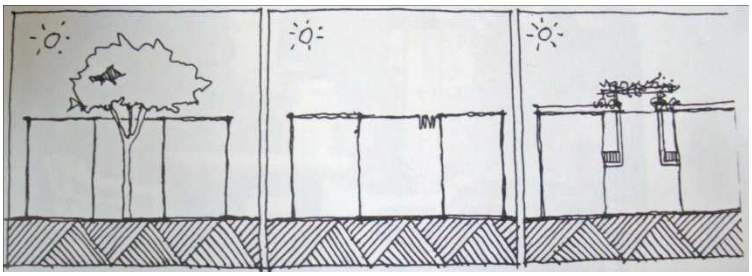


Figure 37Different options for shaded patio[23]

1.4.3 COMFORT AND ENERGY CONSERVATION ISSUES

According to Givoni's guide line we can define some interesting internal characters of the buildings.

First of all: the internal temperature can be of 27- 28 °C during the summer, that can be a high temperature, but in desert climate, with low humidity, can be adequate for comfort. Indoor air speed can be about 1.5 m/s, and 0.5 air changes per hour, stopping the outdoor infiltration during the hot hours, and opening windows during evening, to create flux ventilation from external air. During the winter we can define an internal temperature as 25- 26 °C during the daytime, and 18°C in night-time.

ENERGY CONSERVATION STRATEGIES

Energy conservation is one of the most important issues for a sustainable building, obviously in a hot dry climate. In this case is important to lowering the internal temperature, use the natural ventilation, minimize the heat gain and use a natural energy for heating and cooling, as said before respectively sun and wind. Lowering the internal temperature can be done by a good isolation of the building, a limited air infiltration, minimizing the solar heat by an appropriate orientation, white walls colour, shading on windows. Natural ventilation can be ameliorating by a good disposition and orientation of the windows, an indoor air speed that's the 35/50% of the outdoors wind speed.

1.4.4 Optimization of ventilation

To optimize the ventilation, is important to create street along the main wind direction, and building orientation perpendicular to the wind direction, creating high pressure in front of the wind, and low pressure on the other side. Looking at the Figure below, we can notice the best roof's form for buildings: a double slope, in the same direction, create the best ventilation of the building.

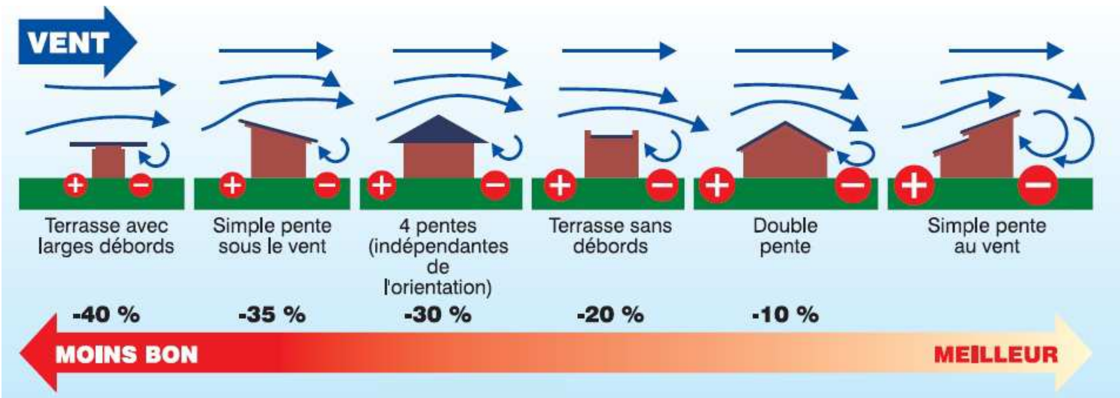


Figure 38How to improve natural ventilation in buildings [2]

Another way to ventilate the building is Wind- scoops (Malqaf) and Wind –tower (Badgir). Wind- scoops are ventilation flues, positioned in the roof of buildings, and directed to the main wind direction, that catch the cold and fresh air, and carry it in the internal ambient, in a reverse chimney action. Wind- towers can catch the wind from many directions, they are improved with evaporative effects, using fountains or piscine, in the path of ventilation.

1.4.5 Vernacular typical building's form

In the Figures below, there are three examples of typical buildings in United Arab Emirates. We've noticed the main features, as the internal courtyard (green), and the wind- tower (yellow). The three buildings have different high, for the different floor. In the two cases, the main entrance is in the South side; from the courtyard are developed the patio and then rooms.

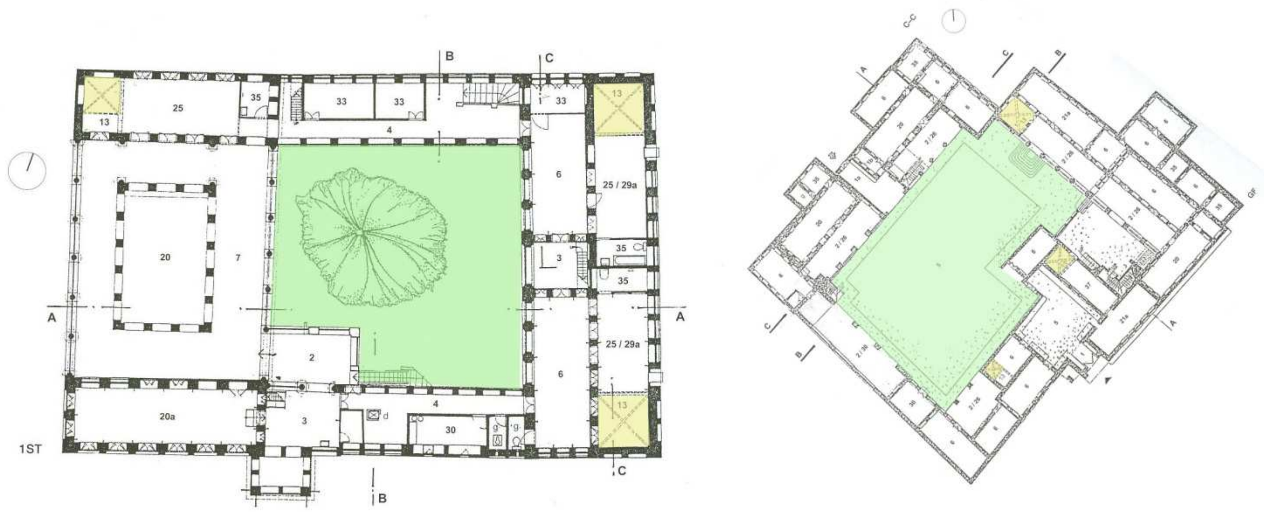


Figure 39 Left: Dubai, house Bukhash[1]. Right: Dubai, house of Sheikh Al- Maktoum[1]. The internal courtyard (green), and the wind- tower (yellow).

Wind tower, as we can notice in the plans, are positioned in the perimeter of the building, as in the first example, or near the courtyard.

1.5 RAS AL KHAIMAH

Figure 40 Ras Al Khaima map

Ras Al Khaimah is the northern emirate of the UAE. His history comes from the antiquity, with archaeological excavations that reveal a settlement with an advanced civilization, as the Umm Al Nar Civilisation in 3rd Millennium [BC]. Later historical records cite that the town of Ras Al Khaimah, known as Julfar, belonged to early Muslim Caliphs. In the 18th century, after the invasions of the Persians, Portuguese and the Dutch, it finally became a part of the Al Qawasim State. It was also once the centre of the naval strength of the southern Gulf States.

The traditional occupations of this emirate are mainly fishing, trading and agriculture which have been heavily modernized to meet the demands of the UAE's economy. Fruits, vegetables, milk and poultry are supplied to the other emirates from here. The sea around Ras Al Khaimah abounds in tuna fish. The mountains have enabled the setup of stone quarries and a cement factory. Also the oilfield of Saleh, has boosted up the revenues of the emirate.

Mina Saqr, located next to the town of Ras Al Khaimah, is a deep-water port with heavily utilized bulk handling facilities where major amounts of transhipment take place. It can handle vessels up to 260 [m] long and 11.5 [m] maximum draught and is ideal for low cost general cargo and container handling.

ECONOMY

Ras al-Khaimah is not a major oil producer, so it has focussed on developing its industrial sector. Today Ras Al Khaimah, especially its capital, is home to many national institutions, government agencies, but also too many international companies. The main sectors of the economy are:

- Real estate, with numerous residential area, office and commercial building.
- Tourism, that have increase during the last years, with a lot of tourism project under construction.
- Production of building material, as the cement production since 1970, and the world's larger ceramic production, founded in 1980.
- Manufacturing and high-tech industry, as the Gulf Pharmaceutical Industries (Julphar), and the Falcon Technologies International (FTI).
- Agriculture and fishing.

RAK CITY

Rak City is the oldest and historical part of the city of Ras Al Khaimah. It is situated near the Golf, and is composed as an ancient Medina, with courtyard houses in a continuous urban texture.

Figure 41 Rak City, panoramic view. Google Earth

Figure 42 Rak City. View of the Golf. Google Earth

Figure 43 National Museum of Ra’s al-Khaimah. Google Earth

The Dhayah Fort is another historic building of the area. It was built of mud-brick in the 16th century on a hill facing the Gulf. It was a strategic military tower that was very important in the history of Ras al-Khaimah. Other ruined fortifications can be seen to the south of the hill and watchtowers are still visible in the nearby town of Rams. A battle in 1819 between the local people and British forces resulted in the destruction of the historic tower.

Figure 44 Dhayah Fort.

1.5.1 CLIMATE

The weather in United Arab Emirates is one of the most important dates that an architect must know to define a bioclimatic approach to the project. As Mohsen M. AboulNaga and Y. H. Elsheshtaway wrote in their article "*Environmental sustainability assessment of buildings in hot climates: the case of UAE"[24]*, the traditional building in UAE are more sustainable then the new modern building, and they explained that by different case study. Buildings in UAE produce high waste, their energy consumption is high, but also the natural resource for building them is higher than in Europe.

In the last decade the urban development didn't care about the traditional heritage, creating a new unsustainability way of life. But how define the architectural sustainability? It depend from a large sphere of issue, from social, environmental, technical, but also from energy consumption, waste production, and obviously from the awareness of the third Principle of the Rio Conference (1992):*"The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations".*

There are also some principles, taken from the green buildings literature, as "*land development, building design and construction, occupant consideration, life cycle assessment, volunteer incentives and marketing programs, facilitate reuse and remodelling, and final disposition of the structure"*[4].

Table 3
Energy-saving measures for regions relevent to UAE climate[a]

		Climatic zones			
Passive comfort measures	Active comfort measures	Mediterranean	Subtropical	Tropical	Desert
Natural ventilation		6	7	7	7
	Mechanical ventilation	4	5	6	6
Night ventilation		6	7	7	7
	Artificial cooling	3	5	5	6
Evaporative cooling		3	2	2	7
	Free cooling	5	6	6	7
Heavy-weight construction		6	2	2	6
Light-weight construction		3	5	5	4
	Artificial heating	4	0	0	1
Solar heating		6	0	0	0
	Free heating	5	0	0	0
Incidental heat		4	0	0	0
Insulation/permeability		5	0	0	4
Solar control/shading		6	6	6	7
	Daytime artificial lighting	3	3	3	2
Daylighting features		6	5	5	4

[a] 0=not important, 4=important, and 7=very important (importance is rated from 0 to 7).

Figure 45 Energy saving measure[22]

The main problems for building consumption are the CO_2 emissions by the energy consumption, mainly for cooling and lighting. In this article the authors make a comparison between four buildings in UAE, two contemporary, the ADMA building in Abu Dhabi and the Chamber of Commerce building in Dubai, and two traditional, Almadfah and Alnaboudah houses in Sharjah. The results show that the average total energy use is 268.00 [kWh/m²] for contemporary buildings, and 55 [kWh/m²] for traditional buildings.

Concluding, they define some way for energy saving in UAE climate that are summarize in figure 45.The main features in tropical climate are the natural and night ventilation, defined as very important.

[4] M. M. AboulNaga, Y. H. Elsheshtawy, *Environmental sustainability assessment of buildings in hot climates: the case of UAE,* in "Renewable Energy", 2001, n.24, p 556

In the table below we can read the weather main topics, of the climate in Ras Al Khaimah, from the files given by Dr. Franco Vigliotti. Looking at the temperature, we can notice that the average daily max is maximum in July, with 43.18 [°C], a minimal average of 30.20 [°C], and a mean temperature of 36.37[°C]. In the other side the minimum temperature is in January, with 12.02°C, and a meaning average of 18.42 [°C].

Table 5Ras Al Khaimah. Temperature, [°C]. Data from Vigliotti

Temperature [°C]						
Date	Averagedaily mean	Averagedaily max	Averagedaily min	Abs max	Abs min	Mean daily thermal amplitude
January	18.42	24.86	12.02	29.56	7.39	12.84
February	20.60	27.71	13.85	33.99	9.01	13.86
March	23.85	31.49	16.55	37.69	11.99	14.94
April	28.07	36.26	20.31	41.82	15.75	15.95
May	32.80	41.50	24.53	45.61	20.87	16.97
June	34.80	42.97	27.27	46.94	24.10	15.70
July	36.37	43.18	30.20	46.72	26.73	12.98
August	36.04	43.00	29.50	46.42	26.34	13.50
Septembe r	33.27	40.92	26.26	44.29	22.41	14.67
October	29.60	37.40	22.19	40.97	18.06	15.21
November	24.88	32.42	17.71	36.80	13.53	14.71
December	20.77	27.40	14.48	31.39	9.80	12.92

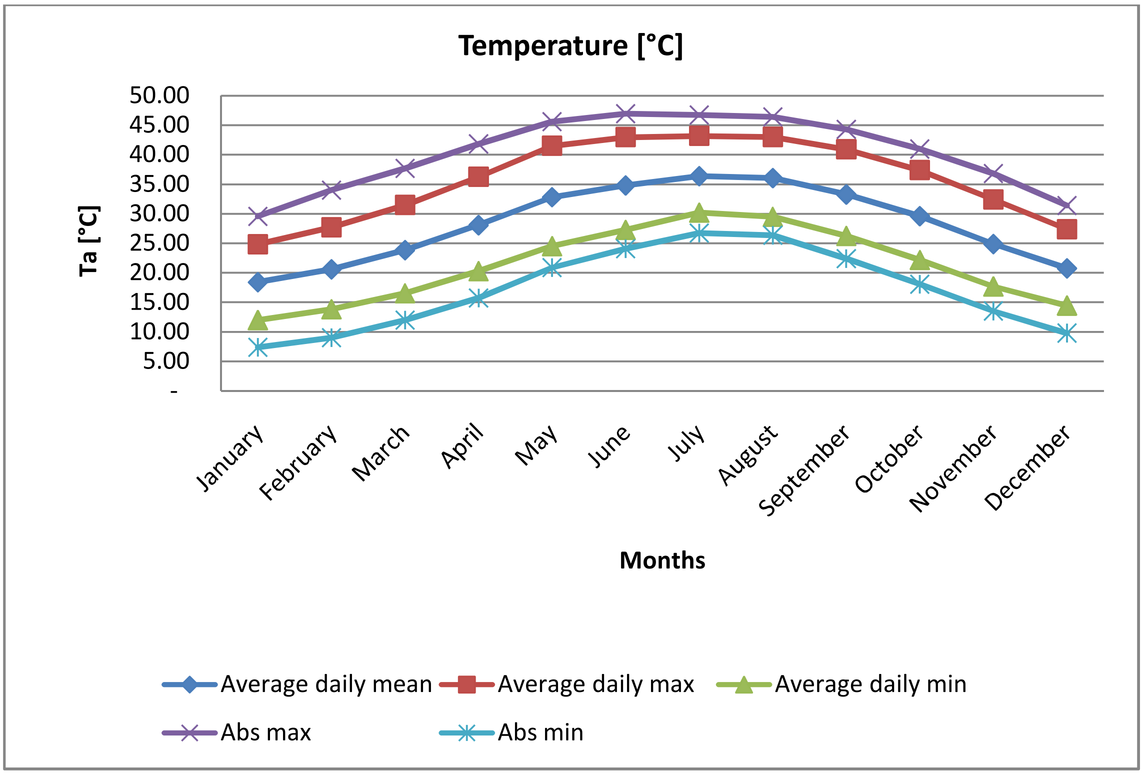


Figure 46Ras Al Khaimah. Temperature, [°C]. Data from Dr Vigliotti[5]

[5]Dr Vigliotti is the dean of EPFL Middle East. The information concerning the climate are given by Dr Vigliotti confidentially.

The relative humidity is an important parameter to define the climate condition. The relative humidity is the ratio between the pressure of water vapour, and the pressure of saturated vapour.

Table 6Ras Al Khaimah. Relative humidity, [%] and rain fall, [mm]. Data from Vigliotti.

	Relative humidity			Rain falls	
Months	Average daily mean	Average daily max	Average daily min	Total	Max in 24 hrs
January	73.20	97.20	26.20	26.26	15.28
February	68.60	98.20	18.80	10.67	8.63
March	63.30	98.80	13.00	18.04	10.32
April	52.40	94.50	9.90	8.06	6.39
May	44.70	90.70	11.00	-	-
June	52.20	91.70	11.80	-	-
July	53.20	89.70	13.90	-	-
August	52.00	90.40	14.00	-	-
September	57.89	96.44	14.89	-	-
October	61.67	98.33	14.11	0.64	0.64
November	63.33	96.22	19.67	2.54	2.12
December	69.67	96.89	29.44	25.03	15.21

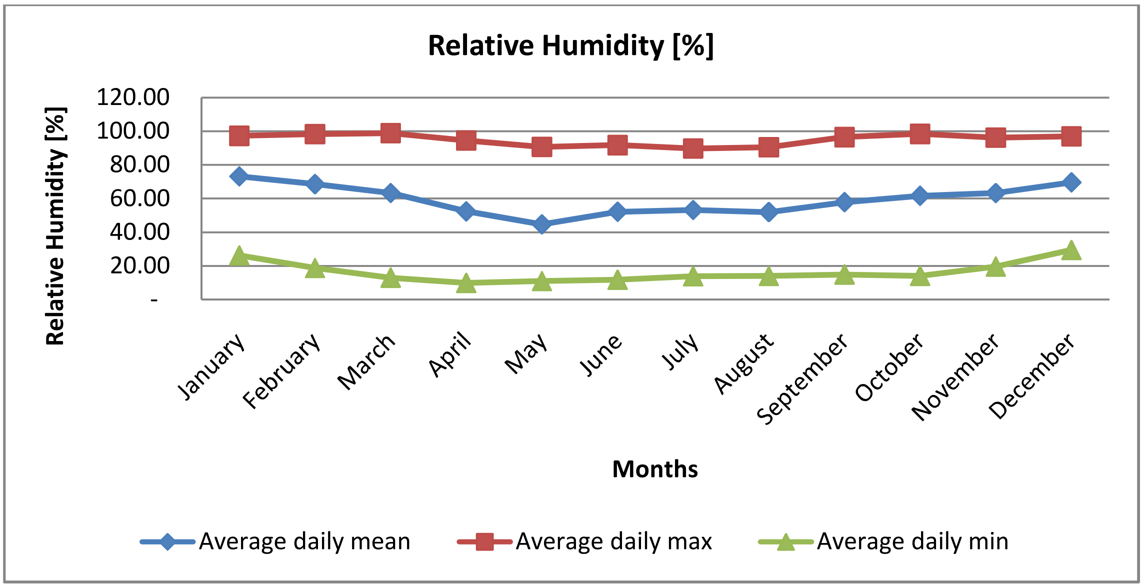


Figure 47Ras Al Khaimah. Relative humidity, [%].Data from Dr Vigliotti

The relative humidity have a difference percentage in value, from the minimum of 44.70 [%] in May, and a maximal humidity of 73.20 [%] in January.

As we can see in the table below, the relative humidity influences the person’s comfort. In the climate of Ras Al Khaimah the perception of the humidity is pleasant for all the months, except for the winter months, from December to February.

Table 7 Relative humidity range

Relative humidity [%]	Perception
0	Dehydrated air
10	Really dry air, like in the desert
25-35	Dry air
35-65	Pleasant
65-75	Humid
>75	Really humid
100	Saturation

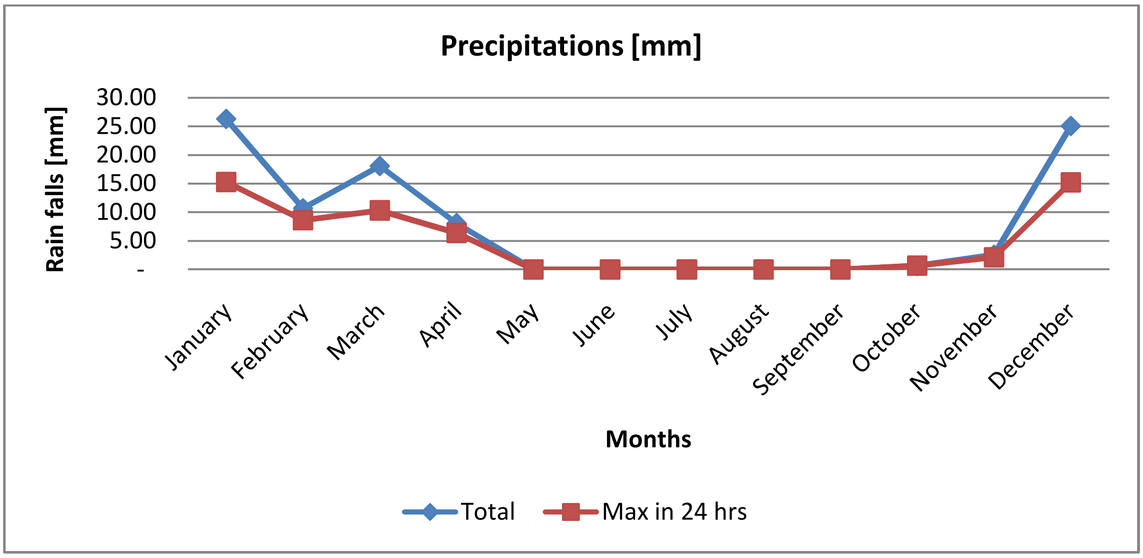


Figure 48Ras Al Khaimah. Precipitations [mm]. Data from Dr Vigliotti

Table 8Ras Al Khaimah. Precipitations [mm]. Data from Dr Vigliotti

Months	Rainfalls [mm]	
	Total	Max in 24 hrs
January	26.26	15.28
February	10.67	8.63
March	18.04	10.32
April	8.06	6.39
Mai	-	-
June	-	-
July	-	-
August	-	-
September	0.76	-
October	85.33	0.64
November	2.54	2.12
December	25.03	15.21

The rain fall is limited on the winter months, from November to March, with a maximal value of 48.00 [mm] on February. This value confirms the humidity, which arrives to the highest values in the same months.

1.5.2 Wind analyse

A paragraph must be dedicated to analyse the wind direction and intensity. Indeed there are two main directions: concerning the wind speed, it reaches the maximal value in South direction, during August, with 4.70 [m/s]. But the main wind direction is North-West, with a maximum speed of 2.39 [m/s] in June.

Table 9 Wind analyse. Data from Meteornom

	Wind speed max [m/s]		Frequency max	
Months	Wind speed [m/s]	Direction [°]	Wind speed [m/s]	Direction [°]
January	2.59	NW	1.21	W
February	2.48	W	2.04	NW
March	2.72	SE	2.23	W
April	2.39	NE SW	2.31	NW
Mai	3.01	SE	2.27	NW
June	2.73	W	2.39	NW
July	3.11	W	2.76	N
August	4.57	S	2.31	NW
September	2.49	NW	2.19	N
October	2.12	S	1.93	NW
November	2.19	NE	1.88	NW
December	1.92	N	1.75	NW

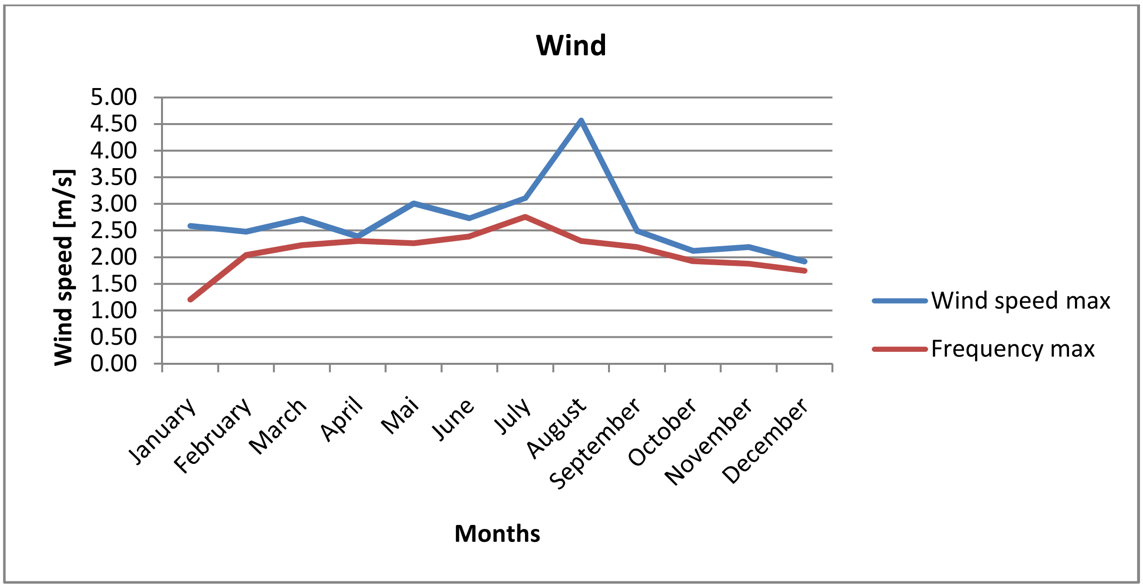


Figure 49 Ras Al Khaimah. Wind speed [m/s]. Data Meteonorm.

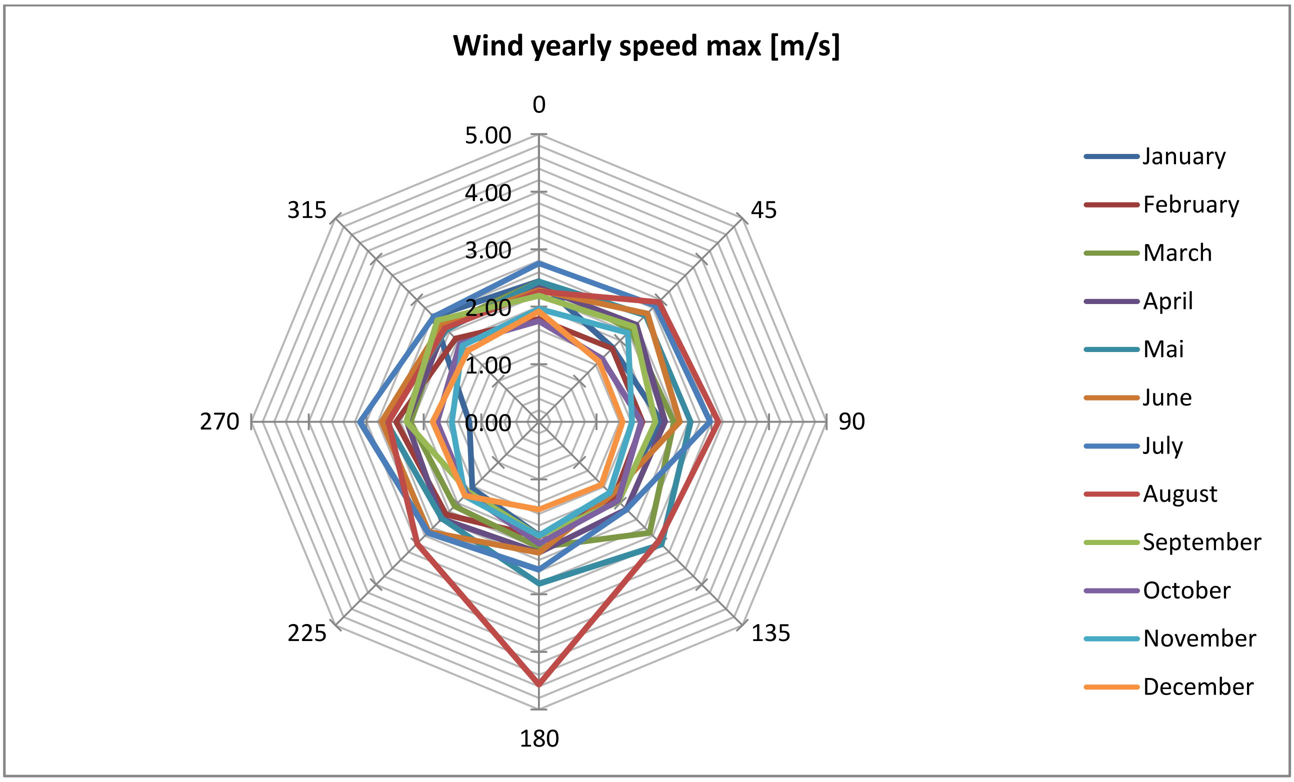


Figure 50Ras Al Khaimah. Wind speed [m/s]. Data Meteonorm.

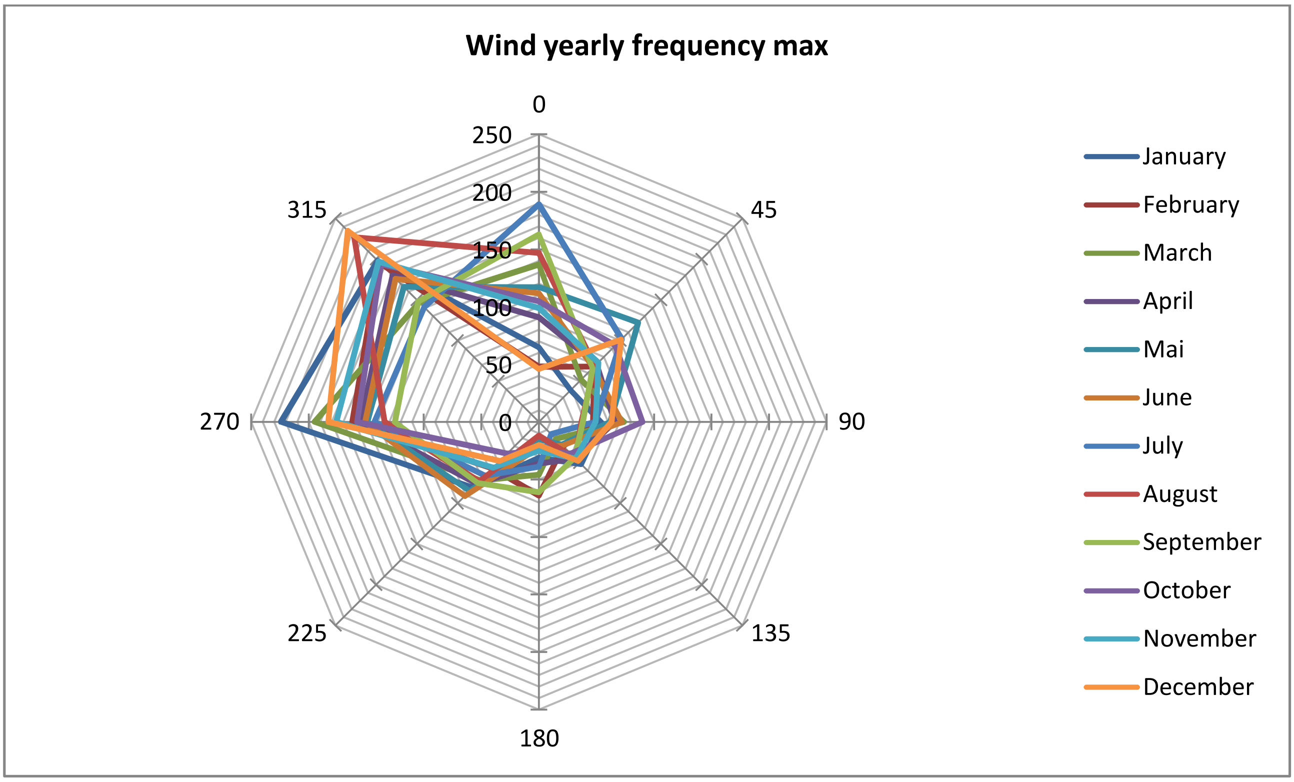


Figure 51Ras Al Khaimah. Wind frequency .Data Meteonorm.

Furthermore the wind is stronger during the day, but is lower during the night-time, as we can notice in the table below. This can be a problem for the natural ventilation of the building, because is better to create a ventilation during the evening and the night, and close all the opening during the day, because of the high temperatures. As average of the wind speed during the year, we can notice that the average wind speed [m/s]during the night- early morning is 1.59 [m/s], during the day is 2.78 [m/s], and during the evening- night is 1.97 [m/s].

Table 10Ras Al Khaimah. Wind speed during the day, [m/s].Meteonorm

Part of the day	Wind speed [m/s]
Night- early morning [0.00- 08.00 h]	1.59
Day [8.00- 18.00 h]	2.78
Evening- night [18.00- 0.00]	1.97

CONCLUSION

As we can notice from Beaufourt Land Scale, the wind from North- West, that arrives from the sea, has an average speed, during the day, of 2.78 [m/s], and a maximal speed of 2.39 [m/s] in June. Those values are on level 2 on the scale Beaufourt, and means "wind felt on face". On the other side the wind from South has a speed of 4.70 [m/s], that correspond on level 3 on the Beaufort Land Scale, and means that "wind extend light flag, hair is disturbed and clothing flaps". Analysing the Beaufourt scale, we can define that a speed around 5 [m/s] is the onset of discomfort for pedestrian, level 3 on Beaufort scale.

Table 11 Beaufourt scale, and description of wind effects [17]

Beaufourt number	Speed [m/s]	Description	Effects
0	0.2	Calm	
1	0.3 -1.5	Light air	Calm, no noticeable wind
2	1.6- 3.3	Light breeze	Wind felt on face
3	3.4- 5.4	Gentle breeze	Wind extends light flag. Hair is disturbed. Clothing flaps
4	5.5- 7.9	Moderate breeze	Raises dust, dry soil and loose paper. Hair disarranged
5	8.0- 10.7	Fresh breeze	Force of wind felt on body. Drifting snow becomes airborne. Limit of agreeable wind on land.
6	10.8- 13.8	Strong breeze	Umbrellas used with difficulty. Hair blown straight. Difficult to walk steadily. Wind noise on ears unpleasant. Windborne snow above head height (blizzard)
7	13.9- 17.1	High wind, Moderate gale, Near gale	Inconvenience felt when walking
8	17.2- 20.7	Gale, Fresh gale	Generally impedes progress. Great difficulty with balance in gusts
9	20.8- 24.4	Strong gale	People blown over by gusts.
10	24.5- 28.4	Storm, Whole gale	Trees are broken off or uprooted, saplings bent and deformed. Poorly attached asphalt shingles and shingles in poor condition peel off roofs
11	28.5- 32.6	Violent storm	Widespread damage to vegetation. Many roofing surfaces are damaged; asphalt tiles that have curled up and/or fractured due to age may break away completely.
12	>32.7	Hurricane force	Very widespread damage to vegetation. Some windows may break; mobile homes and poorly constructed sheds and barns are damaged. Debris may be hurled about.

1.6 Conclusion

From the first analyse we can notice the main elements for a project with a bioclimatic approach:

- We've analyzed the scientific book connected with the climate, in this case the books from Baruch Givoni, and the scientific article regarding the Arab city and the arid climate.
- We've to study the traditional architecture, as the first archetype of a bioclimatic approach, and the modern project in the area, as Masdar were the tradition has been converted in the contemporary building.
- We've study the climate file, defining the main problem and the resources of the area. The territorial analyse is important as the first way to approach to the area.

Then we've defined the bioclimatic element for a sustainable project: starting from the urban scale, to the architectural one. The building must be connected each other, like in the ancient Medina, to reduce the external surface and maximize the internal volume. The material must have a high thermal inertia, like the brick, and the buildings must be isolated from the external of the wall.

The traditional architecture is the courtyard house, in the urban texture of the Medina. The wind tower are the traditional way to implement the natural ventilation of the building, and the Masherabiya the ancient way to protect the internal room from the solar irradiation.

The area of Ras Al Khaimah has a hot and arid climate, with a reduced number of precipitation. The main wind direction is from North- West, and it is a sea breeze that can be useful for the natural ventilation of the buildings. The solar irradiation can be useful for the solar panel, producing electricity, but it is also a negative element concerning the thermal comfort of the building. The main problem of the area is the lack of water, and the need of finding new way to find it, or produce it.

2.0 CitySim

This chapter concerns the analysis of two buildings in Ras Al Khaimah. The two analyses were carried out by two students, Maria Papadopoulou and Aabid Fouad, with the software Energyplus. This program models building heating, cooling, lighting, ventilating, and water usage, as well as carbon emissions. First of all the students considered existing buildings, and then they tried to define a Minergie standard for tropical climates. My objective was to analyze the two buildings with Citysim and to compare the results.

The following definition of the way Citysim works is designed to help in understanding how values are taken into account by the software.

Blinds: the program assumes closing of the blinds when irradiation exceeds 150 [W/m²].

Windows: the program sets a deterministic window opening strategy; the windows are assumed open if the temperature

$T_a > T_{min} + 1°C$

$T_a - T_{ext} > 1°C$

T_a : internal air temperature [°C]

T_{min}: minimal temperature [°C]

T_{ext} :outsider air temperature [°C]

With this strategy, we can ensure night internal ventilation, which is one of the most important elements for ensuring thermal comfort in the building.

2.1 Minergie standards

The Minergie standard is a Swiss certification to define the energy consumption of buildings. The main elements to achieve the Minergie standards are the following [25]:

- Ground-source heat pump for heating and hot water (all year).
- Wood-fired systems for heating and hot water in winter, thermal collectors for hot water in summer.
- Automatic wood-fired systems for heating and hot water (all year), e.g. pellet-furnace.
- Use of waste heat (industry, waste incineration and sewage treatment plants) for heating and hot water (all year as single source).
- Air-to-water heat pump (outside air) for heating and hot water (all year).
- A fan-assisted balanced ventilation system (or comfort ventilation system as it is called by MINERGIE®) with a heat recovery unit with an efficiency of at least 80 % has to be installed. The ventilation has to be driven by a DC- or AC motor.
- A set of U-Values for the building envelope must not be exceeded, e.g. 0,15 [W/m²K] for walls, roof and floor, 1,0 [W/m²K] for windows and 1,2 [W/m²K] for doors.

In the table below we can find the maximal energy consumption for every building in the Swiss Minergie standard.

Exigences MINERGIE® (Norme SIA 380/1:2009)
Exigences pour les nouvelles constructions

	Catégorie	Valeur limite	Exigences primaires	Installation d'aération	Exigences supplémentaires
I	Habitat collectif	**38** kWh/m² CL, EC, aér. él.,*	$Q_h \leq 90\% \ Q_{h,li}$	obligatoire	Pax d'exigences Recommandation pour appareils électroménagers: Etiquette énergie de classe A
II	Habitat individuel	**38** kWh/m² CL, EC, aér. él.,*	$Q_h \leq 90\% \ Q_{h,li}$	obligatoire	Pax d'exigences Recommandation pour appareils électroménagers: Etiquette énergie de classe A
III	Administration	**40** kWh/m² CL, EC, aér. él.,*	$Q_h \leq 90\% \ Q_{h,li}$	obligatoire	Eclairage selon norme SIA 380/4
IV	Ecoles	**40** kWh/m² RH, WW, aér. él.,*	$Q_h \leq 90\% \ Q_{h,li}$	obligatoire	Eclairage selon norme SIA 380/4
V	Commerce	**40** kWh/m² CL, EC, aér. él.,*	$Q_h \leq 90\% \ Q_{h,li}$	obligatoire	Eclairage selon norme SIA 380/4 Froid industriel
VI	Restauration	**45** kWh/m² CL, aér. él.,*	$Q_h \leq 90\% \ Q_{h,li}$	obligatoire	Eclairage selon norme SIA 380/4 EC: 20% des besoins couverts par de l'énergie renouvelable
VII	Lieux de rassemblement	**40** kWh/m² CL, EC, aér. él.,*	$Q_h \leq 90\% \ Q_{h,li}$	obligatoire	Eclairage selon norme SIA 380/4
VIII	Hôpitaux	**70** kWh/m² CL, EC, aér. él.,*	$Q_h \leq 90\% \ Q_{h,li}$	obligatoire	Eclairage selon norme SIA 380/4 Froid industriel
IX	Industrie	**20** kWh/m² CL, EC, (aér. él.),*	$Q_h \leq 90\% \ Q_{h,li}$	conseillée	Eclairage selon norme SIA 380/4
X	Dépôts	**20** kWh/m² CL, EC, (aér. él.),*	$Q_h \leq 90\% \ Q_{h,li}$	conseillée	Eclairage selon norme SIA 380/4
XI	Installations sportives	**25** kWh/m² CL, aér. él.,*	$Q_h \leq 90\% \ Q_{h,li}$	obligatoire	Eclairage selon norme SIA 380/4 EC: 20% des besoins couverts par de l'énergie renouvelable
XII	Piscines couvertes	Pas de valeur limite MINERGIE®	$Q_h \leq 60\% \ Q_{h,li}$	obligatoire	Eclairage selon norme SIA 380/4 EC: 20% des besoins couverts par de l'énergie renouvelable Processus de bain optimalisé

Selon la catégorie de bâtiments, la valeur limite MINERGIE® comprend:
CL = Chauffage des locaux
EC = Eau chaude
Aér. él. = Electricité pour aération mécanique
(Aér. él.) = Une installation d'aération n'est pas obligatoire, mais seulement conseillée pour cette catégorie de bâtiment. La valeur limite MINERGIE® demeure inchangée, avec ou sans aération mécanique.
* = S'il existe une climatisation des locaux (réfrigération, humidification, déshumidification), la consommation d'énergie est comprise dans la valeur limite MINERGIE®.

Figure 52 Standards Minergie

As we can see housing is allowed a maximal energy consumption of 38 [kWh/m²], whereas offices may reach40 [kWh/m²].

2.1.1 Minergie standards in UAE

The study of Maria Papadopoulou defines the values below to reach Minergie Standards in UAE:

Table 12 Minergie standards UAE

Parameters	Minergie	Units
U value roof	0.2	[W/m²K]
U value walls	0.2	[W/m²K]
U value windows	1.0	[W/m²K]
G value windows	0.5	[-]
Shading factor	0.8	[-]
Air infiltration through cracks, open windows	0.05	[per hour]
EER for cooling machine	4	[-]

These values will be used to define the next simulations and the Masterplan.

2.2 BUILDING OFFICE IN RAS AL KHAIMAH

Energyplus developed by Maria Papadopoulou[26]

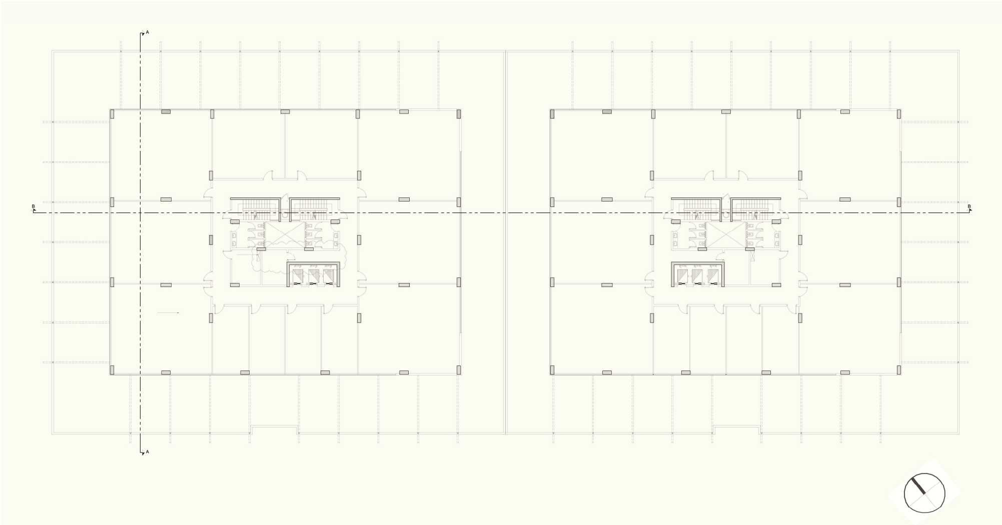


Figure 53 Office. Typical floor plan of the two towers

M. Papadopoulou considered the typical floor of the building, composed of offices, stairs and lifts. The analysis made with Citysim uses the area dimension of the typical floor plan that came from the original architectural plans. As said before, Citysim works at urban scale, and so the floor plan is studied as a gross plan.

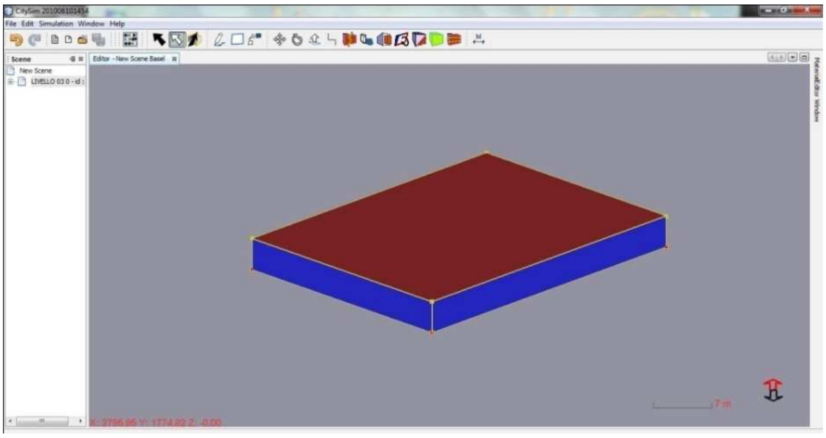


Figure 54 Office. CitySim model

2.2.1 LOCATION WEATHER DATA

Latitude [°] : 25.6801 North

Longitude [°]: 55.7827 East

Altitude [slm]: 31

The weather data are created by the program Meteonorm, using the weather station of the airport of Ras Al Khaimah, interpolated with two other weather stations. The table below shows the results of a comparison between the weather data produced by Meteonorm, and the weather data given by Dr. Vigliotti.

TEMPERATURE, AVERAGE DAILY MEAN

Table 13 Office. Temperature: average daily mean [°C]

Average daily mean [°C]			
	Meteonorm	Vigliotti	Difference
January	18.96	18.42	0.54
February	20.32	20.60	-0.28
March	23.38	23.85	-0.47
April	27.27	28.07	-0.80
May	32.25	32.80	-0.55
June	34.17	34.80	-0.63
July	36.25	36.37	-0.12
August	35.76	36.04	-0.28
September	32.69	33.27	-0.58
October	29.39	29.60	-0.21
November	24.41	24.88	-0.47
December	20.95	20.77	0.18

WIND SPEED

Table 14Office. Wind speed [m/s]

FF Wind speed [m/s]			
	Meteonorm	Vigliotti	Difference
January	1.99	2.04	-0.05
February	2.20	2.27	-0.07
March	2.40	2.37	0.03
April	2.41	2.51	-0.11
May	2.60	2.72	-0.12
June	2.60	2.72	-0.12
July	2.80	3.00	-0.20
August	2.60	2.85	-0.26
September	2.20	2.30	-0.10
October	1.89	1.92	-0.03
November	1.90	1.88	0.03
December	1.80	1.92	-0.12

WIND DIRECTION

Table 15 Office. Wind direction [°]

DD Wind direction [°]			
	Meteonorm	Vigliotti	Difference
January	238.87	218.00	20.87
February	232.32	223.00	9.32
March	203.71	224.00	-20.29
April	212.95	250.00	-37.05
May	195.12	257.00	-61.88
June	208.01	221.00	-12.99
July	179.76	168.00	11.76
August	209.19	178.00	31.19
September	189.23	200.00	-10.77
October	203.54	204.00	-0.46
November	217.06	222.00	-4.94
December	229.21	198.00	31.21

RELATIVE HUMIDITY

Table 16 Office.Relative humidity [%]

RH Relative humidity [%]			
	Meteonorm	Vigliotti	Difference
January	69.41	73.20	-3.79
February	69.68	68.60	1.08
March	59.93	63.30	-3.37
April	49.61	52.40	-2.79
May	41.22	44.70	-3.48
June	47.42	52.20	-4.78
July	47.38	53.20	-5.82
August	49.67	52.00	-2.33
September	57.31	57.89	-0.57
October	59.26	61.67	-2.41
November	63.39	63.33	0.06
December	67.08	69.67	-2.58

SUNRISE AND SUNSET

Table 17 Office.Sunrise and sunset

Month	Day	Sunrise	Sunset
January	15	7.43	18.26
February	15	7.31	18.49
Mars	15	7.06	19.05
April	15	6.33	19.19
Mai	15	6.10	19.34
June	15	6.04	19.48
July	15	6.14	19.49
August	15	6.29	19.31
September	15	6.41	19.00
October	15	6.54	18.28
November	15	7.14	18.08
December	15	7.35	18.08

2.2.2 Existing Parameters of reference and Minergie typical floor plan

Area: 1,196.00 [m²]

Cooled floor area per user: 71.00 [m²]

Orientation: 49 [°] NW

2.2.3 Parameters of reference existing typical floor plan

BUILDING PROPERTIES

Volume [m³]: 4,688.74

Infiltration rate [per hour]: 0.00

This value is not correct as physical model, but this came from the analyse made by Maria Papadopoulou, as we can see in the image below.

		existing	MINERGIE	
1.	U-Value roof	1.3	0.2	W/m^2K
2.	U-values walls	1.7	0.2	W/m^2K
3.	U-value windows:	1.95	1.0	W/m^2K
4.	g-value windows:	0.46	0.5	
	shading factor (ME with mobile shades between glass panes)	0	0.8	
5.	air infiltration through cracks, open windows	0	0.05	/h
	hereof exhaust ventilation from toilets	0.1	-	/h
	air exchange by HRV/ERV (ME: $35m^3/h/P$, $20m^2/P$, 60h/week):	6.23	0.61	m^3/m^2h
	(existing: 60h/week at full load = 34% of 8760 h/a)			
	efficiency of heat recovery:	0	0.85	
	efficiency of enthalpy recovery:	0	0.6	
	electricity use for ventilation (exist: $=1.6kWh/m^2a \times 6.2/0.61/1.5$)	11	1.6	kWh/m^2a
6.	electricity use for lights, appliances, elevators (see app. 2):		27	kWh/m^2a
	- existing: Lights 12W/m2 x 1500h/a + 15W/m2 x 4000h/a	78		kWh/m^2a
	- ME-office rooms (80%) (=18 (light)+4 (appl.) +8 (elev))		30	kWh/m^2a
	- ME-technical rooms, restrooms (9%) (=8 (lights)+8 (elev))		16	kWh/m^2a
	- ME-staircase, hallway (11%) (=2 (lights)+8 (elev))		10	kWh/m^2a
7.	domestic hot water, MINERGIE $0.1\ m^3/m^2a$, 60°C	15	5	kWh/m^2a
8.	EER of cooling machine	2.5	4	

Figure 55 Parameter of reference for Minergie building [26]

Tmin [°C]: 5

Heating start temperature

Tmax[°C]: 23

Cooling start temperature

Target temperature profile: no profile

Maximum number of occupants: 17

1,196.00/71= 16.84

OCCUPANCY PROFILE

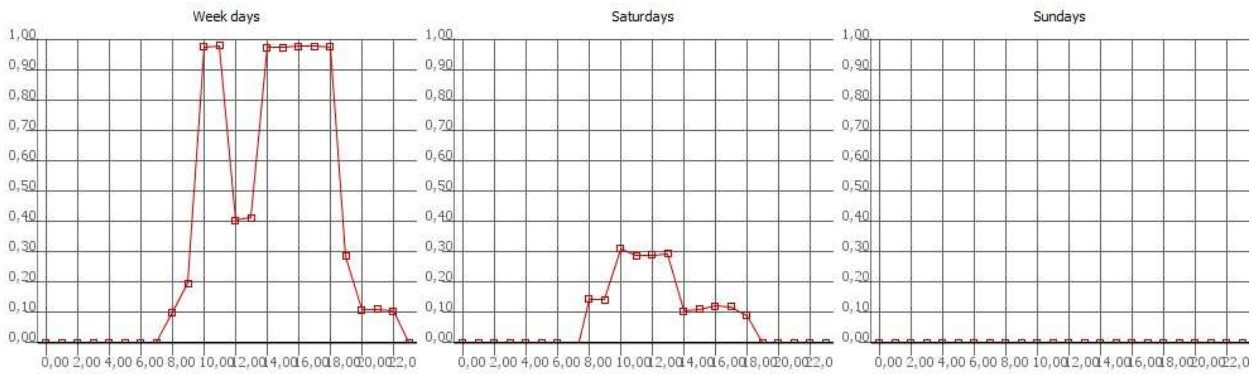


Figure 56 Office.Occupancy profile [1]

THERMAL REGULATION

HVAC: no HVAC

Heating energy converter: no heating energy converter

Start heating date [day]: 1

Stop heating date [day]: 365

Cooling energy converter: Heat pump

Start cooling date [day]: 1

Stop cooling date [day]: 365

Heat tank: standard

Cool tank: standard

Simulate thermal: true

HEAT PUMP

Maximum power source: 372,100.00

COP: 2.5

ηtech: 0.13

ηtech= COP/ ηcarnot

ηcarnot: Ti/ [Ti- Te]

ηcarnot= $\frac{(13+273.15)}{((13+273.15)-(28+273.15))}$

ηcarnot= 19.08

ηtech=$\frac{2.5}{19.08}$

Ti: internal temperature – ΔT

In this case 22 [°C] in Winter and 24 [°C] in Summer

Te [°C]: external temperature

External temperature, 28 [°C], is the average daily mean temperature.

ΔT=10[°C]

Source: air

WALL PROPERTIES

Short wave reflectance: 0.20

Glazing ratio [%]: 0.44

Percentage of window in front

Glazing G value: 0.46

G value is the coefficient of the permeability of total solar radiation energy

Glazing U value [W/m²K]: 1.95

U value is the conductance, expressed in [W/m²K]

Material: U= 1,70 [W/m²K]

Is important to notice that CitySim read the wall composition from external to internal, in the English way. For this reason all the material tables are defined in this order.

Table 18 Existing office. Material

Name	l [m]	p [Kg/m^3]	k[W/mK]	Cp [J/Kg°C]
Plaster	0.02	600	0.29	840
Cement	0.2	1800	0.72	880
Plaster	0.01	600	0.29	840

Where

l: thickness [m]

p: mass density [Kg/m³]

k: thermal conductivity [W/mK]

Cp: specific heat [J/Kg°C]

Glazingratio is 44%, because the “part of windows of total surface of wall is 55%”, but the part of glass of the total window surface is 80%.

ROOF- FLOOR PROPERTIES

Short wave reflectance: 0.20

Glazing ratio [%]: 0.00

U value [W/m²K]: 1.30

Roof and floor properties are the same; indeed the model refers to a typical floor, and is implicit that there is no K value for the floor.

SIMULATIONS RESULTS

Table 19 Existing office. Energy consumption

Month	HeatingNeeds[Wh]	CoolingNeeds[Wh]	DHW[J]	FuelConsumption[J]	ElectricConsumption[J]
1	0	0	1.42E+06	0	0
2	0	-28978.6	1.29E+06	0	6.50E+07
3	0	-3.35E+06	1.42E+06	0	6.80E+09
4	0	-1.83E+07	1.38E+06	0	3.59E+10
5	0	-4.12E+07	1.42E+06	0	9.56E+10
6	0	-5.25E+07	1.38E+06	0	1.29E+11
7	0	-6.05E+07	1.42E+06	0	1.59E+11
8	0	-5.49E+07	1.42E+06	0	1.42E+11
9	0	-3.75E+07	1.38E+06	0	8.73E+10
10	0	-1.87E+07	1.42E+06	0	4.01E+10
11	0	-1.95E+06	1.38E+06	0	4.07E+09
12	0	-1349.13	1.42E+06	0	3.42E+06

In this case we do not have heating needs, because the temperature of Ras al Khaimah never sinks far enough, but we need cooling from February to December. The most cooling need we find in July, with 60,500,000 Wh.

ENERGYPLUS RESULTS

Utility use per total floor area

District cooling intensity: 859.84 [MJ/m²]

CITYSIM RESULTS

Qs cooling: 869.88 [MJ/m²]

Difference between the two models: +10.04 [MJ/m²]

DIAGRAMS

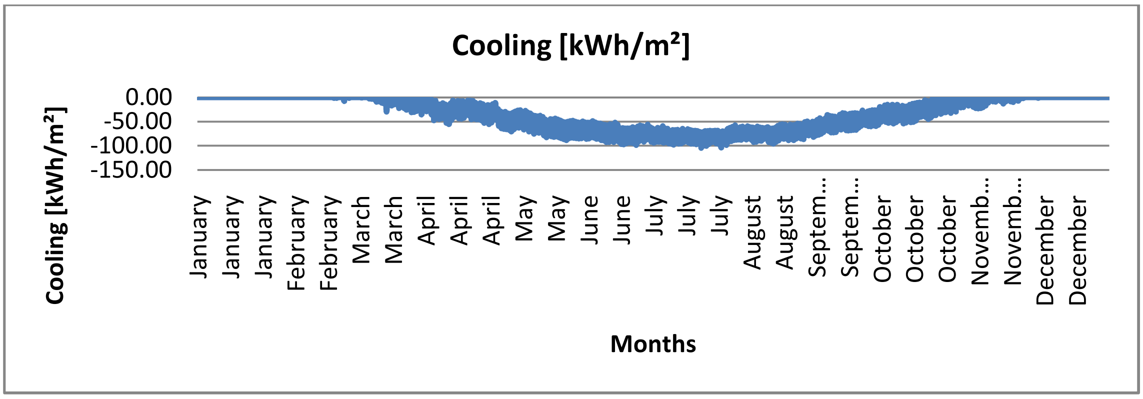


Figure 57 Existing office. Cooling needs [kWh/m²a]

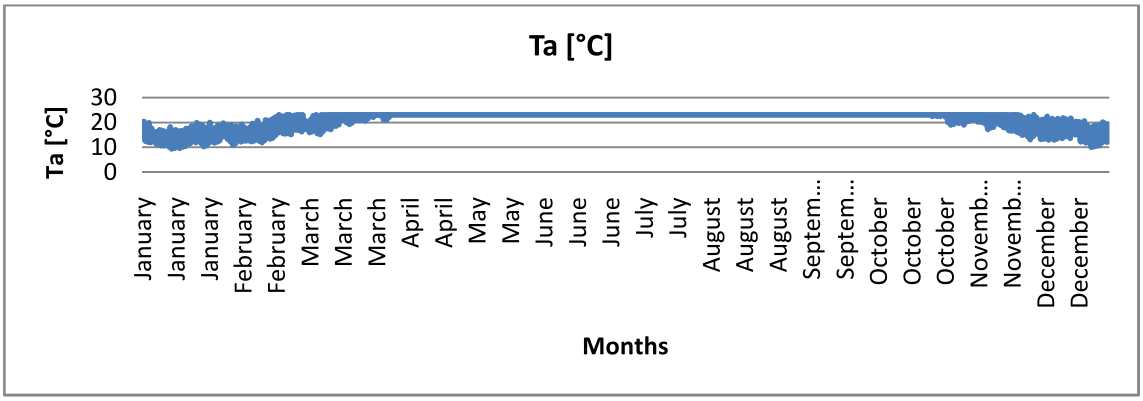


Figure 58 Existing office. Internal temperature [°C]

YEARLY RESULTS

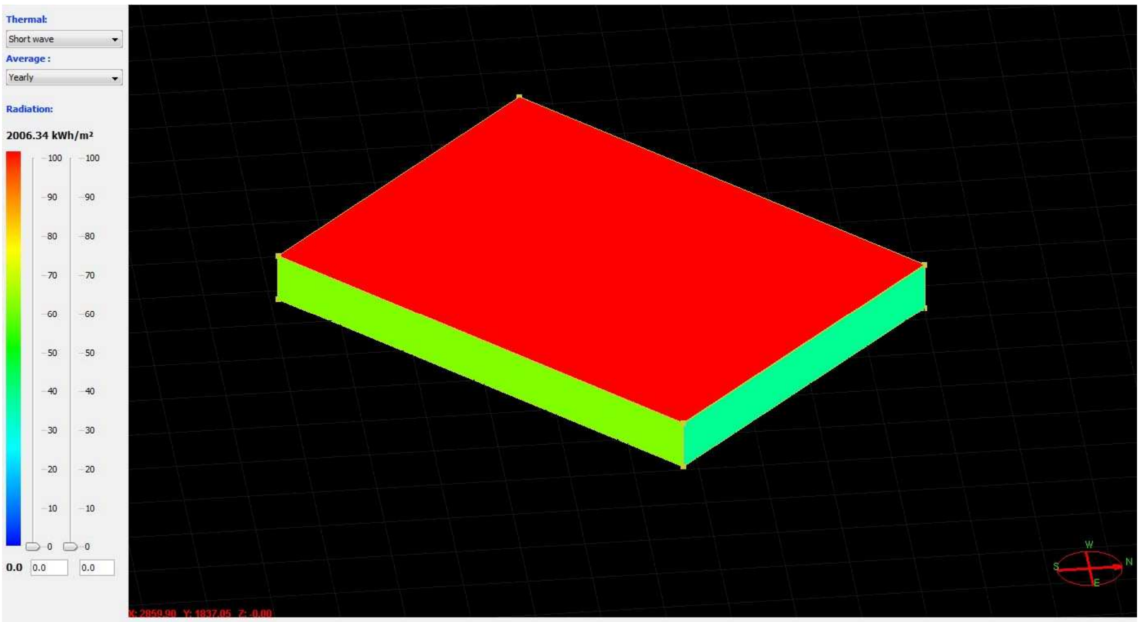


Figure 59 Existing office. Yearly results. Max value 2006 [kWh/m²a]

MONTHLY RESULTS

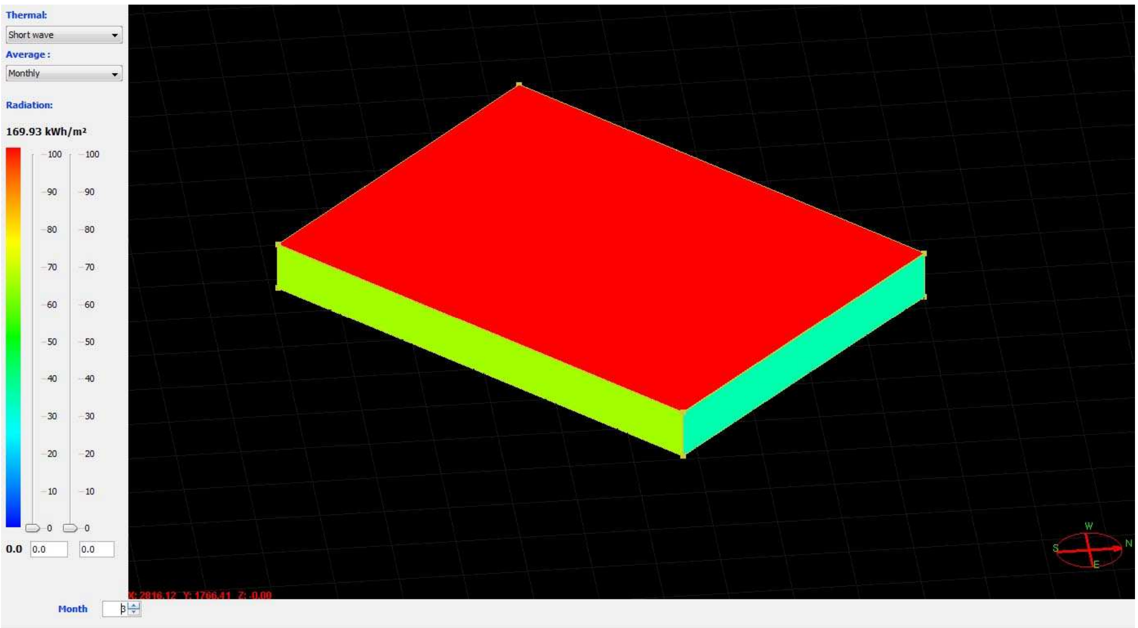


Figure 60 Existing office. Monthly results: March. Max 170 [kWh/m²].

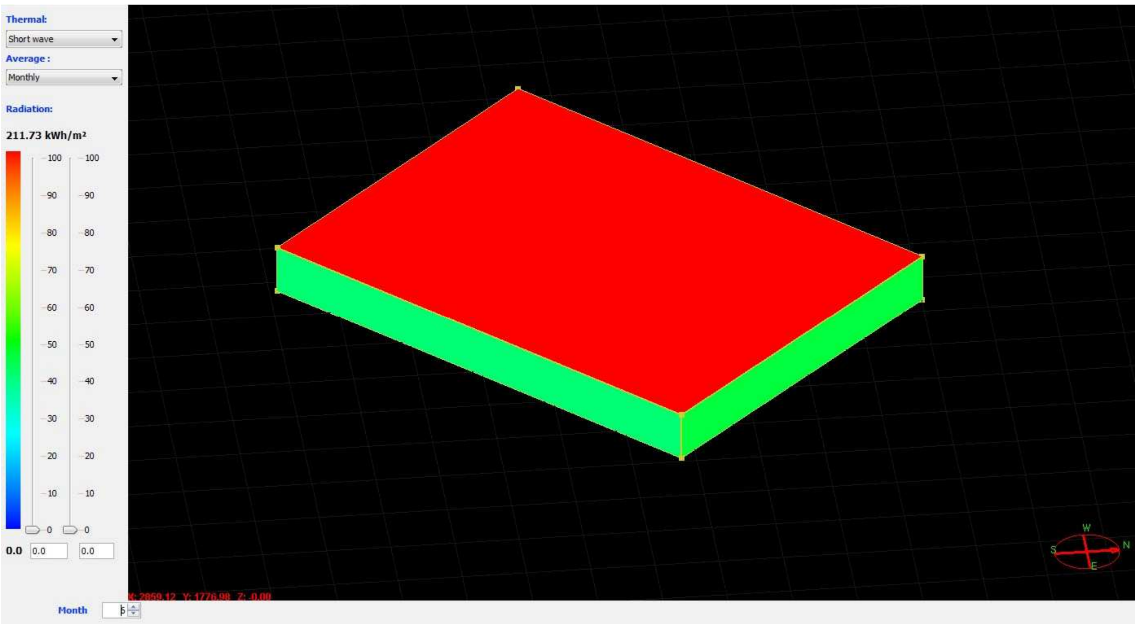


Figure 61 Existing office. Monthly results: June. Max 212 [kWh/m²a]

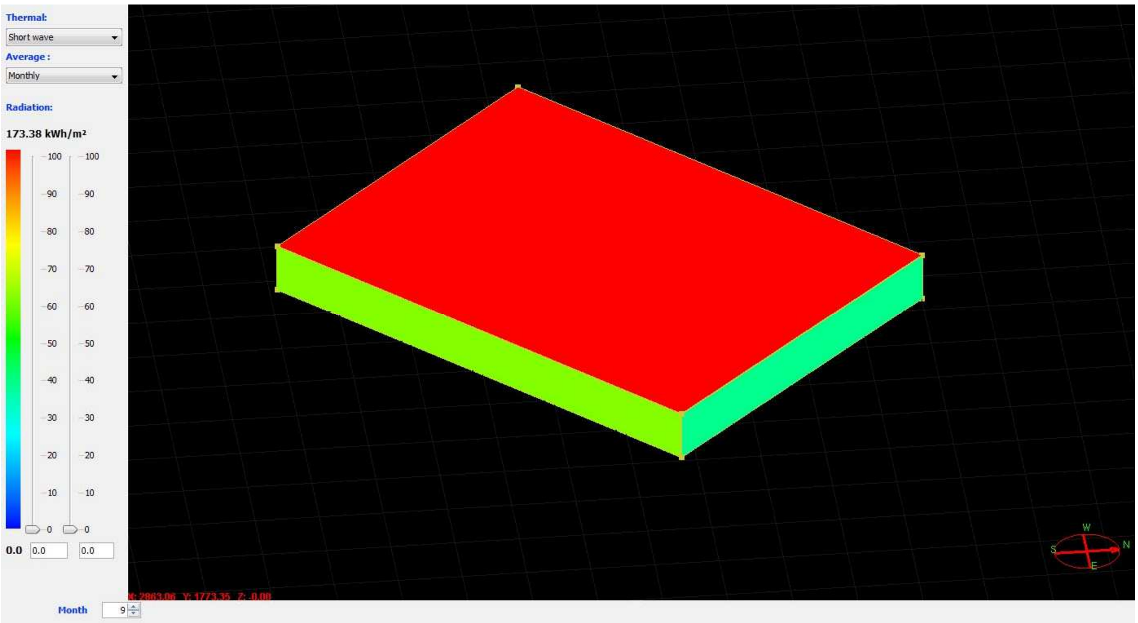


Figure 62 Existing office. Monthly results: September. Max 173 [kWh/m²a]

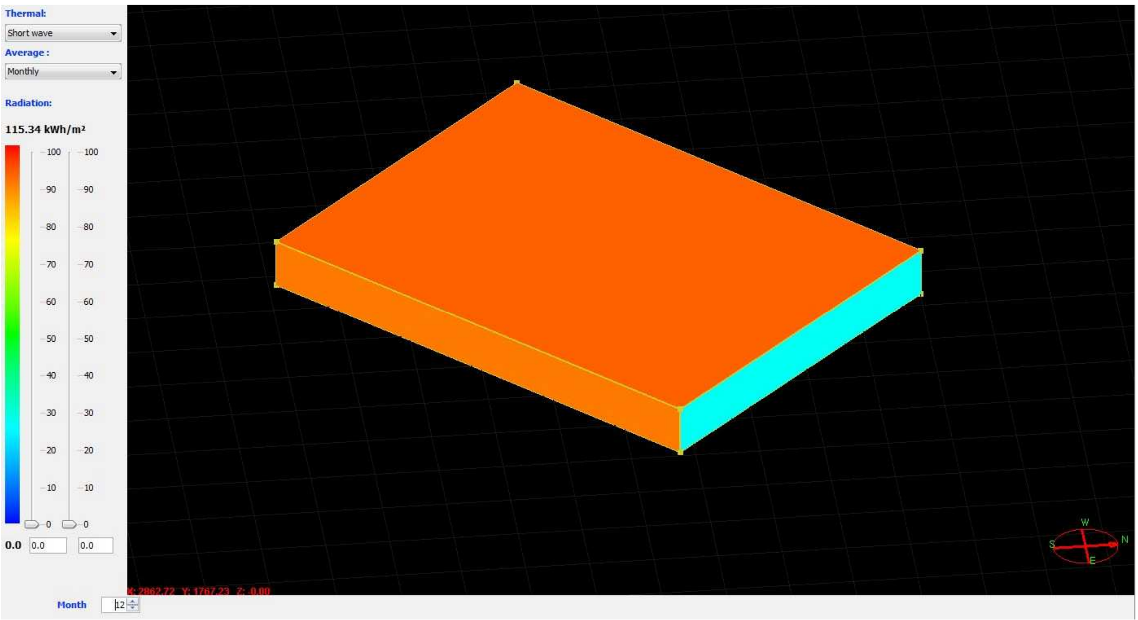


Figure 63 Existing office. Monthly results: December. Max 115 [kWh/m²a]

2.2.4 DIFFERENT VALUES AND NEWS SIMULATIONS

In the next paragraph we want to define the influence of a series of parameters on the total energy consumption for cooling needs. These parameters are the occupancy profile, the infiltration rate, the number of people, the internal temperature and the eta tech of the heat pump.

OCCUPANCY PROFILE

There is a difference in results if we do not insert the people profile the Qs results as **844.05** *[*MJ/m²].

INFILTRATION RATE

Infiltration rate is one of the most important values, changing it means to change the results. The best results come from the minimum infiltration rate.

Using infiltration rate 0.05,the Qs is: 882.26 [MJ/m²a].

Using infiltration rate 1, the Qs is: 1,119.71 [MJ/m²a].

PEOPLE

There are 17, 71 [m²] floor area per person, as written in the .idf of Energyplus. But using the per person value from the draft of M. Papadopoulou is 35[m²], with 34 persons in total, in which case the Qs is 896.10 [MJ/m²a].

TEMPERATURE

If the internal temperature Tais changed, the Qs had a strong variation. Using Tmax: 25 [°C] , Qs is 739.63 [MJ/m²a]. Using Tmax: 20 [°C], Qs is 1,084.51 [MJ/m²].

ETA TECH

Changing the Eta tech of the heat pump, there cannot be noticed any difference between the models, indeed with Eta tech 0.45 or 0.80 the Qs is both times **869.88 [**MJ/m²].

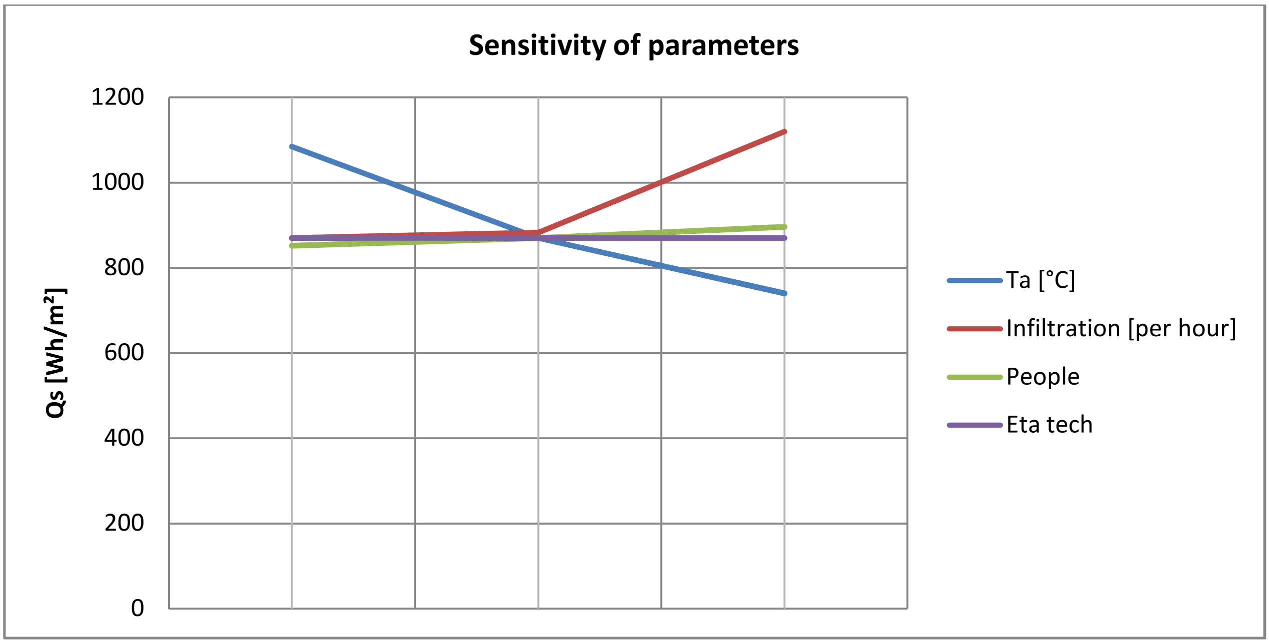


Figure 64 Existing office. Sensitivity of parameters

20	23	25	Ta [°C]
0	0.05	1	Infiltration [per hour]
5	17	34	People
0.13	0.45	0.8	Eta tech

The most sensitive parameters, as we can read from the graph, are Infiltration rate and Ta.

2.2.5 Parameters of reference Minergie typical floor plan

BUILDING PROPERTIES

Volume [m³]: 4,688.74

Infiltration rate [per hour]: 0.05

The infiltration rate is taken from the .idf file of Energyplus named "EPlus2Standard_systemGlazed", as we can read below, from line 16819

!- =========== ALL OBJECTS IN CLASS: ZONEINFILTRATION:DESIGNFLOWRATE ===========

Zone Infiltration: DesignFlowRate,

infiltration-1, !- Name

sp-1-Office, !- Zone or Zone List Name

FanSch-34, !- Schedule Name

AirChanges/Hour, !- Design Flow Rate Calculation Method

, !- Design Flow Rate [m3/s]

, !- Flow per Zone Floor Area [m3/s-m2]

, !- Flow per Exterior Surface Area [m3/s-m2]

0.05, !- Air Changes per Hour

1, !- Constant Term Coefficient

0, !- Temperature Term Coefficient

0, !- Velocity Term Coefficient

0; !- Velocity Squared Term Coefficient

Tmin [°C]: 5

Heating start temperature

Tmax[°C]: 25

Cooling start temperature

OCCUPANCY PROFILE

Target temperature profile: no profile

Maximum number of occupants: 17

1,196.00/71= 16,84

Occupancy profile: no profile

THERMAL REGULATION

HVAC: no HVAC

Heating energy converter: non heating energy converter

Start heating date [day]: 1

Stop heating date [day]: 365

Cooling energy converter: Heat pump

Start cooling date [day]: 1

Stop cooling date [day]: 365

Heat tank: standard

Cool tank: standard

Simulate thermal: true

HEAT PUMP

Maximum power source: 372,100.00

COP: 4

ηtech: 0.25

ηtech: COP/ ηcarnot

ηcarnot: Ti/ [Ti- Te]

$$\frac{[10 + 273.15]}{(10 + 273.15) - [28 + 273.15]}$$

Ti: internal temperature – ΔT

Te: external temperature

Temperature target: 15°C

Source: air

WALL PROPERTIES

Short wave reflectance: 0.20

Glazing ratio [%]: 0.44

Percentage of window in front

Glazing G value [%]: 0.05

G value is the coefficient of the permeability of total solar radiation energy, expressed in %
Glazing U value [W/m²K]: 1.00

U value is the conductance, expressed in W/m²K

Material: U= 0.20 W/m²K

Table 20 Minergie office. Material

Name	l [m]	p [Kg/m^3]	k[W/mK]	Cp[J/Kg°C]
Plaster	0.02	600	0.29	840
Isolation	0.2	30	0.04	840
Cement	0.2	1800	0.72	880
Plaster	0.01	600	0.29	840

Where

l: thickness [m]

p: mass density [Kg/m³]

k: thermal conductivity [W/mK]

Cp: specific heat [J/Kg°C]

Glazing ratio is 44%, because the "part of windows of total surface of wall is 55%", but the part of glass of the total window surface is 80%.

The G value is given by the mobile shades, which can reduce the solar gain through <0.10, as the Gvalue without them is 0.50. This is why the G value is 0.05.

ROOF- FLOOR PROPERTIES

Short wave reflectance: 0.20

Glazing ratio [%]: 0.00

U value [W/m²K]: 0.20

Roof and floor properties are the same, indeed the model refers to a typical floor, and it is implicit that there is no K value for the floor.

SIMULATIONS RESULTS

Table 21Minergie office. Energy consumption

Month	Heating Needs[Wh]	Cooling Needs[Wh]	DHW[J]	Fuel Consumption[J]	Electric Consumption[J]
1	0	0	0	0	0
2	0	0	0	0	0
3	0	-249784	0	0	2.44E+08
4	0	-2.17E+06	0	0	1.97E+09
5	0	-6.39E+06	0	0	6.38E+09
6	0	-8.44E+06	0	0	8.80E+09
7	0	-1.01E+07	0	0	1.13E+10
8	0	-9.13E+06	0	0	1.01E+10
9	0	-5.92E+06	0	0	5.85E+09
10	0	-2.58E+06	0	0	2.47E+09
11	0	-105194	0	0	1.07E+08
12	0	0	0	0	0

In this case we need cooling from Mars to November, because the internal temperature is 25°C, instead of 23°C. Increasing insulation, but also creating a new facade with a GIG holding system, M. Papadopoulou had reduced the cooling needs from 859.84 [MJ/m²] to 110.51 [MJ/m²] Energyplus. As we can see in the table the maximum cooling need is in July, as before, but it amounts to 10,100,000 [Wh] instead of 60,500,000 [Wh].

ENERGYPLUS RESULTS

Utility use per total floor area

District cooling intensity: 110.51 [MJ/m²]

CITYSIM RESULTS:

Qs cooling: 135.69 [MJ/m²]

Difference between the two models: +25.18 [MJ/m²].

DIAGRAMS

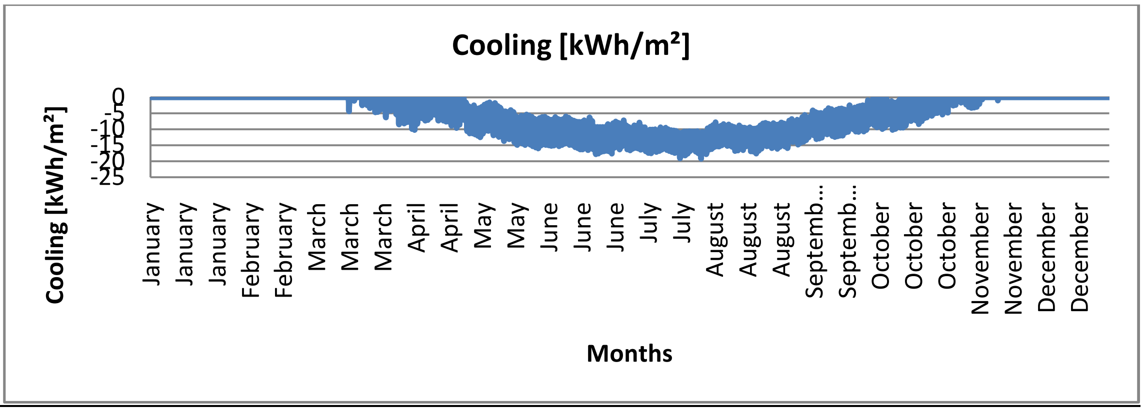


Figure 65 Minergie office. Cooling need [kWh/m²]

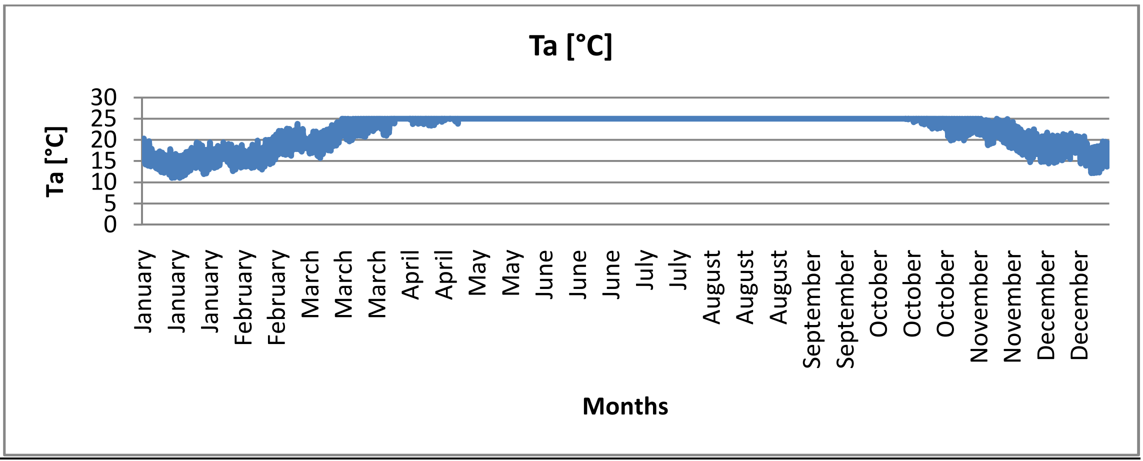


Figure 66 Minergie office. Internal temperature [°C]

2.2.6 DIFFERENT VALUES AND NEW SIMULATIONS

In the next paragraph we want to once more define the influence of a series of parameters, on the total energy consumption for cooling needs. These parameters are the infiltration rate, the internal temperature, the eta tech of the heat pump and the Uvalue for the roof and the floor.

INFILTRATION RATE

Infiltration rate is one of the most important values, indeed changing it means to change the results. The best results come from the minimum infiltration rate.

Using infiltration rate 0.00,the Qs is: 126.05 [MJ/m²].

We know that the value 0.00 has no physical application. But it was chosen just to define the influence of this parameter on the total energy consumption.

Using infiltration rate 1,the Qs is: 324.47 [MJ/m²].

TEMPERATURE

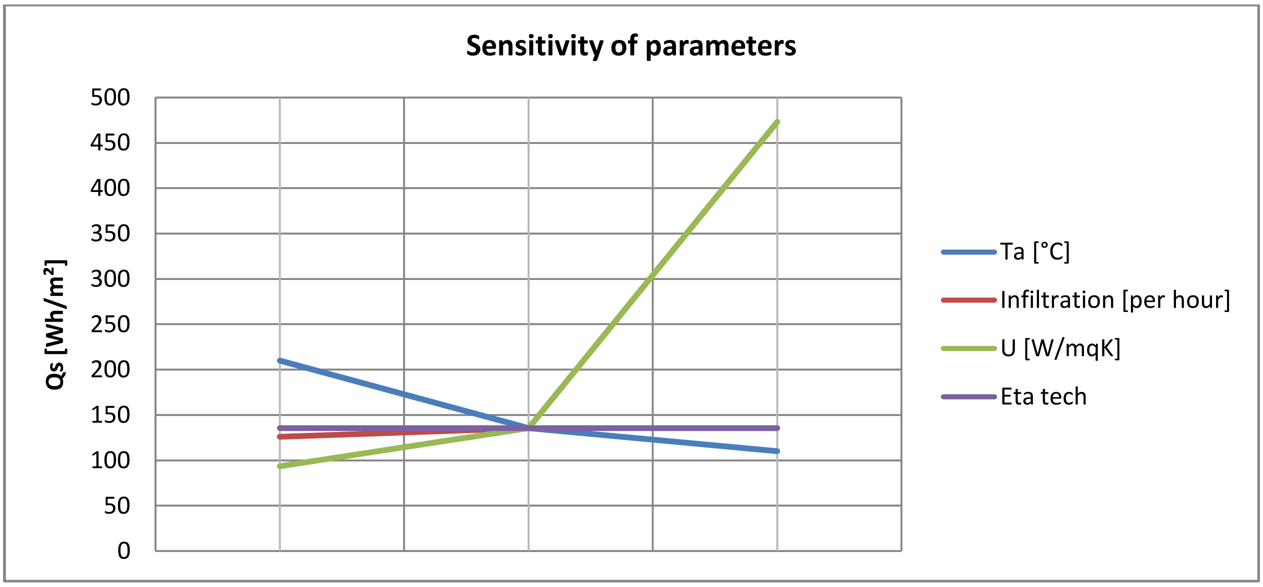
Changing the internal temperature, Ta, the Qs had a strong variation. Using Tmax: 27 [°C], Qs is 110.18 [MJ/m²]. Using Tmax: 20 [°C], Qs is 209.88 [MJ/m²].

ETA TECH

Changing the Eta tech of the heat pump, no difference can be observed between the models, indeed with Eta tech 0.45 or 0.80 the Qs is **135.69** [MJ/m²].

U ROOF AND FLOOR

Changing the conductance the Qs had a strong variation. Using U: 0.1, Qs is 93.71 [MJ/m²]. Using U: 1, Qs is 473.19 [MJ/m²].



20	25	27	Ta [°C]
0	0.05	1	Infiltration [per hour]
0.1	0.2	1	U [W/m²K]
0.13	0.45	0.8	Eta tech

Figure 67 Minergie office. Sensitivity of parameters

2.2.7 Comparison between the two models

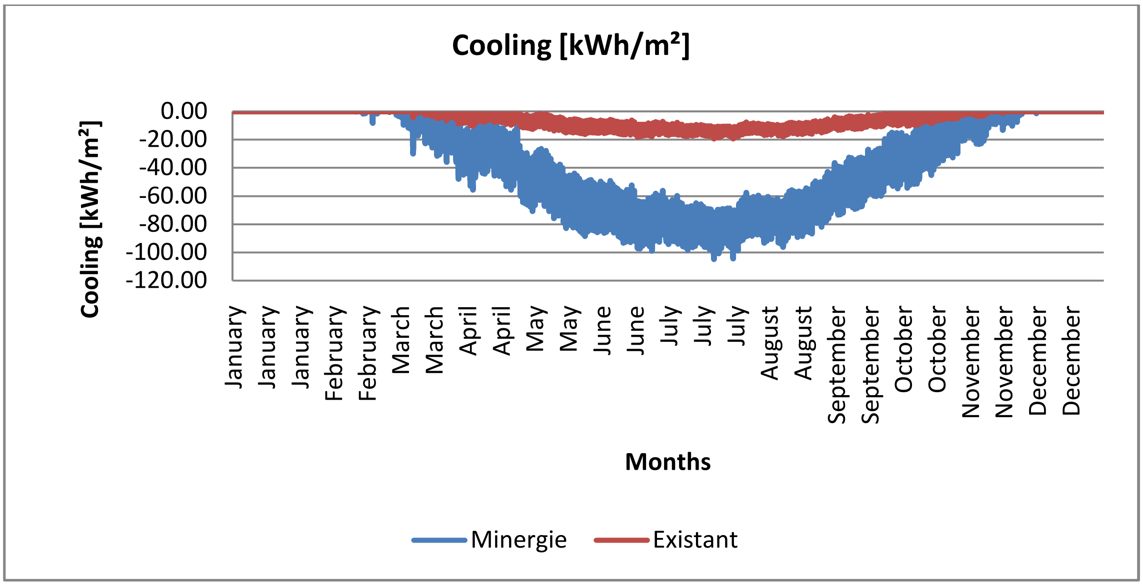


Figure 68 Office. Comparison: cooling needs [kWh/m²]

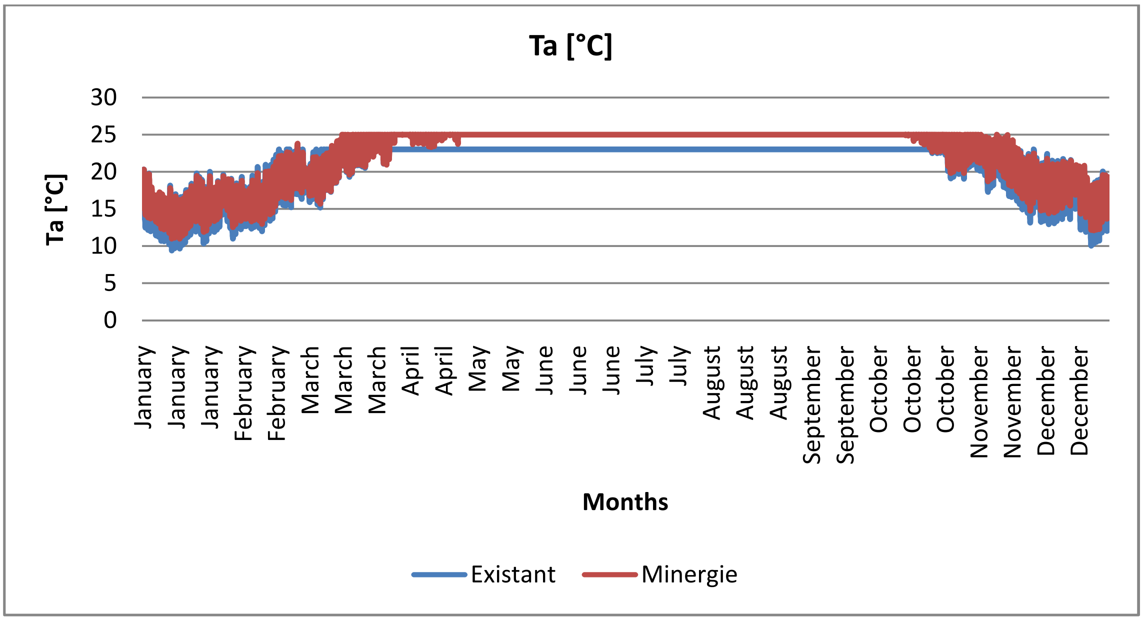


Figure 69 Office. Comparison: internal temperature [°C]

2.3 Villa in Ras Al Khaimah

ENERGYPLUS DEVELOPED BY AABI FOUAD

The analysis made with Citysim uses the area dimension of the floor plan that came from the original architectural plans.

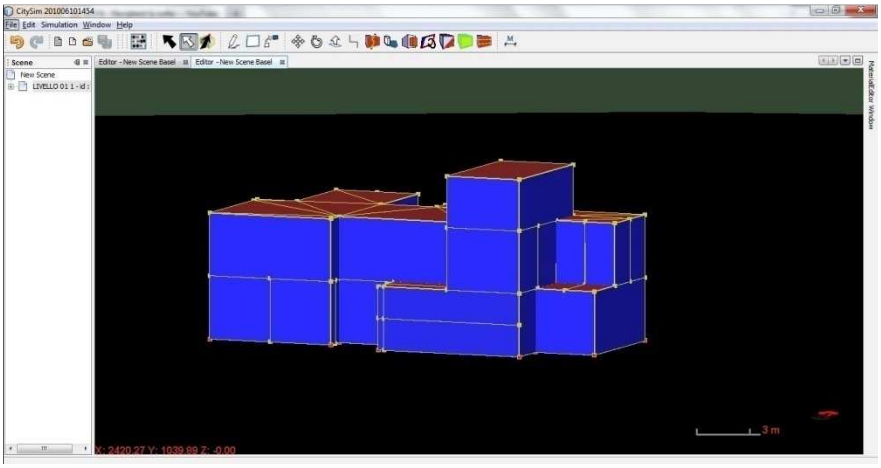


Figure 70 Villa. CitySim model

2.3.1 Location weather data

Latitude [°] : 25.62 North
Longitude [°]: 55.93 East
Altitude [m]: 31

The weather data are created by the program Meteonorm, using the weather station of the airport of Ras Al Khaimah. The table below shows the results of a comparison between the weather data produced by Meteonorm, and the weather data given by Dr Vigliotti.

TEMPERATURE. AVERAGE DAILY MEAN

Table 22 Villa. Temperature, average daily mean [°C]

Average daily mean [°C]

	Meteonorm	Vigliotti	Difference
January	18.96	18.42	0.54
February	20.32	20.60	-0.28
March	23.38	23.85	-0.47
April	27.27	28.07	-0.80
May	32.25	32.80	-0.55
June	34.17	34.80	-0.63
July	36.25	36.37	-0.12
August	35.76	36.04	-0.28
September	32.69	33.27	-0.58
October	29.39	29.60	-0.21
November	24.41	24.88	-0.47
December	20.95	20.77	0.18

WIND SPEED

Table 23 Villa. Wind speed [m/s]

	FF Wind speed [m/s]		
	Meteonorm	Vigliotti	Difference
January	1.99	2.04	-0.05
February	2.20	2.27	-0.07
March	2.40	2.37	0.03
April	2.41	2.51	-0.11
May	2.60	2.72	-0.12
June	2.60	2.72	-0.12
July	2.80	3.00	-0.20
August	2.60	2.85	-0.26
September	2.20	2.30	-0.10
October	1.89	1.92	-0.03
November	1.90	1.88	0.03
December	1.80	1.92	-0.12

WIND DIRECTION

Table 24 Villa. Wind direction [°]

	DD Wind direction [°]		
	Meteonorm	Vigliotti	Difference
January	238.87	218.00	20.87
February	232.32	223.00	9.32
March	203.71	224.00	-20.29
April	212.95	250.00	-37.05
May	195.12	257.00	-61.88
June	208.01	221.00	-12.99
July	179.76	168.00	11.76
August	209.19	178.00	31.19
September	189.23	200.00	-10.77
October	203.54	204.00	-0.46
November	217.06	222.00	-4.94
December	229.21	198.00	31.21

RELATIVE HUMIDITY

Table 25 Villa. Relative humidity [%]

RH Relative humidity [%]			
	Meteonorm	Vigliotti	Difference
January	69.41	73.20	-3.79
February	69.68	68.60	1.08
March	59.93	63.30	-3.37
April	49.61	52.40	-2.79
May	41.22	44.70	-3.48
June	47.42	52.20	-4.78
July	47.38	53.20	-5.82
August	49.67	52.00	-2.33
September	57.31	57.89	-0.57
October	59.26	61.67	-2.41
November	63.39	63.33	0.06
December	67.08	69.67	-2.58

2.3.2 Parameters of reference existing and Minergie Villa

Ground floor area: 226.24 [m²]

First floor area: 197.20[m²]

Roof area: 34.76 [m²]

Total: 458.20 [m²]

Ground floor net height: 3.4 [m²]

First floor net height: 3.35 [m²]

Roof net height: 2.60 [m²]

Every floor: 0.30 [m²]

Roof: 0.30 [m²]

Orientation: 11° NE

2.3.3 Parameters of reference existing Villa

BUILDING PROPERTIES

Volume [m³]: 1,615.28

Infiltration rate [per hour]: 0.7

Tmin [°C]: 5

Tmax[°C]: 25

Target temperature profile: no profile

OCCUPANCY PROFILE

Occupancy profile: no profile

Maximum number of occupants: 6

THERMAL REGULATION

HVAC: no HVAC

Heating energy converter: no heating energy converter

Start heating date [day]: 1

Stop heating date [day]: 365

Cooling energy converter: Heat pump

Start cooling date [day]: 1

Stop cooling date [day]: 365

Heat tank: standard

Cool tank: standard

Simulate thermal: true

HEAT PUMP

Maximum power source: 65,515,000 Wh

COP: 3

ηtech: 0.16

ηtech= COP/ ηcarnot

ηcarnot: Ti/ [Ti- Te]

ηcarnot= $\frac{(15+273.15)}{((15+273.15)-(30.62+273.15))}$

ηcarnot= 18.45

ηtech=$\frac{3}{18.45}$

Ti: internal temperature – ΔT

Te: external temperature

External temperature, 30.62°C, is the average daily mean temperature during the cooling period [March- November].

Table 26 Villa. Temperature, average daily mean from March to November [°C]

Month	T [°C]
March	23.38
April	27.27
May	32.25
June	34.17
July	36.25
August	35.76
September	32.69
October	29.39
November	24.41
Total	30.62

$\Delta T=10°C$

Source: air

WALL PROPERTIES

Short wave reflectance: 0.20

Glazing ratio [%]: 0.14

Percentage of window in front

Glazing G value: 0.58

G value is the coefficient of the permeability of total solar radiation energy
Glazing U value [W/m²K]: 2.84

U value is the conductance, expressed in W/m²K

Material: U= 1,289 W/m²K

Table 27 Existing villa. Material

Name	l [m]	p [Kg/m^3]	k[W/mK]	Cp [J/Kg°C]
Plaster	0.02	600	0.29	840
Cement	0.17	1100	0.34	880
Plaster	0.01	600	0.29	840

Where

l: thickness [m]

p: mass density [Kg/m³]

k: thermal conductivity [W/mK]

Cp: specific heat [J/Kg°C]

ROOF PROPERTIES

Short wave reflectance: 0.20

Glazing ratio [%]: 0.00

U value [W/m²K]: 1.8

FLOOR PROPERTIES

Short wave reflectance: 0.20

Glazing ratio [%]: 0.00

U value [W/m²K]: 1.8

SIMULATIONS RESULTS

Table 28 Existing villa. Energy consumption

Month	Heating Needs [Wh]	Cooling Needs [Wh]	DHW [J]	Fuel Consumption [J]	Electric Consumption [J]
1	0	0	0	0	0
2	0	-52446.7	0	0	9.20E+07
3	0	-1.71E+06	0	0	2.92E+09
4	0	-7.38E+06	0	0	1.27E+10
5	0	-1.73E+07	0	0	3.36E+10
6	0	-2.18E+07	0	0	4.45E+10
7	0	-2.55E+07	0	0	5.53E+10
8	0	-2.35E+07	0	0	5.01E+10
9	0	-1.62E+07	0	0	3.13E+10
10	0	-8.42E+06	0	0	1.53E+10
11	0	-1.37E+06	0	0	2.35E+09
12	0	-44959.4	0	0	8.18E+07

ENERGYPLUS RESULTS

Electricity end use chiller: 150.53 [kWh/m²a]

CITYSIM RESULTS:

Qs cooling: 268.88 [kWh/m²a]

Electric consumption is: 150.59 [kWh/m²a]

COP: 2.14

DIAGRAMS

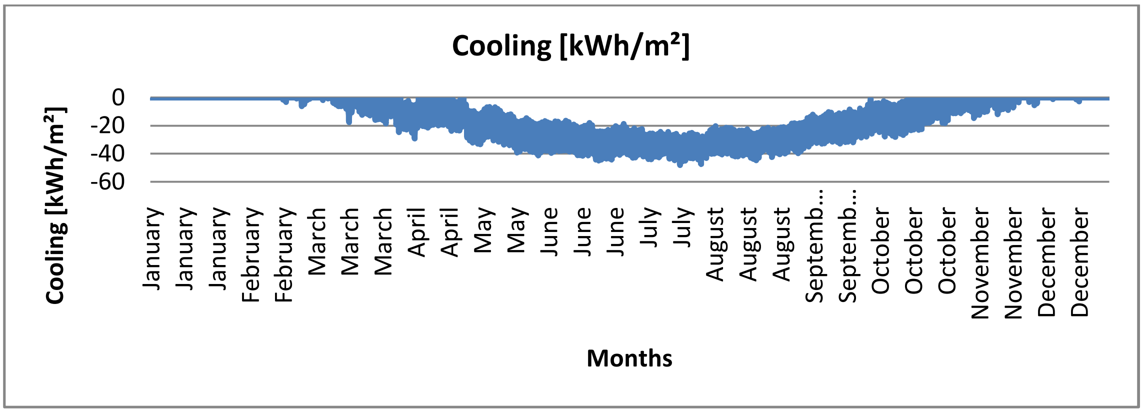


Figure 71 Existing villa. Cooling needs [kWh/m²]

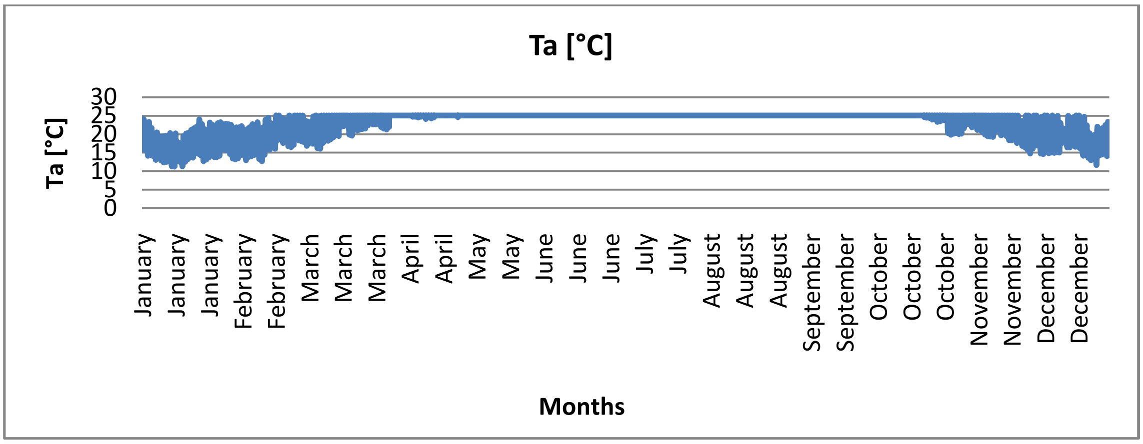


Figure 72 Existing villa. Internal temperature [°C]

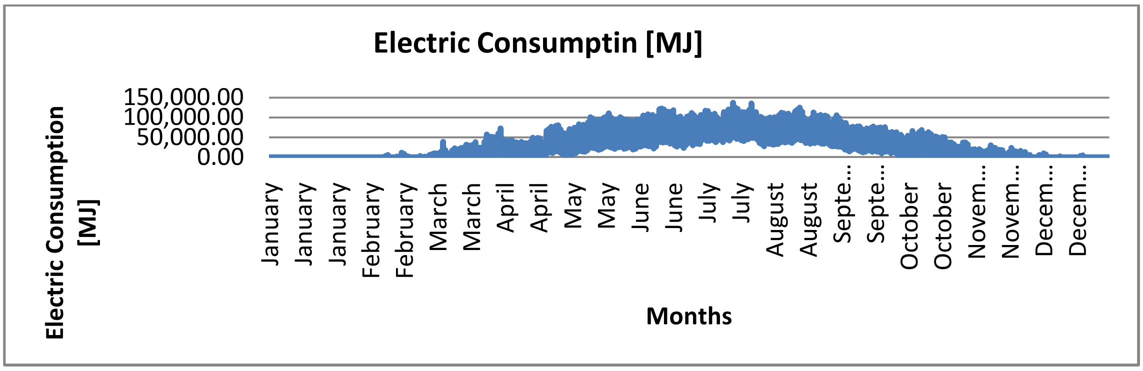


Figure 73 Existing villa. Electric consumption [MJ]

The main problem about this simulation is the COP value, the COP from excel is 2.14, not 3.00; but the electric consumption is the same for the two models.

YEARLY RESULTS

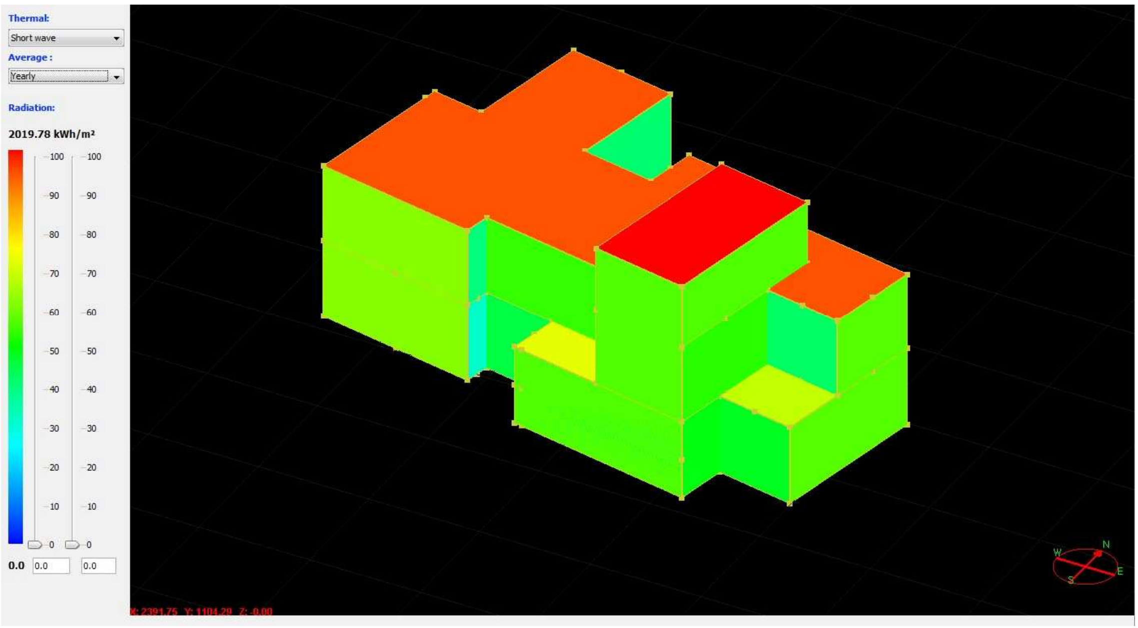


Figure 74 Existing villa. Yearly results. Max value 2019 [kWh/m²a]

Figure 75 Existing villa. Yearly results. Max value 2019 [kWh/m²a]

As we can see in the images of the yearly results there is a difference in solar irradiation on the roofs: the roof of the third floor receives the highest solar irradiation because the others roofs are covered by the shadows of the other wall and roof.

MONTHLY RESULTS

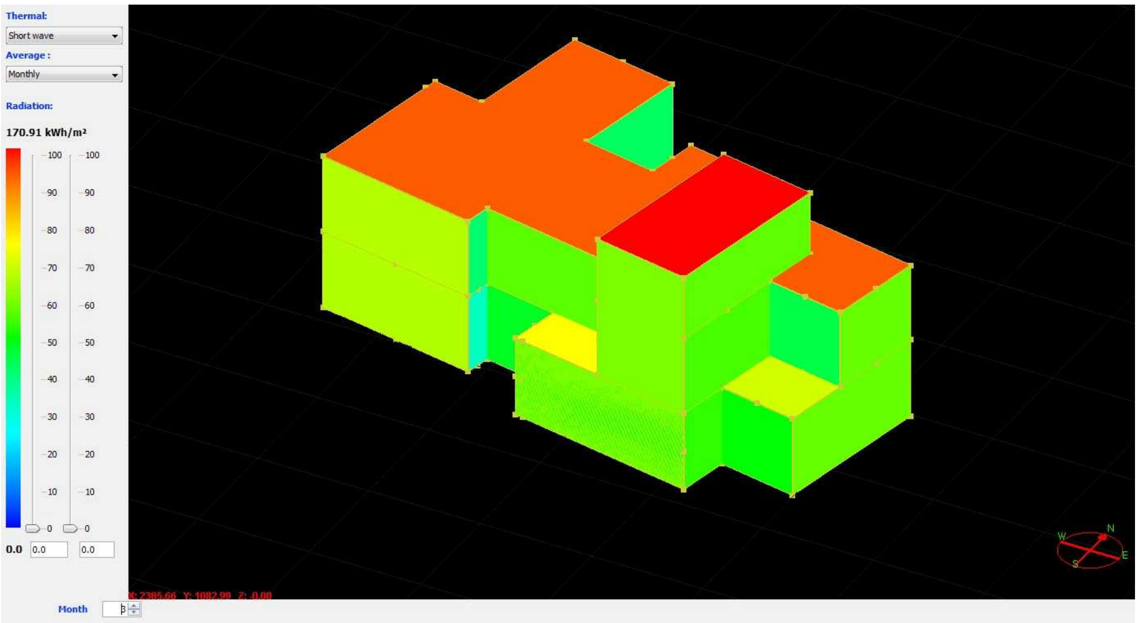


Figure 76 Existing villa. Monthly results. March. Max value 171[kWh/m²a].

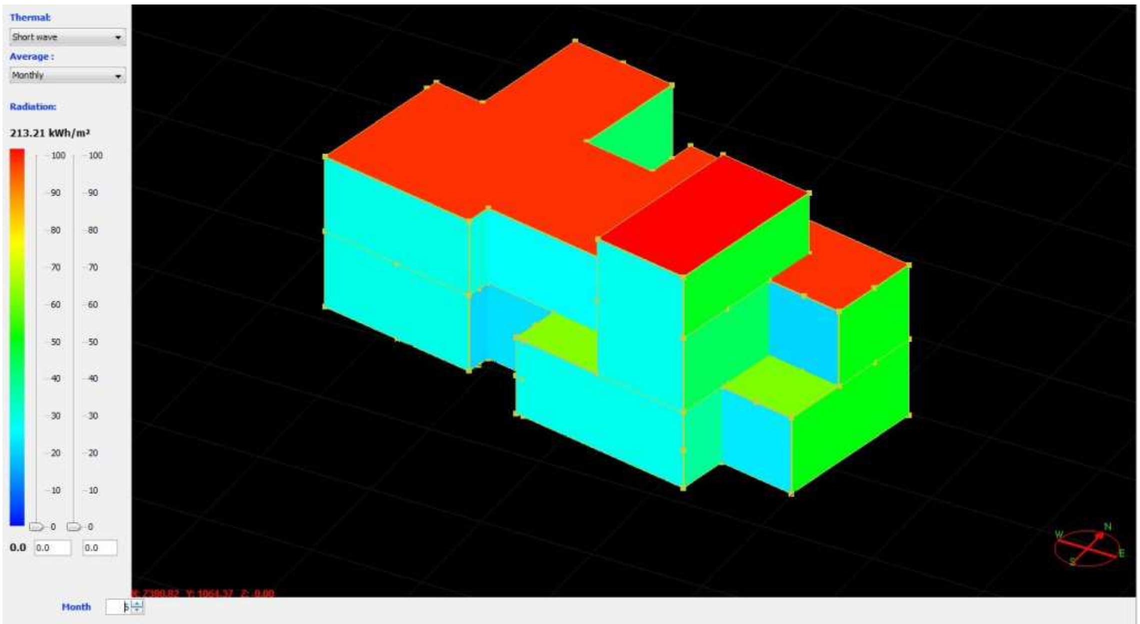


Figure 77 Existing villa. Monthly results. June. Max value 213[kWh/m²a].

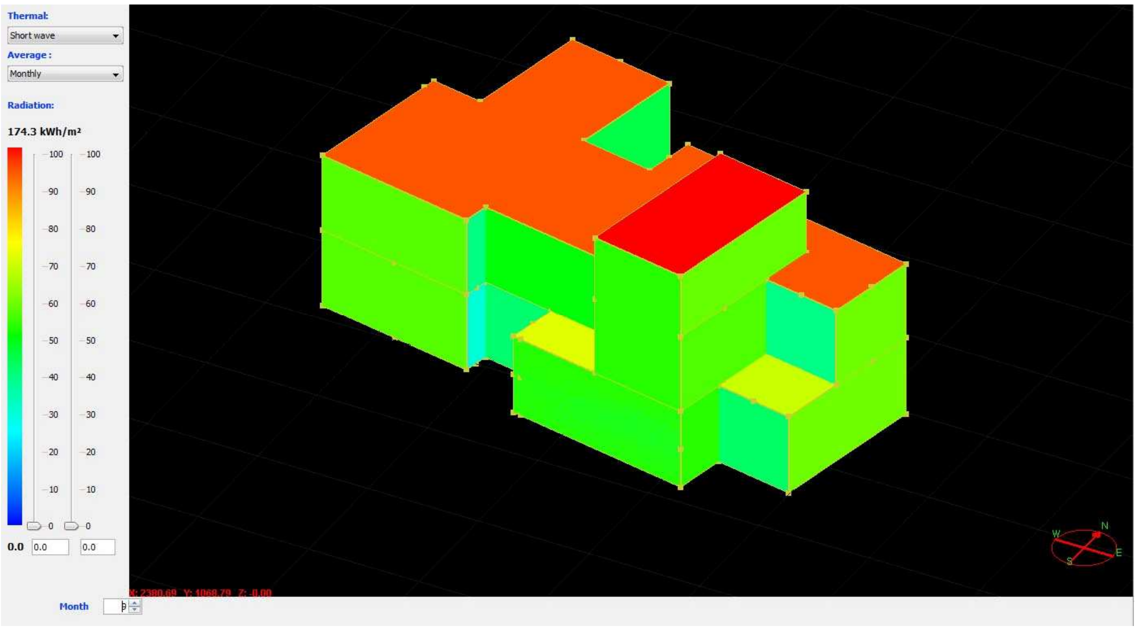


Figure 78 Existing villa. Monthly results. September. Max value 174[kWh/m²a].

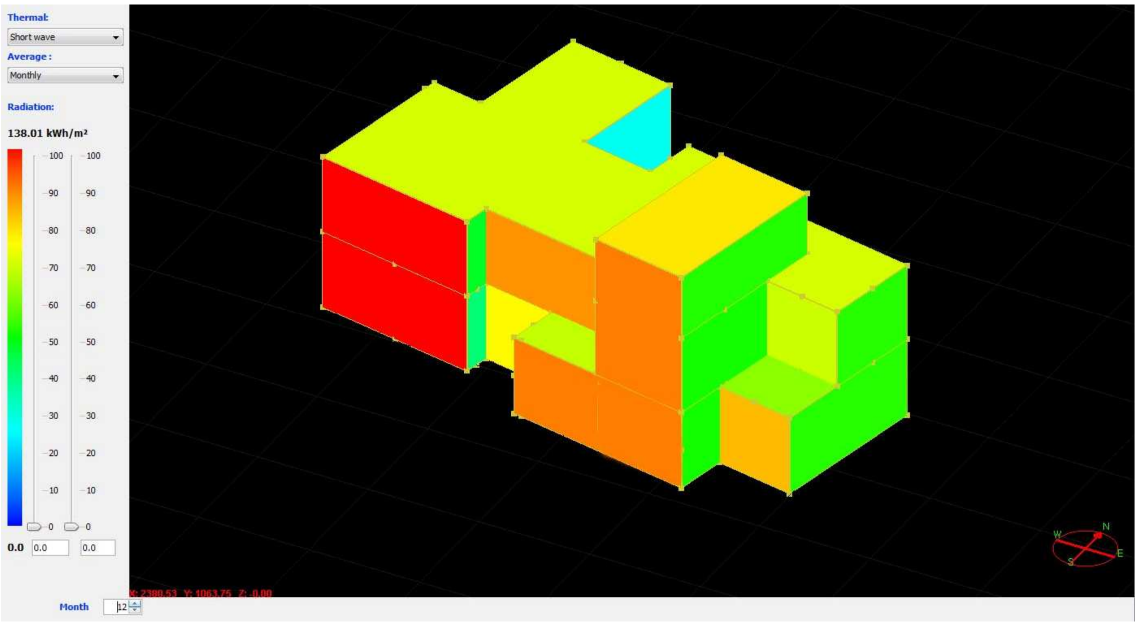


Figure 79 Existing villa. Monthly results. December. Max value 138 [kWh/m²a].

2.3.4 DIFFERENT VALUES AND NEW SIMULATIONS

In the next paragraph we again want to define the influence of a series parameters on the total energy consumption for cooling needs. These parameters are the eta tech of the heat pump and the infiltration rate.

ETA TECH

Changing the value of the Eta tech, and the temperature target, there are many differences between the models, as we can see below.

Eta tech 0.16, ΔT: 12

Te: 28 [°C]

Ti: 13[°C]

Eta carnot: 19.07

Qs: 268.88 [kWh/m²a]

Electric consumption is: 137.61[kWh/m²a]

COP: 2.40

Eta tech 0.18, ΔT: 12

Te: 30.62[°C]

Ti: 13 [°C]

Eta carnot: 16.24

Qs: 268.88 [kWh/m²a]

Electric consumption is: 122.32 [kWh/m²a]

COP: 2.70

Eta tech 0.22, ΔT: 15

Te: 30.62 [°C]

Ti: 10 [°C]

Eta carnot: 13.73

Qs: 268.88 [kWh/m²a]

Electric consumption is: 86.16 [kWh/m²a]

COP: 4.06

Eta tech 0.19, ΔT: 13

Te: 30.62 [°C]

Ti: 12 [°C]

Eta carnot: 15.31

Qs: 268.88 [kWh/m²a]

Electric consumption is: 110.47 [kWh/m²a]

COP: 3.04

INFILTRATION RATE

Infiltration rate 0.00

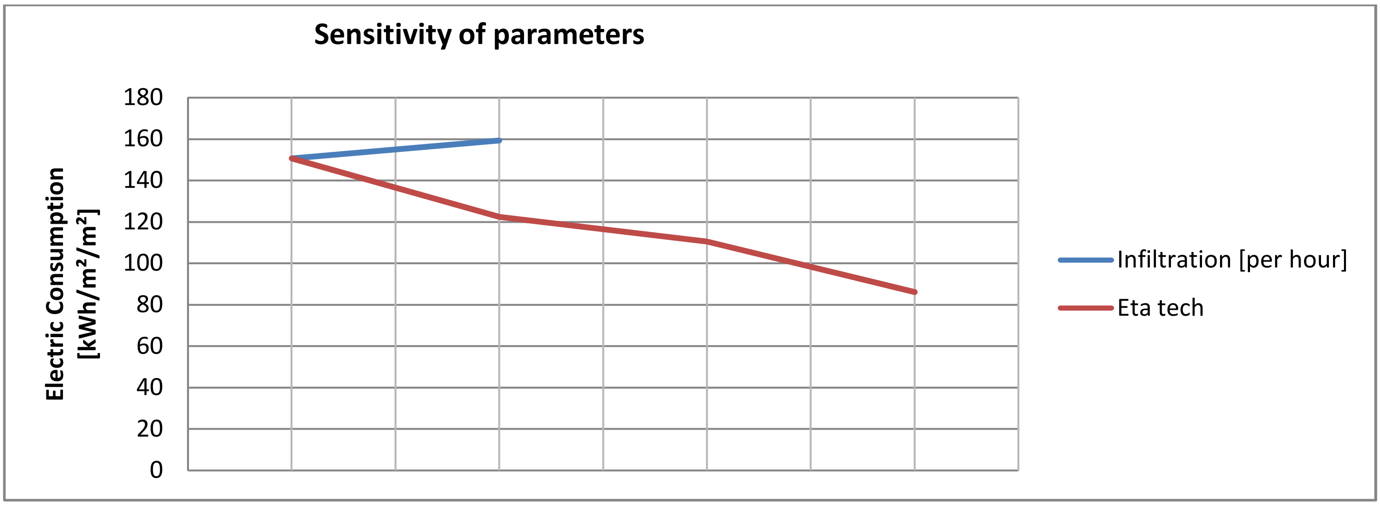
Qs: 234.25 [kWh/m²a]

Electric consumption is: 130.25 [kWh/m²a]

Infiltration rate 1.00

Qs: 283.83 [kWh/m²a]

Electric consumption is: 159.34 [kWh/m²a]



0.7	1				Infiltration [per hour]
0.16	0.18		0.19	0.22	Eta tech

Figure 80 Existing villa. Sensitivity of parameters

2.3.5 Parameters of reference Minergie Villa

BUILDING PROPERTIES

Volume [m³]: 1,615.28

Infiltration rate [per hour]: 0.1

Tmin [°C]: 5

Tmax[°C]: 25

OCCUPANCY PROFILE

Target temperature profile: no profile

Maximum number of occupants: 6

THERMAL REGULATION

HVAC: no HVAC

Heating energy converter: no heating energy converter

Start heating date [day]: 1

Stop heating date [day]: 365

Cooling energy converter: Heat pump

Start cooling date [day]: 1

Stop cooling date [day]: 365

Heat tank: standard

Cool tank: standard

Simulate thermal: true

HEAT PUMP

Maximum power source: 65’515’000 [Wh]

COP: 4

COP = quantity of heat-cool delivered / energy required by pump

For example, a COP of about 3.5 means that the heat pump can remove heat at a rate of about 3.5 [KW] while consuming about 1 [kW] of electrical energy.

ηtech: 0.20

ηtech= COP/ ηcarnot

ηcarnot: Ti/ [Ti- Te]

ηcarnot= $\frac{(16+273.15)}{((16+273.15)-(30.62+273.15))}$

ηcarnot= 19.78

ηtech=$\frac{4}{19.78}$

Ti: internal temperature – ΔT

Te: external temperature

External temperature, 30.62 [°C], is the average daily mean temperature during the cooling period [March-November].

ΔT=9[°C]

Source: air

WALL PROPERTIES

Short wave reflectance: 0.20

Glazing ratio: 0.14

Glazing G value: 0.162
Glazing U value [W/m²K]: 1.00

Material: U= 0.20 [W/m²K]

Table 29 Minergie villa. Material

Name	l [m]	p [Kg/m³]	k [W/mK]	Cp[J/Kg°C]
Plaster	0.02	600	0.29	840
Cement	0.17	1100	0.34	880
Isolation	0.10	30	0.04	840
Plaster	0.01	600	0.29	840

Where

l: thickness [m]

p: mass density [Kg/m³]

k: thermal conductivity [W/mK]

Cp: specific heat [J/Kg°C]

ROOF PROPERTIES

Short wave reflectance: 0.20

Glazing ratio [%]: 0.00

U value [W/m²K]: 0.20

FLOOR PROPERTIES

Short wave reflectance: 0.20

Glazing ratio [%]: 0.00

U value [W/m²K]: 0.20

SIMULATIONS RESULTS

Table 30 Minergie villa. Energy consumption.

Month	Heating Needs [Wh]	Cooling Needs [Wh]	DHW [J]	Fuel Consumption [J]	Electric Consumption [J]
1	0	0	0	0	0
2	0	0	0	0	0
3	0	-340162	0	0	5.43E+08
4	0	-1.58E+06	0	0	2.38E+09
5	0	-3.44E+06	0	0	5.77E+09
6	0	-4.19E+06	0	0	7.33E+09
7	0	-4.92E+06	0	0	9.14E+09
8	0	-4.60E+06	0	0	8.42E+09
9	0	-3.22E+06	0	0	5.40E+09
10	0	-1.86E+06	0	0	2.96E+09
11	0	-276046	0	0	4.64E+08
12	0	0	0	0	0

ENERGYPLUS RESULTS

Utility use per total floor area

Electricity end use chiller: 25.09 [kWh/m² y]

CITYSIM RESULTS:

Qs cooling: 53.33 [kWh/m² y]

Electric consumption is 25.71 [kWh/m² y]

COP: 2.57

DIAGRAMS

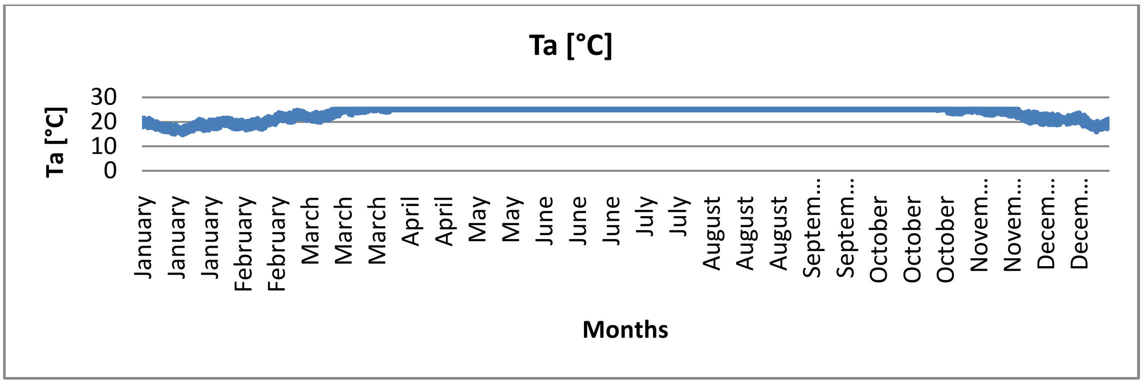


Figure 81 Minergie villa. Internal temperature [°C]

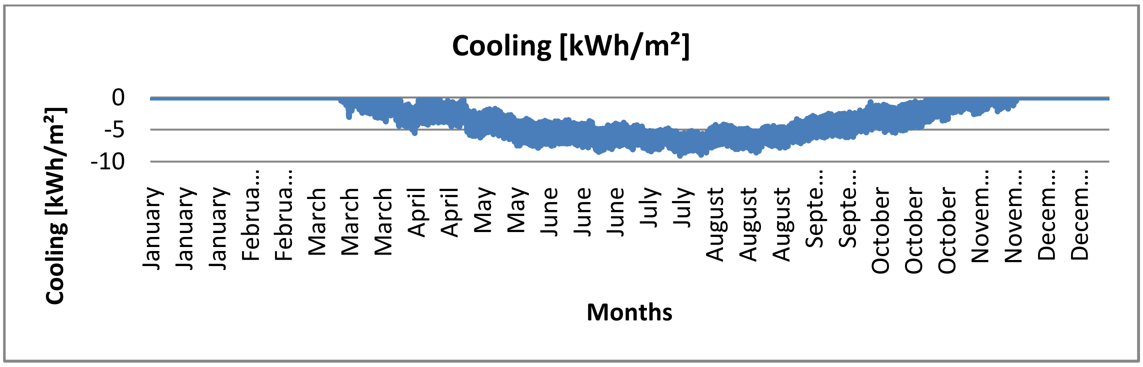


Figure 82 Minergie villa. Cooling needs [kWh/m²]

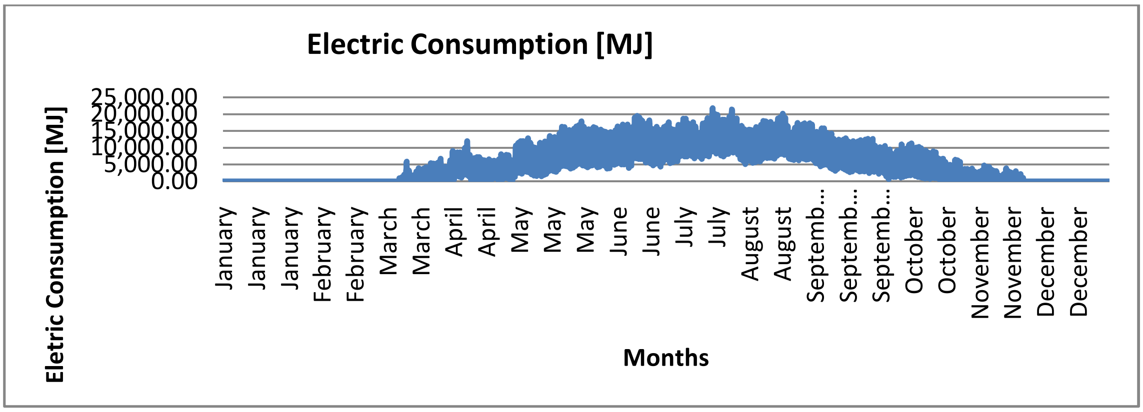


Figure 83 Minergie villa. Electric consumption [MJ]

CONCLUSION

The main problem about this simulation is the COP value: the COP from excel is 2.57, not 4.00; but the electric consumption is the same for the two models.

From the geometry of the model, there can be seen some differences: in particular there is no the staircase in the roof plan, as opposed to the architectural plan.

2.3.6 Different values and new simulations

In the next paragraph we again define the influence of series parameters, as the eta tech of the heat pump and the infiltration rate.

ETA TECH

Changing the value of the Eta tech, and the temperature target, there are many differences between the models, as we can see below.

Eta tech 0.26, ΔT: 12

Te: 30.62 [°C]

Ti: 13 [°C]

Eta carnot: 15.31

Qs: 53.33 [kWh/m² y]

Electric consumption is: 17.28 [kWh/m² y]

COP: 3.97

Eta tech 0.29, ΔT: 15

Te: 30.62 [°C]

Ti: 10 [°C]

Eta carnot: 13.73

Qs: 53.33 [kWh/m² y]

Electric consumption is: 13.30 [kWh/m² y]

COP: 5.50

Eta tech 0.22, ΔT: 10

Te: 30.62 [°C]

Ti: 15 [°C]

Eta carnot: 18.44

Qs: 53.33 [kWh/m² y]

Electric consumption is: 22.38 [kWh/m² y]

COP: 2.98

INFILTRATION RATE

Changing infiltration rate:

Infiltration rate [per hour]: 1.00

Qs: 97.58[kWh/m² y]

Electric consumption: 47.31 [kWh/m² y]

Infiltration rate [per hour]: 0.5

Qs: 72.77[kWh/m² y]

Electric consumption: 35.24 [kWh/m² y]

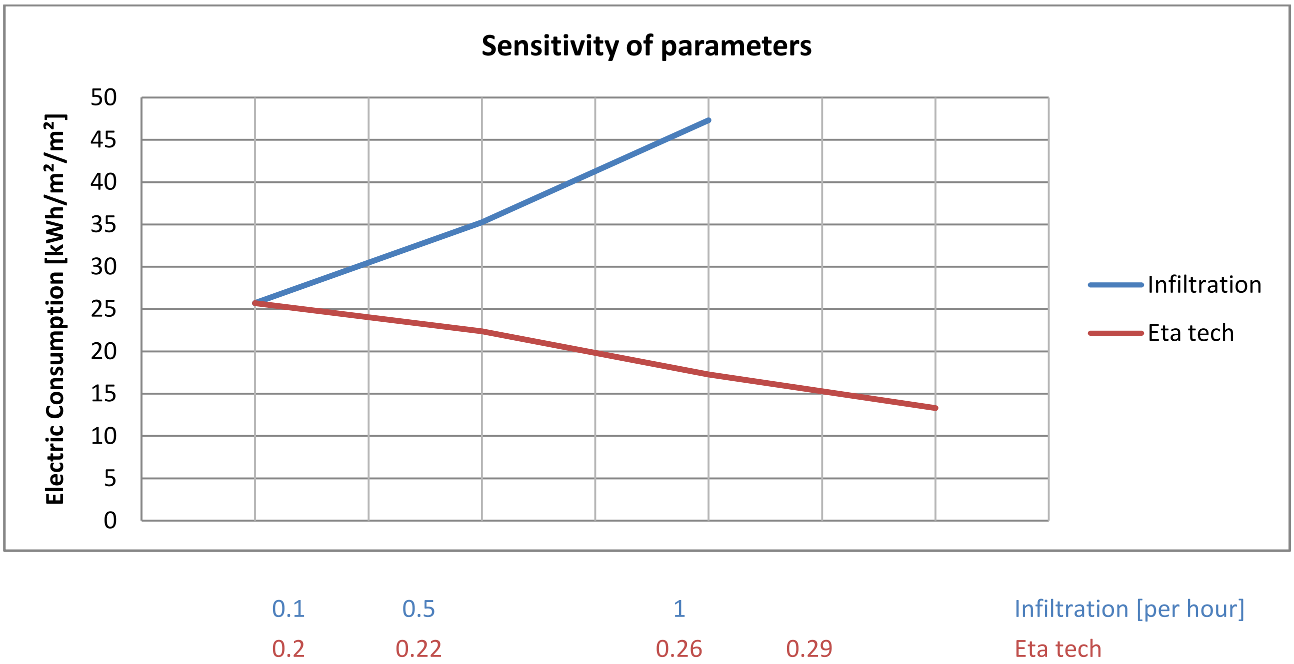


Figure 84 Minergie villa. Sensitivity of parameters

2.3.7 COMPARISON BETWEEN THE TWO MODELS

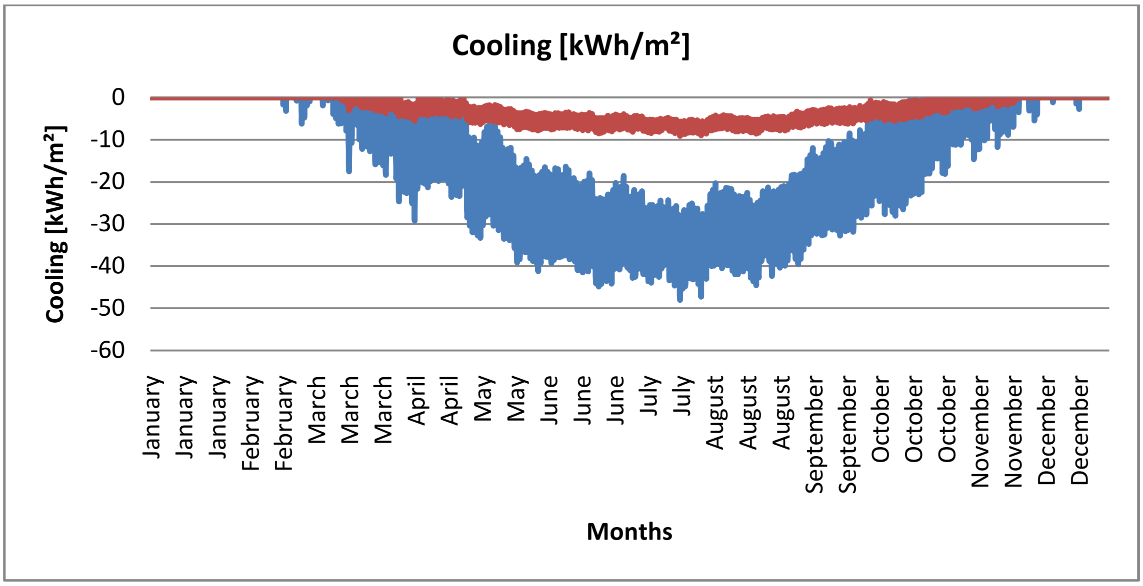


Figure 85 Villa.Comparison: cooling needs [kWh/m²]

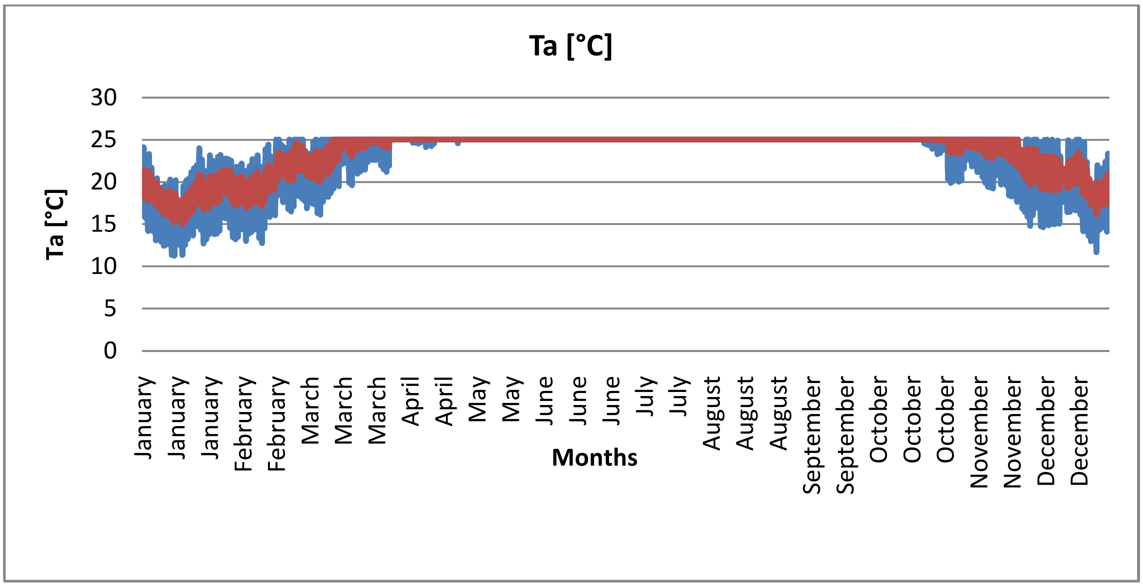


Figure 86 Villa. Comparison: internal temperature [°C]

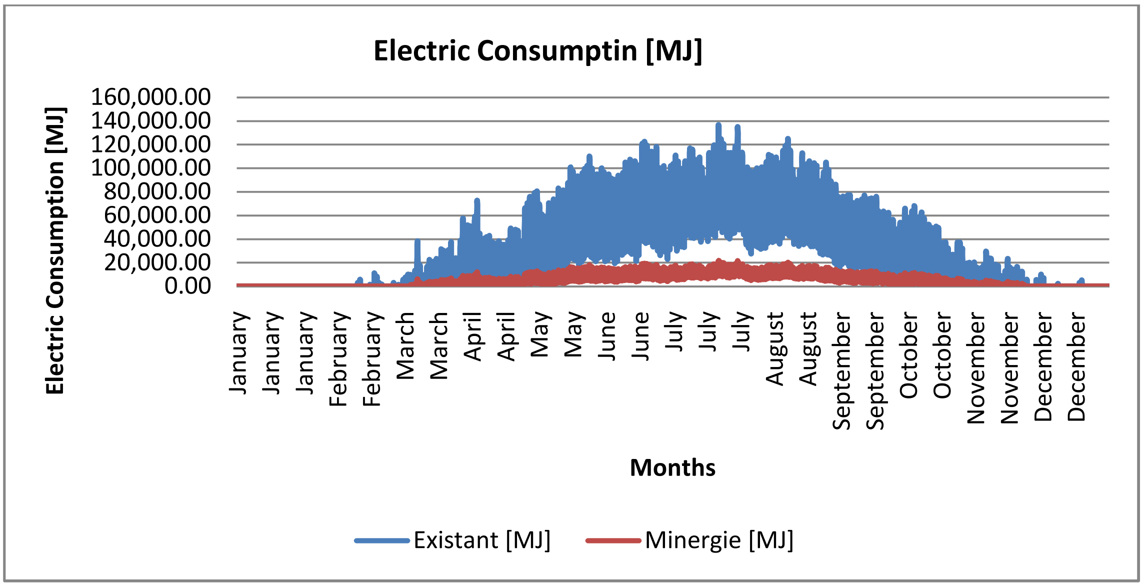


Figure 87 Villa. Comparison: electric consumption [MJ]

2.4 CONCLUSION

In this chapter we've analyzed the Minergie standards in UAE. Starting from the simulation made by Maria Papadopoulou and Aabid Fouad, with the software Energyplus. We've compared the two software and we've seen that CitySim can achieve correct results. Indeed we've defined the impact of the parameters, as the infiltration rate, or the eta tech of the heat pump. We've seen that the infiltration rate is one of the most important element to achieve good simulation result.

With these simulation we've studied how to achieve the Minergie Standard in UAE, as we can see in the table below.

Parameters	Minergie	Units
U value roof	0.2	[W/m²K]
U value walls	0.2	[W/m²K]
U value windows	1.0	[W/m²K]
G value windows	0.5	[-]
Shading factor	0.8	[-]
Air infiltration through cracks, open windows	0.05	[per hour]
EER for cooling machine	4	[-]

Table 31 Minergie Standard in UAE

These parameters will be usefully for the definition of the EPFL Masterplan in Ras Al Khaimah, achieving Minergie Standards.

3.0 MASTERPLAN A AND B

3.1 BIOCLIMATIC ELEMENTS OF THE MASTERPLAN

To define a correct analysis of the newly established Masterplan, it was important to define the main target values for the building. The values were taken from the Middle East Minergie standard, proposed by Maria Papadopoulou and Aabi Fouad. The preliminary indications were defined by Dr Vigliotti, the Dean of the EPFL Middle East. The documentation prepared by him, gives the surface area as the main reference value as well as the main concepts.

LOCALIZATION

Latitude:25.634098 [25° 38' 2.75'' N]
Longitudine:55.843849 [55° 50' 37.86'' E]

The area concerned by the Masterplan is in Ras al Khaimah, in the desert, precisely on the crossroads of the main road through the Emirates, and the Airport Road that connects the city of Ras Al Khaimah with the international airport. In this area will be developed the new “Knowledge city”, a modern campus for an international University.

Figure 88 RAK Masterplan[26]

According to Givoni[6]. and to vernacular Arab architecture, the elements that are important in the definition of a bioclimatic approach to the project are solar irradiation, wind, levels and gradients of the floor, street orientation and courtyards.

Solar radiation

The high solar radiation is a source of discomfort, this is why it is important to reduce solar gain, with a correct orientation of the building [North- South orientation, with windows on the South side, reducing the opening in the East- West side]. Sunshades and screens are essential to reduce the solar gain, as is the positioning of the windows on the high part of the walls.

[6] Baruch Givoni is Israeli Architect, one of the most recognize specialists in bio-climatic architecture.

Wind

As natural ventilation is essential in this climate the building must be positioned perpendicular to the main wind direction, improving cross ventilation and guiding the air flow through the buildings.

Levels and gradient

In the Emirates there is not much rain, hence it is important to create good drainage of rain water, by means of different topographic earth levels.

Street

The built form can guarantee adequate shadowing on pedestrian passages. As we can notice in the images below,this can be achieved by arcades, trees or atrium. Furthermore, it is important to define additional shading devices, such as wood structures, covered by vegetation all along the pedestrian street.

Courtyard houses

Courtyard houses can guarantee natural ventilation and reduced solar irradiation. We just have to know that the proportion between the ratio of the height of the external wall to the depth of the courtyard must not exceed 1:3, and the long axis must be perpendicular to the wind direction.

We have defined some elements that are common to the whole Masterplan. These elements regard the bioclimatic pattern, as the object of the Masterplan is to define the best efficiency of the buildings within an urban concept. Using the above bioclimatic elements, respecting the Minergie standard, we can define the position of the building, the correspondence between the different volumes as well as the shadowing, and influence the energetic consumption of the building.

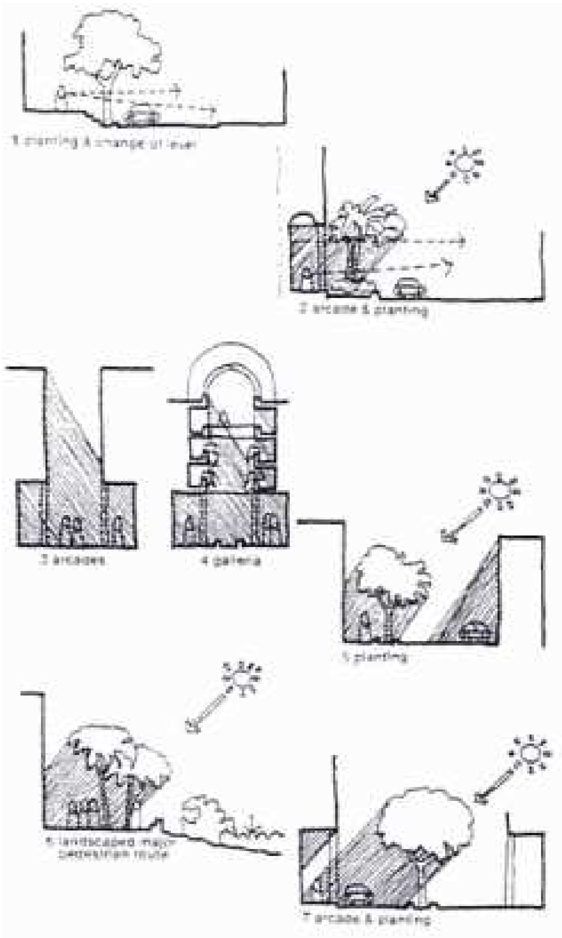


Figure 89Shadows analyse[1]

In the picture below we can see the area of the masterplan, in the loess desert of Ras Al Khaimah.

Figure 90 Panoramic view of the area

3.2 MASTERPLAN A

The general topic of this Masterplan is the cancer constellation. The main streets are defined by the main stars of the constellation: every star corresponds to a function, in this case *Decapoda* is a laboratory area, *Asellus Australis* is the social area and learning centre*, Acubens* is the sport's area, and *Tarf* is the residence.

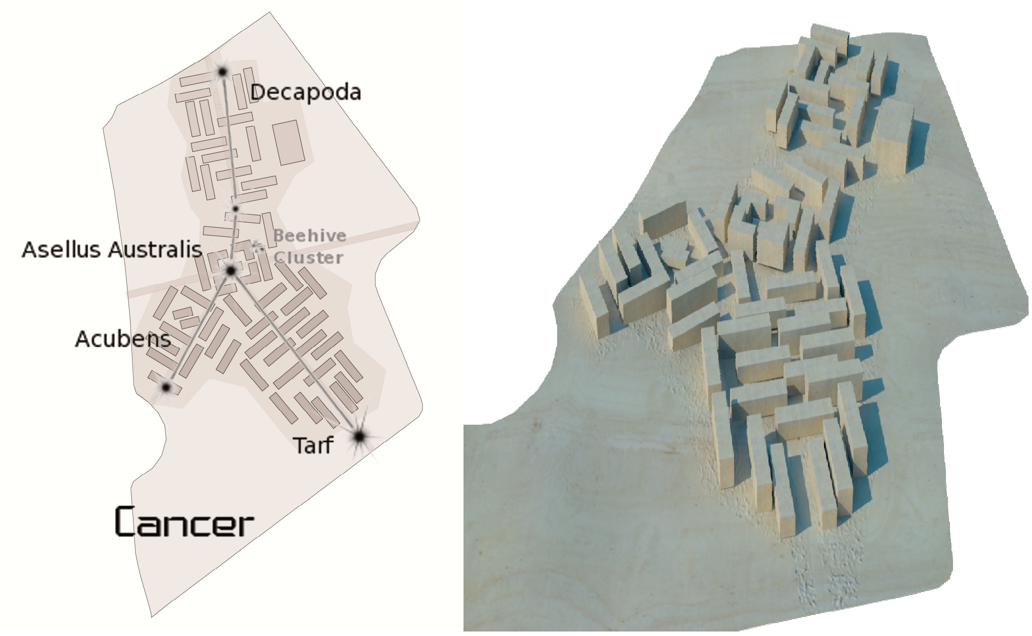


Figure 91 Masterplan A. Concept and panoramic view.

3.2.1 BIOCLIMATIC PATTERN

- External buildings are higher than internal ones, creating a solar and wind protection.
- Streets cross the buildings, and are shadowed by them.
- Streets are not regular, creating privacy and a variety of perspectives during the walk.
- No building courts, but courts created by buildings.
- Reduced distance between buildings in East- West direction, augmenting in North South, as proposed by Givoni: 1:5 [distance- high] in East- West direction, 2:2 in North- South direction.
- No many windows in building in the South side, to create a protection by the dune created by the South wind.
- Central and protected courts as places of social aggregation.
- Vegetation external and internal of the campus, protecting from wind [external] and canalizing wind in the buildings [internal].
- External higher building can be used as wind catcher.

3.2.2 FUNCTIONS

Figure 92 Masterplan A. Functions

As we can see in the table below the total surface meets the requirements defined byF. Vigliotti.

F. VIGLIOTTI

Lab+ infrastructure: 32,000.00 [m²]

Learning+ social area: 15,200.00 [m²]

Residence: 22,000.00 [m²]

Sport: 20,000.00 [m²]

Total: 89,200.00 [m²]

MASTERPLAN

Lab+ infrastructure: 32,100.00 [m²]

Learning+ social area: 15,250.00 [m²]

Residence: 21,600.00 [m²]

Sport: 20,400.00 [m²]

Total: 89,350.00 [m²]

3.2.3 VIEW

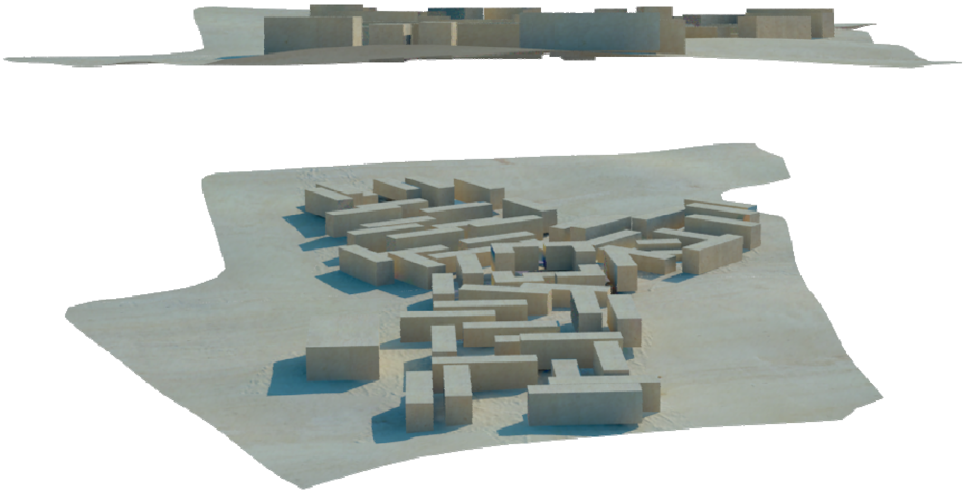


Figure 93 Masterplan A. North view

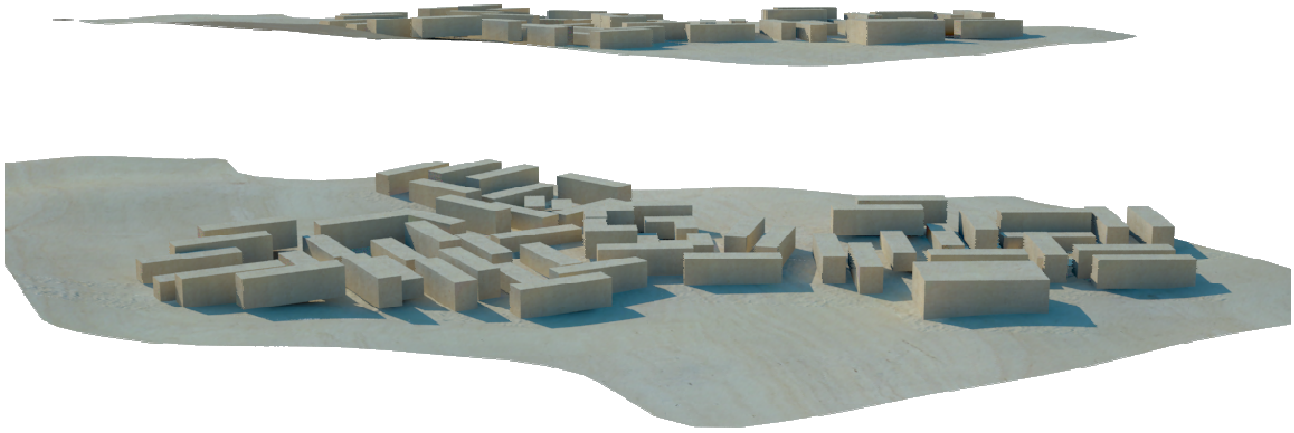


Figure 94 Masterplan A. East view

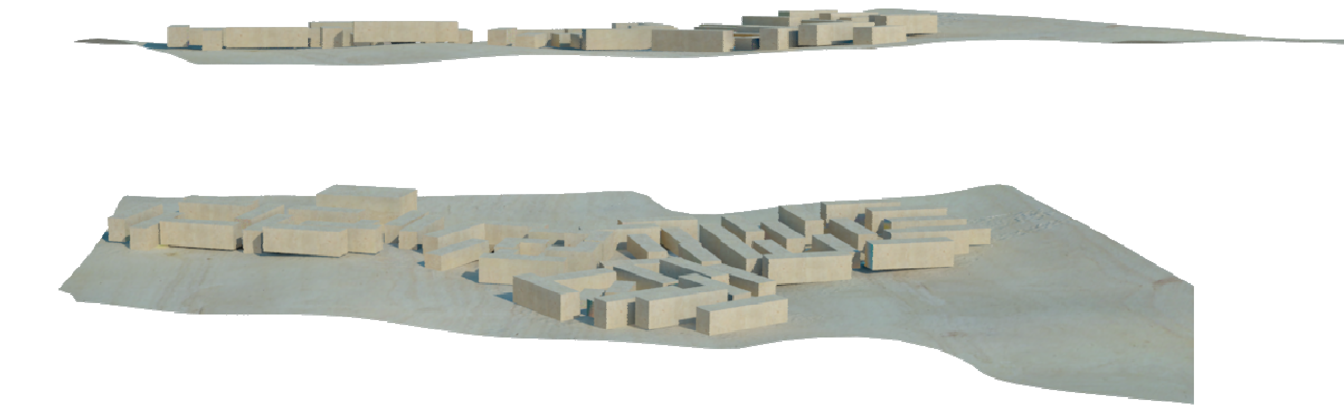


Figure 95 Masterplan A. West view

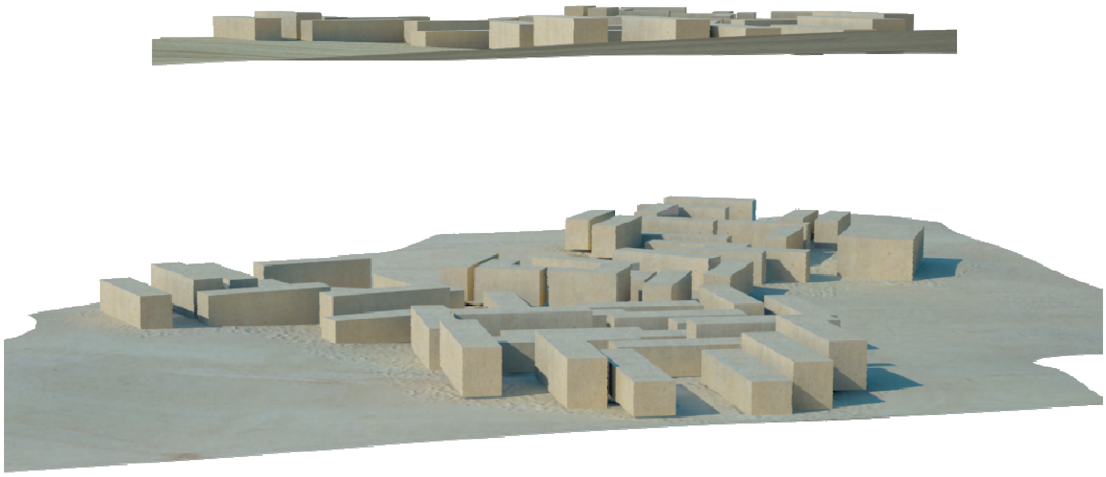


Figure 96 Masterplan A. South view

3.2.4 IMAGES

Figure 97 Masterplan A. Central street.

Figure 98 Masterplan B. View of the central street.

3.3 MASTERPLAN_ B

This Masterplan has been developed as a function of the **wind**. Givoni points out that that wind is one of the most important elements for a building's energy balance in such climates, due to its potential cooling effect during the summer. However, although wind can refresh during the summer, it can also create some problems, especially when there are sand storms; in this case it is important to canalize wind into buildings, while at the same time protecting them from storm. As we can see in the diagrams below, a speed of 4.57 [m/s] can be reached by Southern winds in August, which can carry sand storms from the desert. The main wind direction is North-westerly, with a maximal wind speed of 2.73 [m/s] in July. The wind speed is maximal during daytime, and minimal during night time, which can be a problem for night time ventilation.

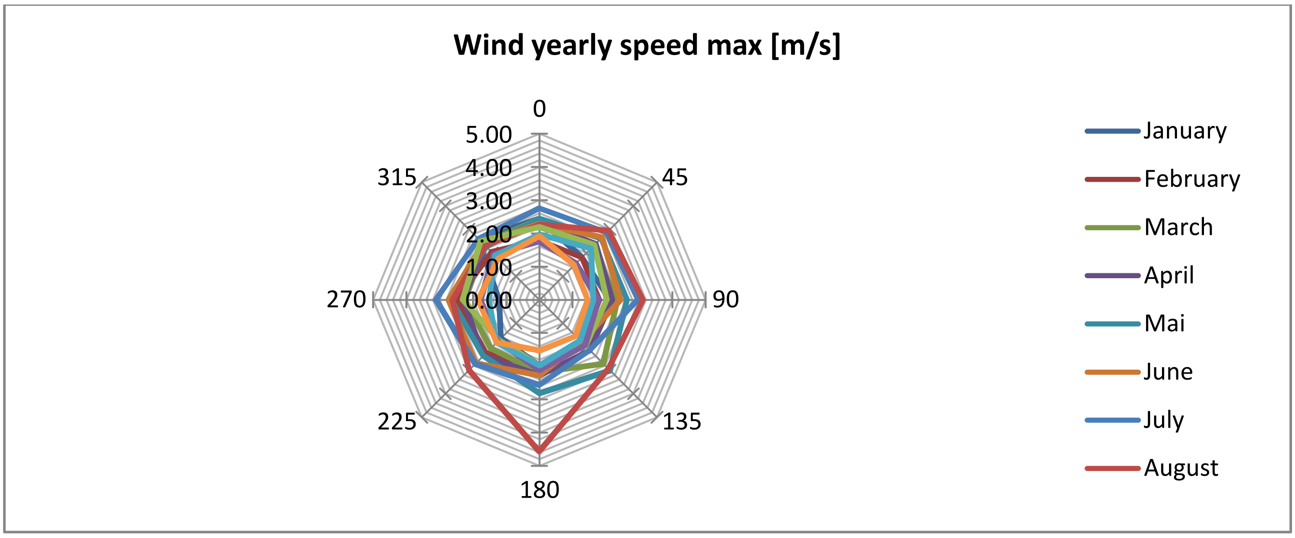


Figure 99 Wind yearly speed max [m/s]

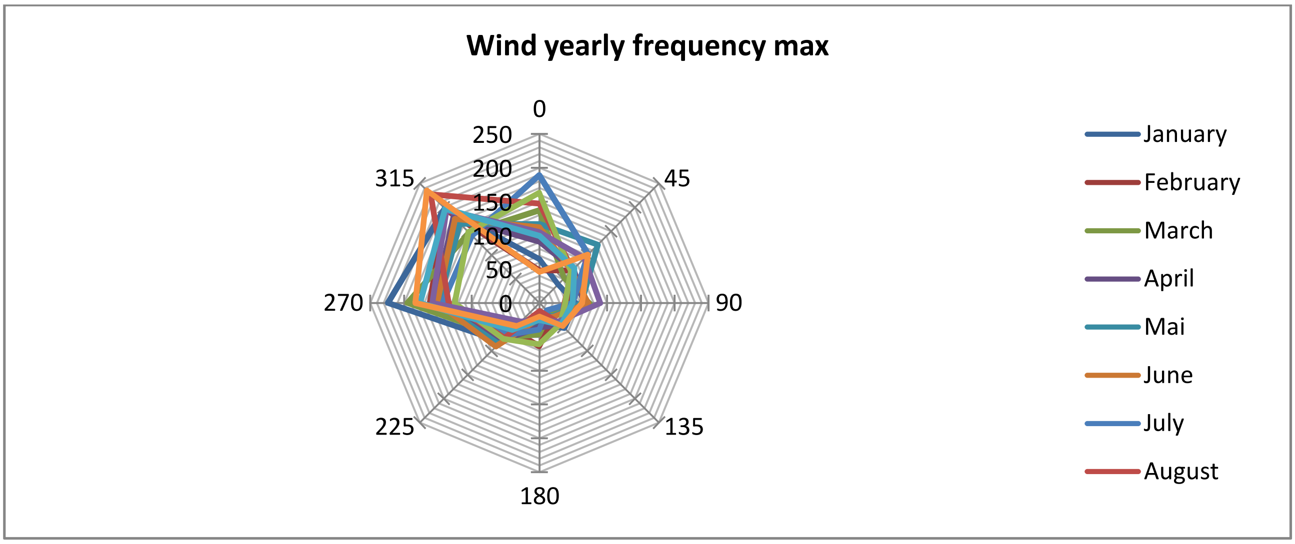


Figure 100 Wind yearly frequency max

Table 32 Wind speed max [m/s] and wind frequency max [°]

	Wind speed max [m/s]		Frequency max	
Months	Wind speed [m/s]	Direction [°]	Wind speed [m/s]	Direction [°]
January	2.59	NW	1.21	W
February	2.48	W	2.04	NW
March	2.72	SE	2.23	W
April	2.39	NE SW	2.31	NW
May	3.01	SE	2.27	NW
June	2.73	W	2.39	NW
July	3.11	W	2.76	N
August	4.57	S	2.31	NW
September	2.49	NW	2.19	N
October	2.12	S	1.93	NW
November	2.19	NE	1.88	NW
December	1.92	N	1.75	NW

Table 33 Average wind speed, defined for every part of the day

Part of the day	Average Wind speed [m/s]
Night- early morning [0.00- 08.00 h]	1.59
Day [8.00- 18.00 h]	2.78
Evening- night [18.00- 0.00]	1.97

In tropical areas the main winds comes from the West. With a precise analysis we have defined the main wind direction, intensity and frequency for every month of the year, in particular the intensity of the wind during the different parts of the day, confirming Givoni's precept, that winds are stronger during the day, and lower during night time. Buildings must be perpendicular to the wind direction, to obstruct wind flow. In this Masterplan the buildings can obstruct the wind, but also create a passage for it, as the gallery passages are opened upon the street.

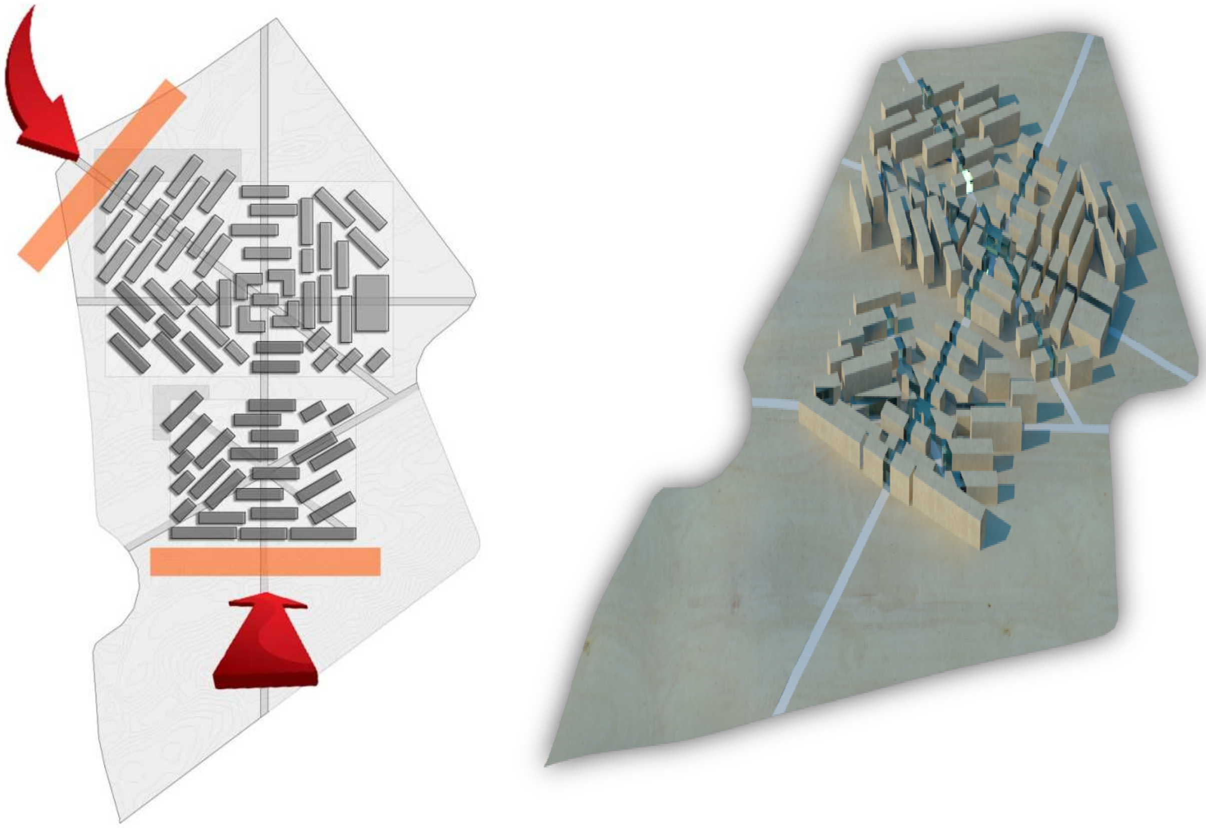


Figure 101 Masterplan B. Concept

The main form of the Masterplan is created by two rectangles, defined by the green open space. The passage created by buildings and the street is an open space, like a chimney where hot air can flow. On the ground floor there will be a small water gutter to increase the humidity of the air and the cooling effects. All the rooms and corridors that overlook the gallery benefit from this cold flux of air.

3.3.1 Bioclimatic pattern

- Streets are covered by buildings, creating shadows.
- Where streets meet buildings, they become an open gallery, with water along the ground, creating wind towers for cooling air.
- Streets are defined by the main wind direction, they can be open or closed by the wind intensity.
- No building courtyards, but courtyards created by buildings.
- Reduced distance between buildings in East- Western direction, larger distance in the North Southern direction, as proposed by Givoni: 1:5 [distance- high] in East- West direction, 2:2 in North- South direction.
- No many windows in building in the South side, to create a protection by the dune created by the South wind.
- Buildings positioned as a function of the wind: perpendicular to the main wind directions [NW and S].
- Central and protected courtyards, as a place of social aggregation.
- Vegetation is external and internal of the campus, protecting from wind [external] and canalizing wind into the building [internal].

3.3.2 FUNCTIONS

Figure 102 Masterplan B. Fonctions

VIGLIOTTI

Lab+ infrastructure: 32,000.00 [m²]

Learning+ social area: 15,200.00 [m²]

Residence: 22,000.00 [m²]

Sport: 20,000.00 [m²]

Total: 89,200.00 [m²]

MASTERPLAN

Lab+ infrastructure: 33,768.00 [m²]

Learning+ social area: 16,380.00 [m²]

Residence: 22,560.00 [m²]

Sport: 18,372.00 [m²]

Total: 91,080.00 [m²]

3.3.3 VIEW

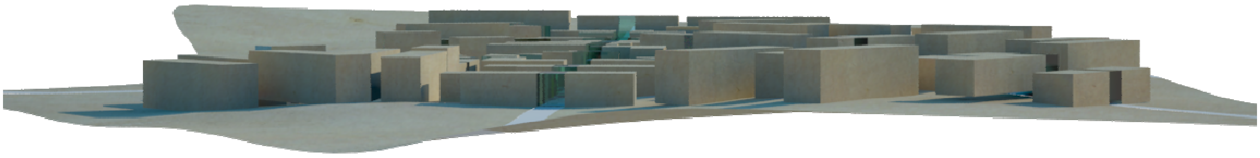


Figure 103 Masterplan B. North view

Figure 104 Masterplan B. East view

Figure 105 Masterplan B. West view

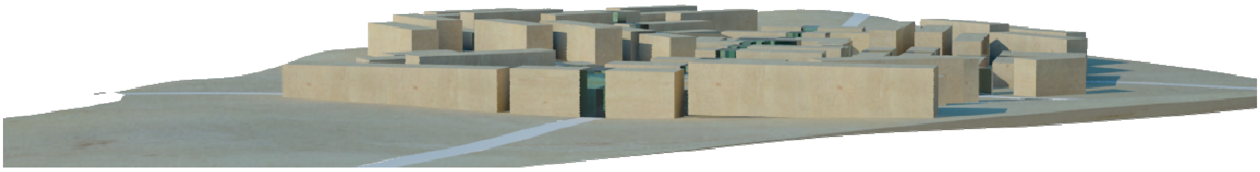


Figure 106 Masterplan B. South view

3.3.4 Images

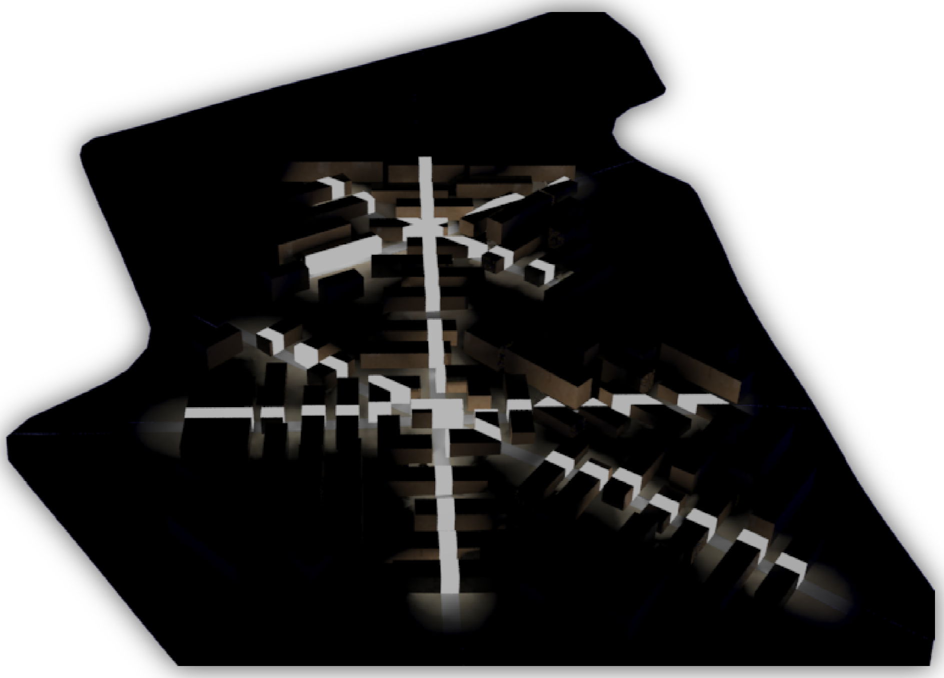


Figure 107 Masterplan B. Night view

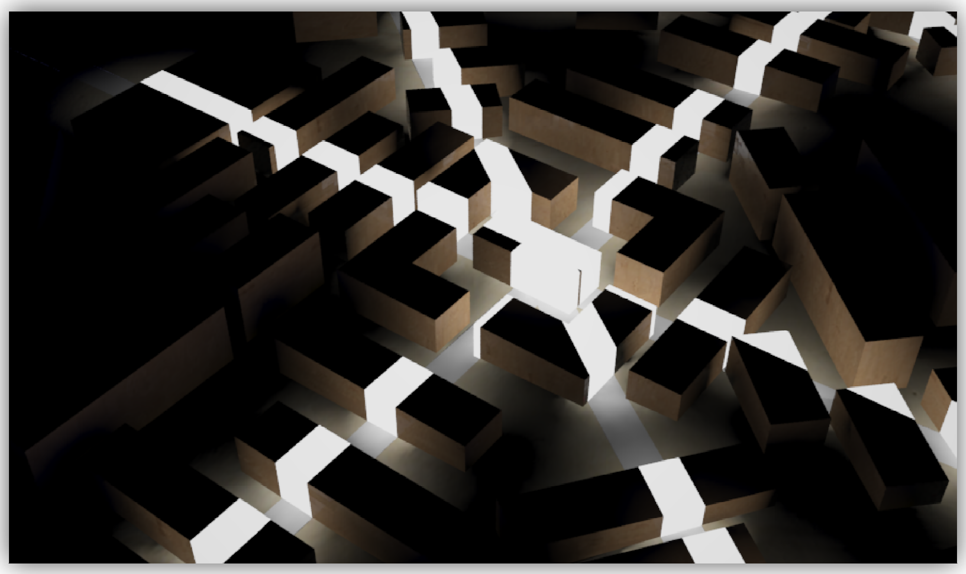


Figure 108 Masterplan B. Night view in the central court

4.0 SIMULATIONS WITH CITYSIM TO DEFINE THE MASTERPLAN

4.1 MORPHOLOGY_ DIFFERENT NUMBER OF FLOORS

The first simulation concerning the optimisation of the morphology of the Masterplan regards social centre of Masterplan A. In this case we have analysed different buildings with a different number of floors from three floors in the external buildings, to one floor in the central buildings.

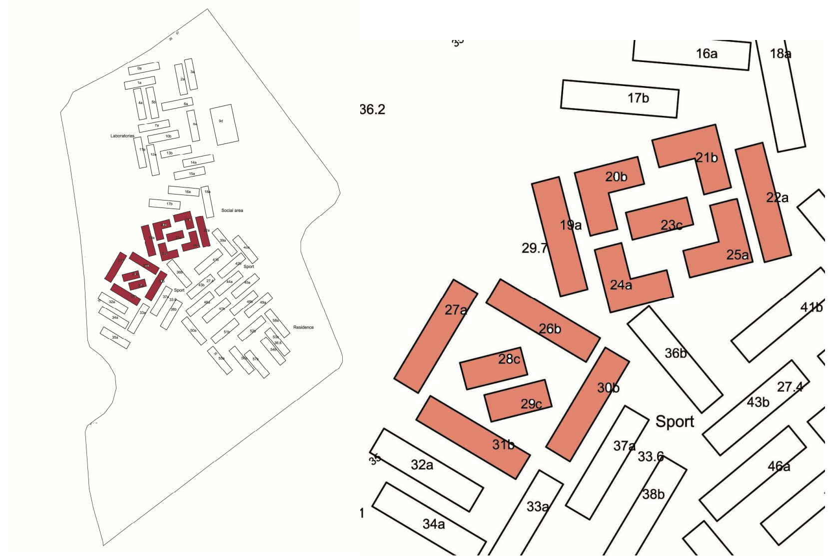


Figure 109 Masterplan B. Social Area

The first hypothesis was to put windows on the roof, to implement the natural ventilation of the building. As we can see from the results, the simulation with CitySim showed that the buildings are more efficient without windows upon roof.

CITYSIM PARAMETERS

We studied the six building with CitySim to define the heating and cooling needs. The parameters that characterise every building are defined below.

BUILDING PROPERTIES

Infiltration rate [per hour]: 0.05

Tmin [°C]: 5

Tmax[°C]: 26

Target temperature profile: no profile

Maximum number of occupants: 0

THERMAL REGULATION

HVAC: no HVAC

Heating energy converter: Cogen

Start heating date [day]: 1

Stop heating date [day]: 365

Cooling energy converter: Heat pump

Start cooling date [day]: 1

Stop cooling date [day]: 365

Heat tank: standard

Cool tank: standard

Simulate thermal: true

COGEN

The "Dachs" micro-cogeneration system was chosen (model G5.5, with natural gas).

Maximum power source [W]: 14,800.00

ηel: 0.27

$\eta tech$: 0.72

HEAT PUMP

Maximum power source [W]: 372,100.00

COP: 4

$\eta tech$: 0.25

$\eta tech$: COP/ $\eta carnot$

$\eta carnot$: Ti/ [Ti- Te]

$$\frac{[10 + 273.15]}{(10 + 273.15) - [28 + 273.15]}$$

Ti: internal temperature – ΔT

Te: external temperature

Temperature target [°C]: 15

Source: air

WALL PROPERTIES

Short wave reflectance: 0.20

Glazing ratio

The walls are divided in two parts, for the glazing ratio:

- E-W direction, with a 0.20 glazing ratio, or external wall;
- N-S direction, with a 0.50 glazing ratio, or internal wall.

Glazing G value [%]: 0.05

The G value is given by the mobile shades, which can reduce the solar gain to < 0.10. The G value without them is 0.50; this is why the G value is 0.05.
Glazing U value [W/m²K]: 1.00

PV ratio: 0.40

Material: U [W/m²K]= 0.15

Table 34Morphology. Different building. Material

Name	l [m]	p [Kg/m^3]	k [W/mK]	Cp [J/Kg°C]
Plaster	0.02	600	0.29	840
Isolation	0.25	30	0.04	840
Brick	0.12	2000	0.9	840
Plaster	0.01	600	0.29	840

Where

l: thickness [m]

p: mass density [Kg/m³]

k: thermal conductivity [W/mK]

Cp: specific heat [J/Kg°C]

ROOF PROPERTIES

Short wave reflectance: 0.20

Glazing ratio: 0.00 and 0.20

Glazing G value [%]: 0.05

Glazing U value [W/m²K]: 1.00

Uvalue [W/m²K]: 0.15

PV ratio: 0.50

FLOOR PROPERTIES

Short wave reflectance: 0.20

Glazing ratio: 0.00

Uvalue [W/m²K]: 0.15

PV ratio: 0.00

SIMULATION RESULTS

Table 35 Morphology. Different numbers of floors. Building with windows on the roof. Energy consumption

Building	Area	Coolings needs [kWh/m²]	Heatings needs [kWh/m²]	Floor	Difference [%]
19	1800	-31.27	2.66	3	-6.67
20	1056	-47.30	3.19	2	-61.34
21	1056	-35.79	3.40	2	-22.09
22	1800	-29.33	2.92	3	-0.04
23	324	-55.40	7.01	1	-88.98
24	1584	-40.96	2.40	3	-39.71
25	1584	-31.03	2.81	3	-5.85
26	1200	-32.81	3.56	2	-11.92
27	1800	-29.32	2.91	3	0.00
28	323	-55.66	7.00	1	-89.85
29	323	-55.37	6.77	1	-88.88
30	1200	-33.15	3.66	2	-13.09
31	1200	-33.39	3.52	2	-13.91

Table 36 Morphology. Different numbers of floors. Building without windows on the roof. Energy consumption

Building	Area	Coolings needs [kWh/m²]	Cooling Difference [%]	Heatings needs [kWh/m²]	Heating Difference [%]
19	1800	-28.78	7.98	2.37	11.10
20	1056	-43.51	8.01	2.71	15.06
21	1056	-32.06	10.44	2.95	13.12
22	1800	-26.85	8.45	2.63	9.87
23	324	-47.86	13.62	6.08	13.25
24	1584	-38.45	6.13	2.09	12.85
25	1584	-28.54	8.04	2.51	10.61
26	1200	-29.10	11.30	3.13	11.96
27	1800	-26.84	8.44	2.63	9.76
28	323	-48.11	13.55	6.07	13.27
29	323	-47.83	13.62	5.84	13.76
30	1200	-29.45	11.19	3.23	11.66
31	1200	-29.68	11.12	3.09	12.24

As we can see in Table 3 the difference between the two models is included between 6 and 14 [%], with a reduced energy consumption in the buildings without roof windows. The buildings with the highest consumption are numbers 23, 28 and 29, which use more than 47 [kWh/m²] with just one floor. For this reason we decided to proceed in the Masterplan with a minimum of two floors.

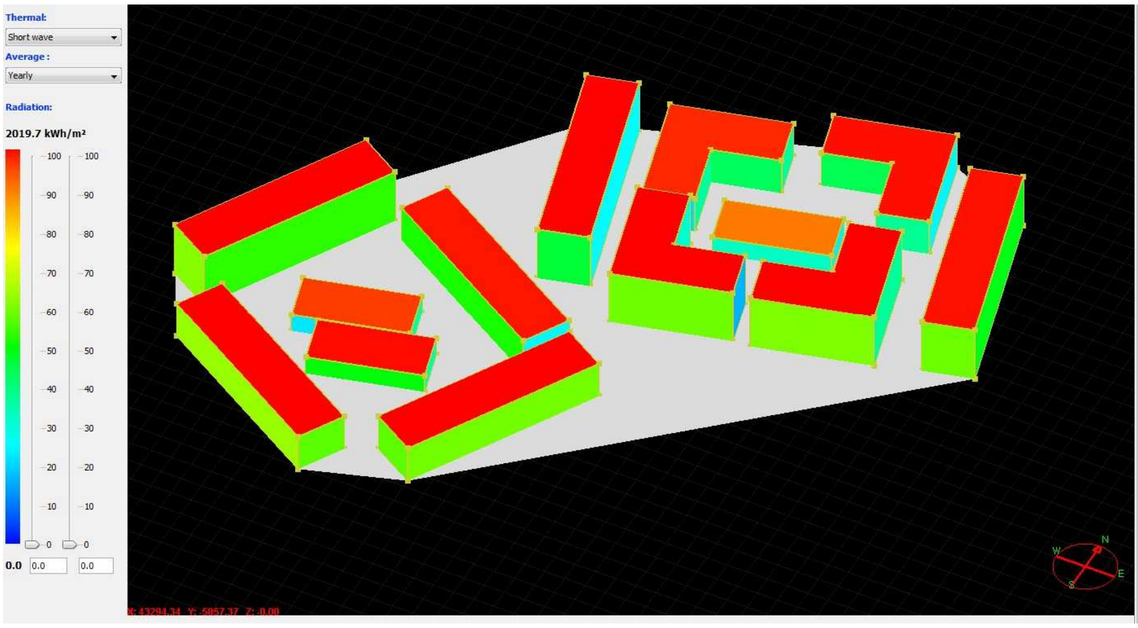


Figure 110 Morphology. Different number of floors. Yearly results.
Max value 2020 [kWh/m²]

4.2 MORPHOLOGY_ DIFFERENT BUILDING

The main topic in this paragraph is to define the best urban form by studying the urban morphology, as a bioclimatic pattern. We have defined four types of buildings, as we can see in the image below.

We defined two single buildings, A/B and C/D, respectively of 50*12 [m] and 25*12 [m], oriented North-South and East-West. Then we simulated two kinds of courtyard house, E and F/G, with a plan dimension of 50*50 [m] and 50*34 [m].

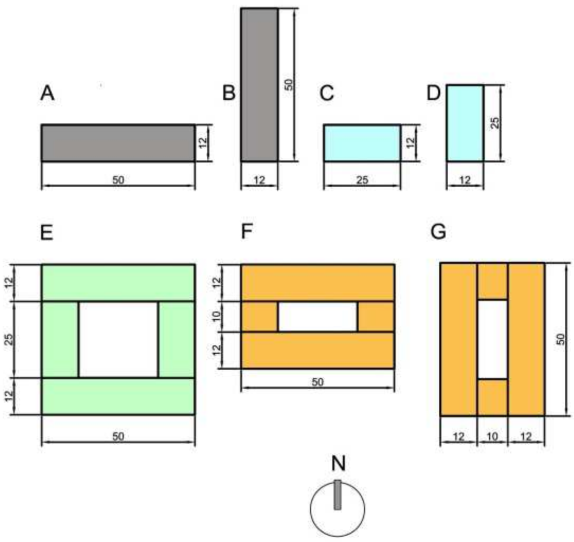


Figure 111Morphology. Different buildings. Plan

CITYSIM PARAMETERS

We studied the six building with CitySim, to define the heating and cooling needs. The parameters that characterise every building are defined below.

BUILDING PROPERTIES

Infiltration rate [per hour]: 0.05

Tmin [°C]: 5

Tmax[°C]: 26

Target temperature profile: no profile

Maximum number of occupants: 0

THERMAL REGULATION

HVAC: no HVAC

Heating energy converter: Cogen

Start heating date [day]: 1

Stop heating date [day]: 365

Cooling energy converter: Heat pump

Start cooling date [day]: 1

Stop cooling date [day]: 365

Heat tank: standard

Cool tank: standard

Simulate thermal: true

COGEN

The Dachs" micro cogeneration was chosen (model G5.5, with natural gas).

Maximum power source [W]: 14,800.00

ηel: 0.27

$\eta tech$: 0.72

HEAT PUMP

Maximum power source [W]: 372,100.00

COP: 4

$\eta tech$: 0.25

ηtech: COP/ ηcarnot

ηcarnot: Ti/ [Ti- Te]

$$\frac{[10 + 273.15]}{(10 + 273.15) - [28 + 273.15]}$$

Ti: internal temperature – ΔT

Te: external temperature

Temperature target [°C]: 15

Source: air

WALL PROPERTIES

Short wave reflectance: 0.20

Glazing ratio

The walls are divided into two parts, for the glazing ratio:

- E-W direction, with a 0.20 glazing ratio, or external wall;
- N-S direction, with a 0.50 glazing ratio, or internal wall.

Glazing G value [%]: 0.05

The G value is given by the mobile shades, that can reduce the solar gain to<0.10, as the G value without them is 0.50, this is why the G value is 0.05.
Glazing U value [W/m²K]: 1.00

PV ratio: 0.40

Material: U [W/m²K]= 0.15

Table 37 Morphology. Different building. Material

Name	l [m]	p [Kg/m^3]	k [W/mK]	Cp [J/Kg°C]
Plaster	0.02	600	0.29	840
Isolation	0.25	30	0.04	840
Brick	0.12	2000	0.9	840
Plaster	0.01	600	0.29	840

Where

l: thickness [m]

p: mass density [Kg/m³]

k: thermal conductivity [W/mK]

Cp: specific heat [J/Kg°C]

ROOF PROPERTIES

Short wave reflectance: 0.20

Glazing ratio: 0.00

Glazing G value [%]: 0.05

Glazing U value [W/m²K]: 1.00

Uvalue [W/m²K]: 0.15

PV ratio: 0.50

FLOOR PROPERTIES

Short wave reflectance: 0.20

Glazing ratio: 0.00

Uvalue [W/m²K]: 0.15

PV ratio: 0.00

4. 2.1 SIMULATION RESULTS_ TWO FLOORS

This simulation is related to the number of floors, in this case two-floor buildings. Building C shows the highest energy consumption for cooling needs, 36.95 [kWh/m²], and building E the lowest, 28.97 [kWh/m²].

Table 38 Morphology. Different buildings with two floors. Energy consumption and solar irradiation.

	Type A	Type C	Type E	Type F
	Orientation N/S	Orientation N/S	Orientation N/S	Orientation N/S
Heating [kWh/m²]	3.05	3.08	2.79	2.67
Cooling [kWh/m²]	33.75	36.95	28.97	29.32
Area [m²]	1200	600	3600	2880
Floor	2	2	2	2

4.2.2 SIMULATION RESULTS_ THREE FLOORS

The best results connected with heating and cooling needs are in the courtyard houses, with values from 26.24 to 26.91 [kWh/m²] for cooling needs. Type B also has good results, but these are related to the fact that it has a limited percentage of window areas (20% in E- W side, 40% in N-S side). Courtyard houses (type E, F, G) can guarantee a better protection from the sun, as we can see in the yearly average. Solar radiation upon the façade is higher on external houses and lower in the courtyards: we observed a minimum difference from internal to external of 179.80 [kWh/m²] on the North side, and a maximum difference of 682.5 [kWh/m²] on the West side. Therefore it is better to put windows in the internal courtyard. On the other hand, façades oriented South and West receive the highest solar radiation, whereas North and East oriented façades receive the lowest solar radiation. Windows should therefore be oriented North and East, and West and South oriented façades need to be protected by the solar radiation. Solar panels should be positioned on South and West facades to guarantee a maximum yield. As can be seen from the results, it is preferable to have higher façades in the Northern and Eastern orientation, to guarantee lower values of solar irradiation upon walls.

Table 39Morphology. Different building types with three floors. Energy consumption and solar irradiation.

	Type A	Type B	Type C	Type D	Type E	Type F	Type G
	Orientation N/S	Orientation E/W	Orientation N/S	Orientation E/W	Orientation N/S	Orientation N/S	Orientation E/W
Heating [kWh/m²]	2.5	1.88	2.68	2.1	2.54	2.23	2.23
Cooling [kWh/m²]	31.03	25.99	34.44	30.77	26.27	26.91	26.24
Area [m²]	1800	1800	900	900	5400	4320	4320
Floor	3	3	3	3	3	3	3
Yearly average							
External surface							
N [kWh/m²]	532.93	525.7	538.35	532.89	537.79	536.11	531.74
S [kWh/m²]	1158.27	2407.4	1211.14	1204.26	1148.72	1162.89	1145.87
W [kWh/m²]	1086.39	1184.15	1183.02	1179.36	1156.91	1147.39	1159.68
E [kWh/m²]	903.94	977.86	974.46	973.15	961.9	939.82	953.32
Internal surface							
N [kWh/m²]					357.99	264.59	242.49
S [kWh/m²]					838.68	590.71	535.1
W [kWh/m²]					812.57	563.69	477.15
E [kWh/m²]					700.11	473.74	550.87
Roof [kWh/m²]	1927.41	2005.84	2006.67	1990.61	1885.36	1850.15	1853.44
Difference external internal							
N [kWh/m²]					179.8	271.52	289.25
S [kWh/m²]					310.04	572.18	610.77
W [kWh/m²]					344.34	583.7	682.53
E [kWh/m²]					261.79	466.08	402.45

As we can see in the table below, the three-storey buildings have lower energy consumption for cooling and heating compared to the two-storey buildings. The highest difference is in building E, with a 9.32 [%]difference of cooling needs, as 2.70 [kWh/m²]. We can also define a maximal difference of +18.03% for heating needs in the type A building. We can affirm that a compact building, of three floors is better than building with just two floor. But the interesting element in this simulation is the solar irradiation upon the wall. The courtyard house can guarantee a reduced solar irradiation in the wall facing to the court, that means that the internal space have a better climate than the other. The maximal difference is in the wall facing to the court on the West side, with a difference of 682 [kWh/m²]: the external wall has a solar irradiation of 1159 [kWh/m²], and the internal one of 477 [kWh/m²]. That means a reduction of 58 [%] on solar irradiation.

Table 40Morphology. Different buildings. Difference between the two modes.

	Type A	Type C	Type E	Type F
	Orientation N/S	Orientation N/S	Orientation N/S	Orientation N/S
Heating [kWh/m²]	0.55	0.4	0.25	0.44
Cooling [kWh/m²]	2.72	2.51	2.7	2.41

Percentage	Type A	Type C	Type E	Type F
Heating [%]	18.03	12.99	8.96	16.48
Cooling [%]	8.06	6.79	9.32	8.22

IMAGES

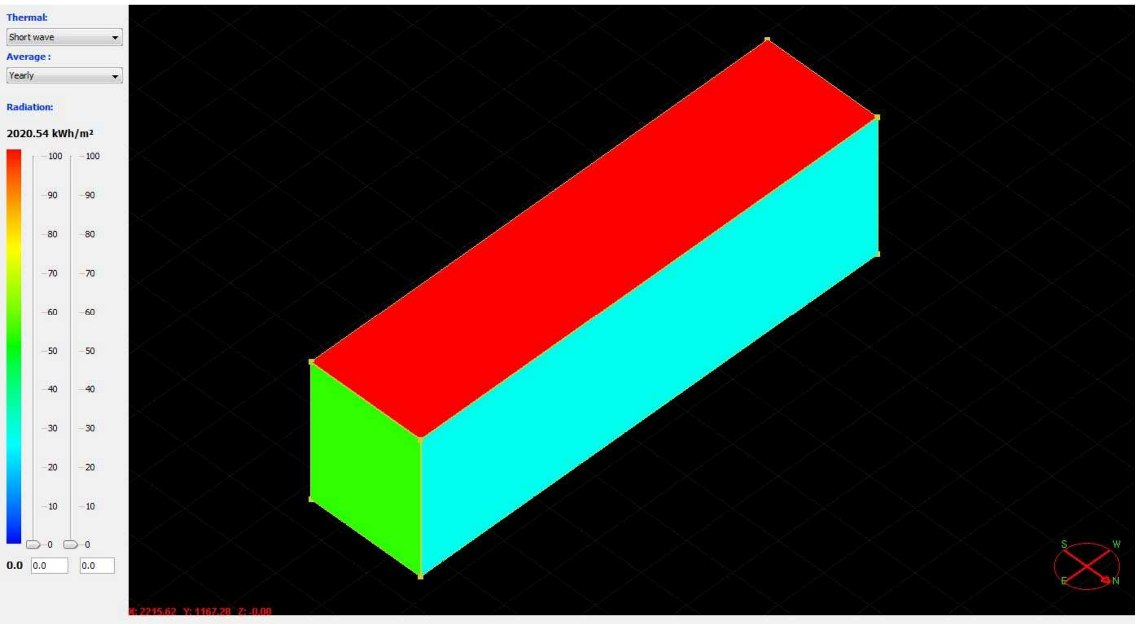


Figure 112 Morphology. Different building. Building A. Yearly results. Max value 2020 [kWh/m²]

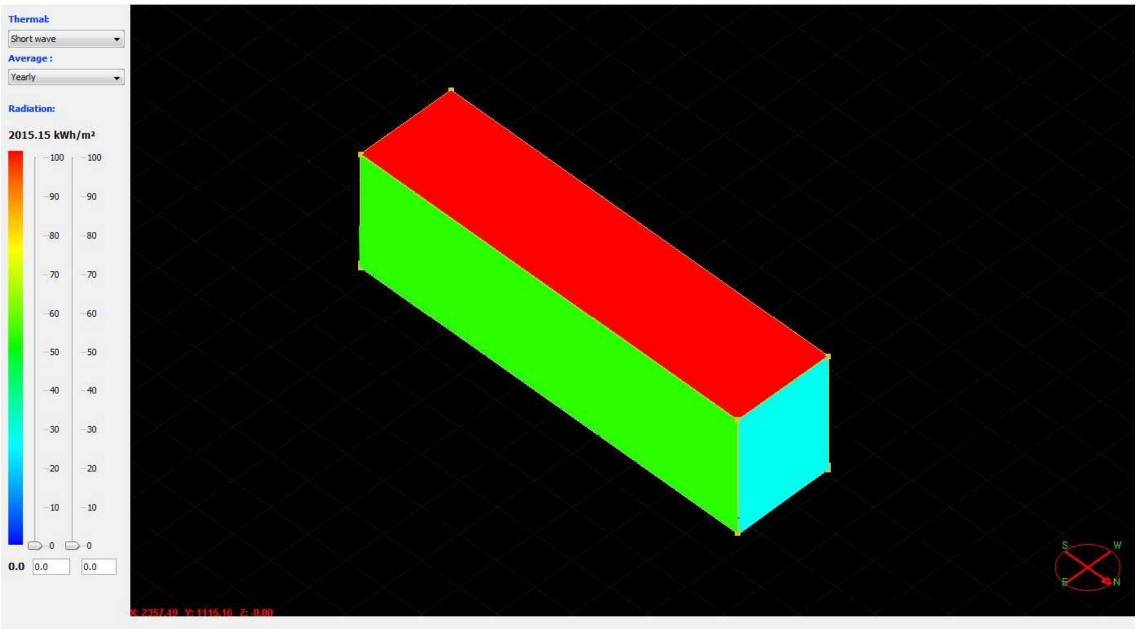


Figure 113 Morphology. Different building. Building B. Yearly results. Max value 2015 [kWh/m²]

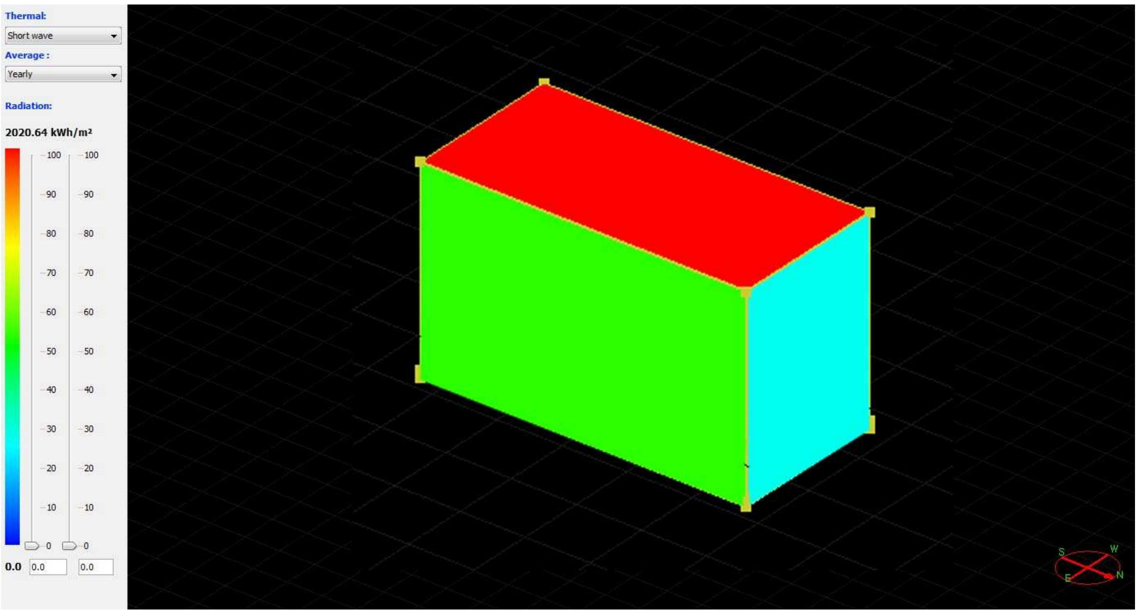


Figure 114 Morphology. Different building. Building C. Yearly results. Max value 2020 [kWh/m²]

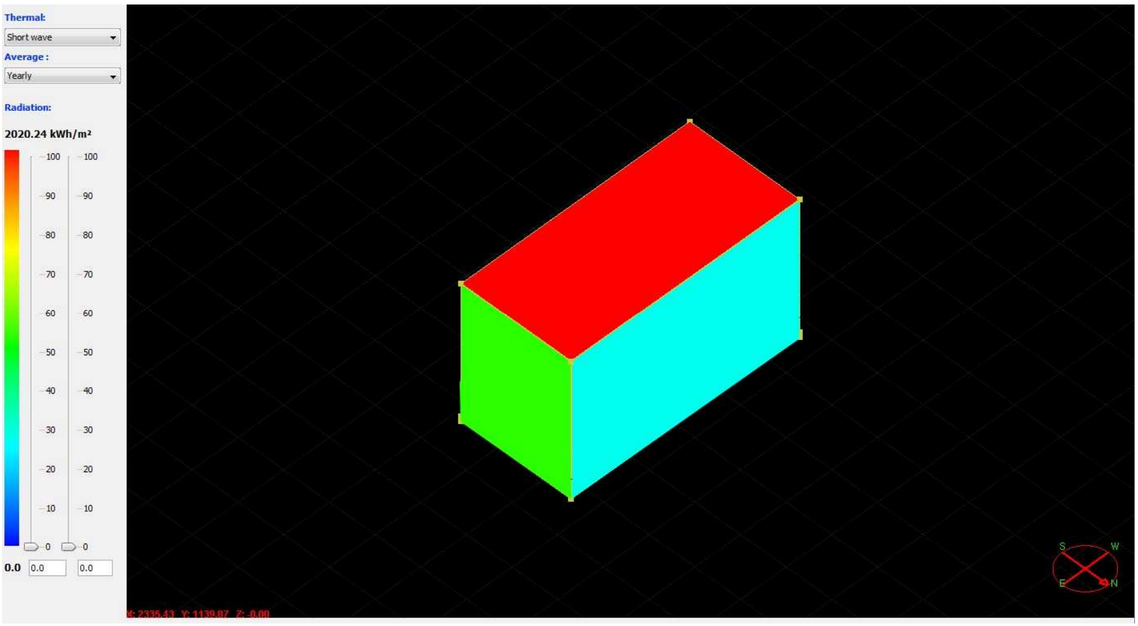


Figure 115Morphology. Different building. Building D. Yearly results. Max value 2020 [kWh/m²]

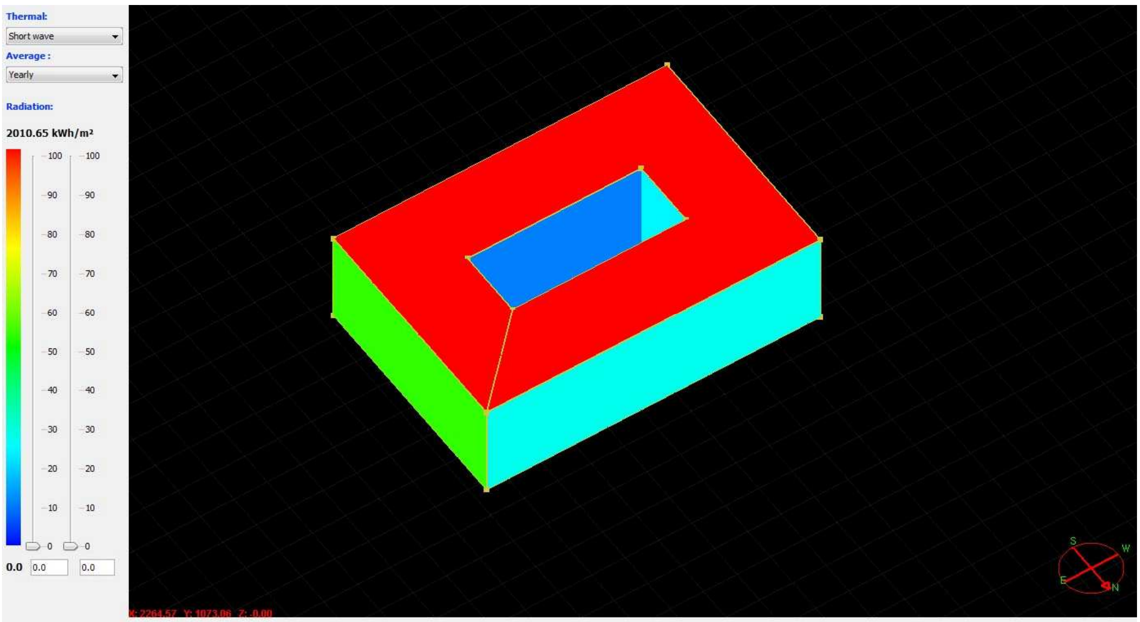


Figure 116 Morphology. Different building. Building F. Yearly results. Max value 2010 [kWh/m²]

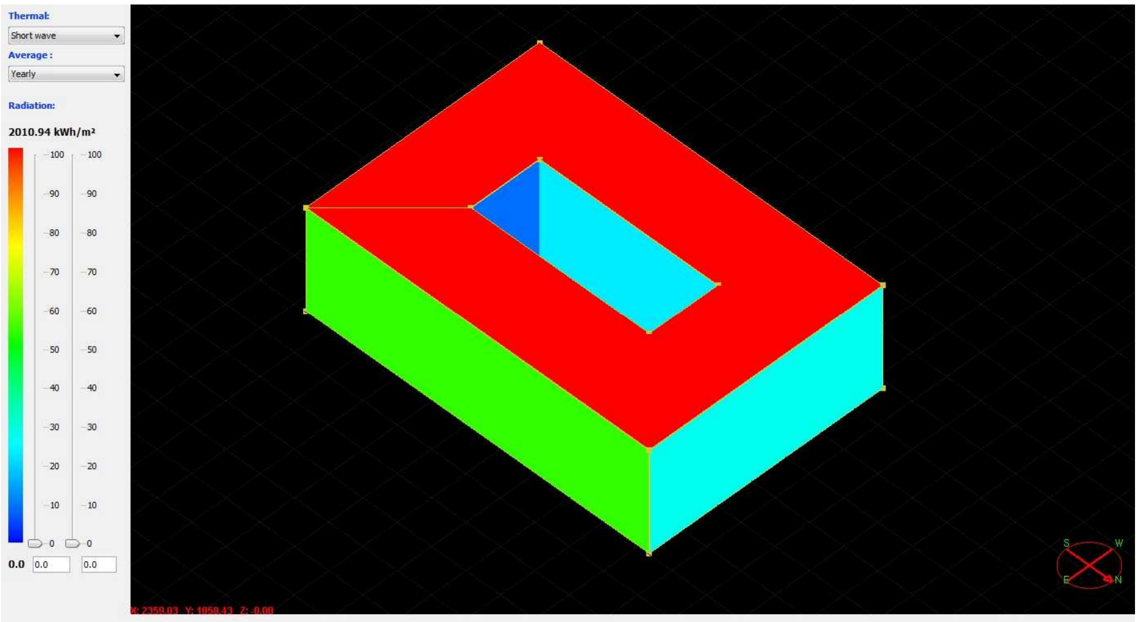


Figure 117 Morphology. Different building. Building G. Yearly results. Max value 2010 [kWh/m²]

The most interesting element is the difference in solar irradiation between the external wall and the wall facing the courtyard. The minimal difference between internal and external is 179.80[kWh/m²] on the North side of building E, and a maximal difference of 682.53 [kWh/m²] was observed on the South side of building G. These two simulations show that to guarantee a protection from solar radiation it is better to put windows facing North and East. But to assess Givoni's point of view that it is better to put windows facing North and South, we decided to improve the simulation and study the solar irradiation on the South wall. With the next simulation we can confirm that the solar radiation is higher on the South façade during winter months, but is limited during summer months, which has a positive impact on solar and heating needs.

We used the type F building, and we studied the solar radiation on the different façades during the year.

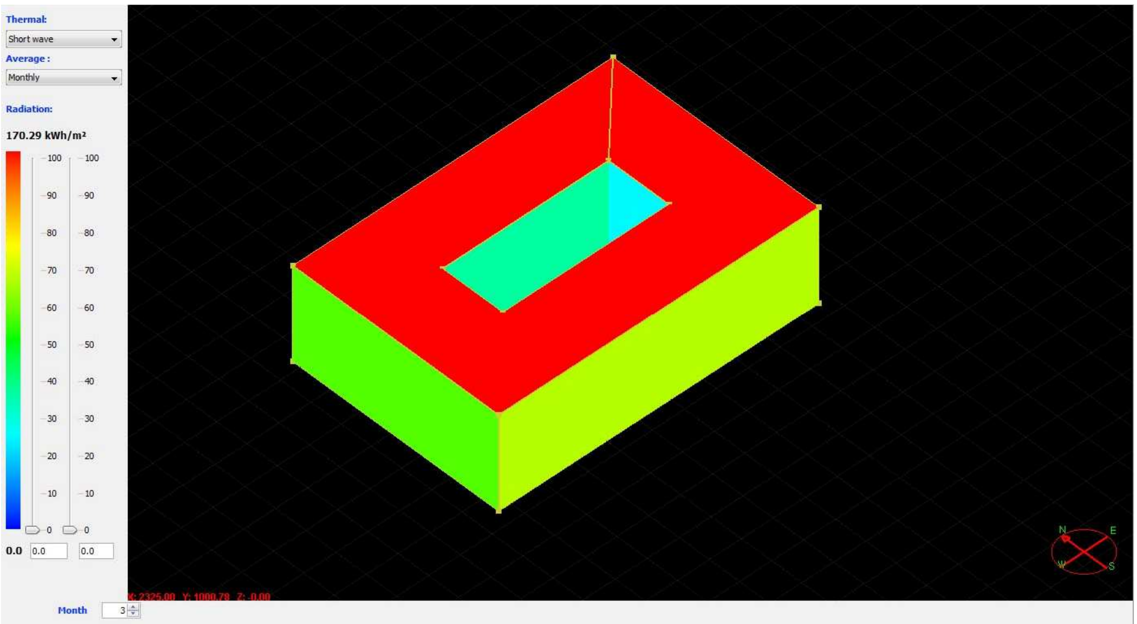


Figure 118 Morphology. Different buildings. Building F. Monthly results: March. Max value 170 [kWh/m²]

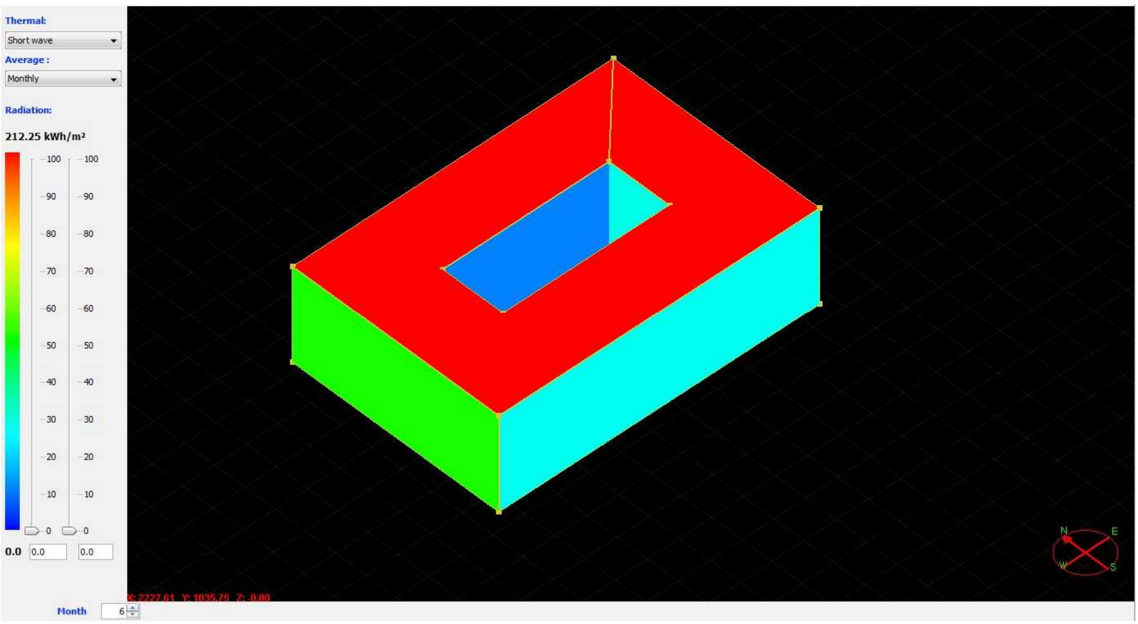


Figure 119 Morphology. Different buildings. Building F. Monthly results: June. Max value 212 [kWh/m²]

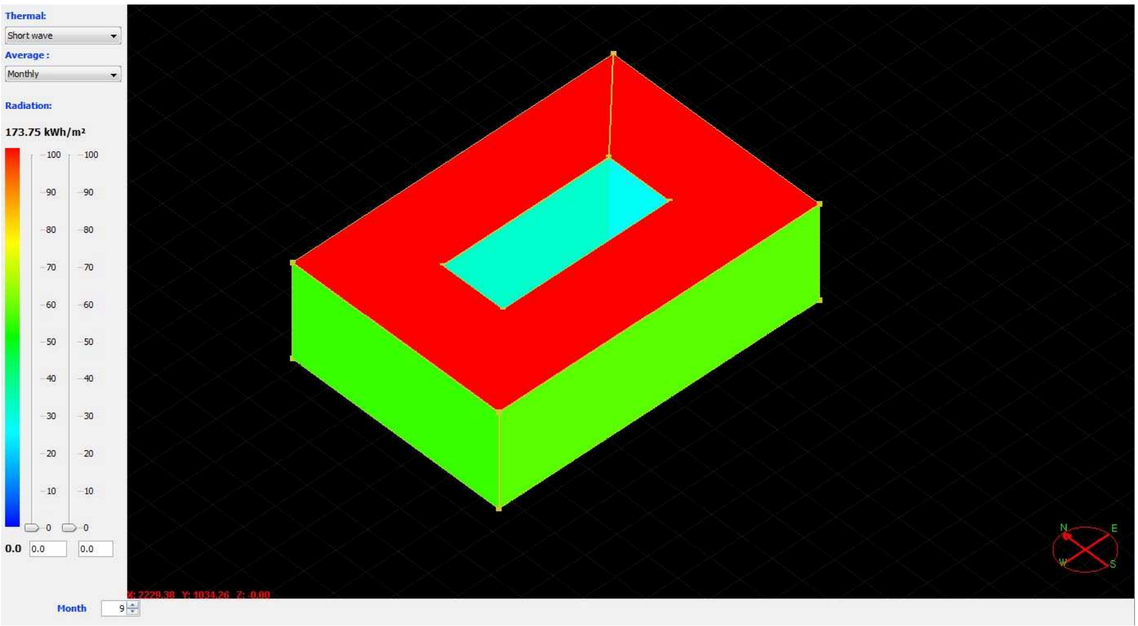


Figure 120 Morphology. Different buildings. Building F. Monthly results: September. Max value 174 [kWh/m²]

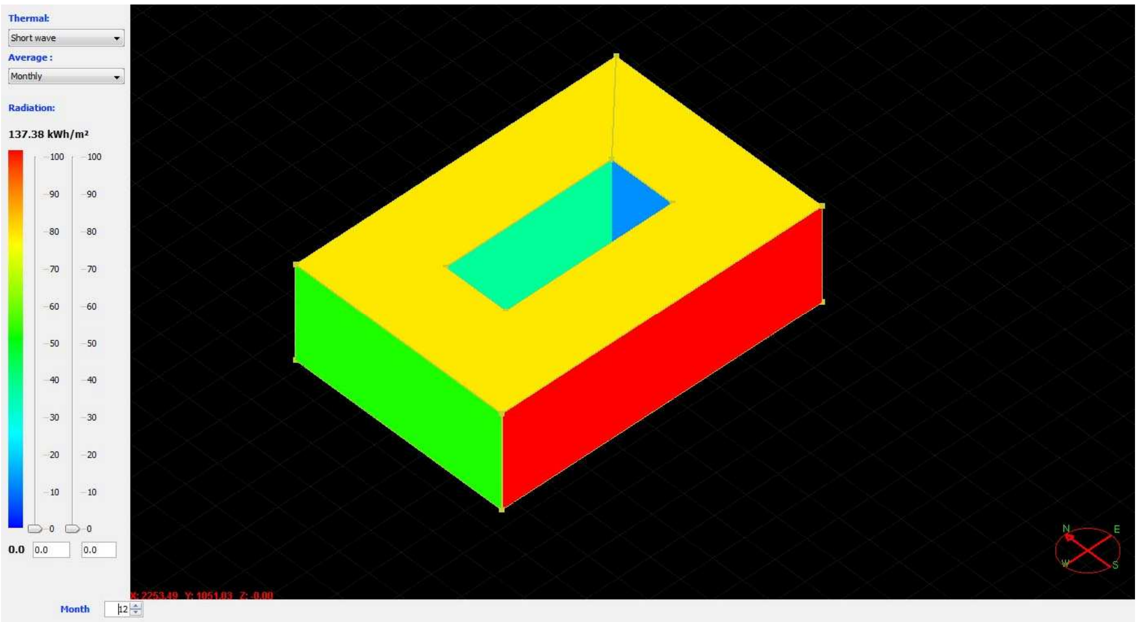


Figure 121 Morphology. Different buildings. Building F. Monthly results: December. Max value 170 [kWh/m²]

We can conclude that solar radiation is higher on East and West facades during the hotter months, but higher on the South facade during winter months. Hence we conclude that solar panels should be positioned on the roofs and on East and West facing facades. The windows percentage must be higher on the South and North side to provide a good illumination of the internal space and also to protect from solar radiation during summer. Furthermore the courtyard surfaces are protected from solar radiation during summer months, but illuminated during winter months.

4.3 MORPHOLOGY_ COURTYARD HOUSE WITH DIFFERENT FLOOR

We decided to study the courtyard type house, defining a different number of floors for different orientations. In this case the object was a building oriented North-West, with 3 floors on the North-Western side, and 2 floors on the South-Eastern side.

As shown in the table below, the results differ as a function of the number storeys of the building and their orientation. Simulations showed that the highest irradiation on courtyard facing walls, is on the third floor of the wall oriented South East, with a yearly solar irradiation of 1093.18 [kWh/m²]. The lowest value is on the wall oriented North-West, on the first floor, with a solar irradiation of 326.00 [kWh/m²]. The highest difference between storeys can be observed on wall B, with a 41 [%] variation between the first floor and the third floor.

Table 41 Morphology courtyard house with different floors.

Wall	Floor	Exposition	Orientation	Yearly solar irradiation [kWh/m^2]	Area [m^2]	Difference between floors [%]
A1	1	Internal	South- East	662.30	114.58	39
A2	2	Internal		892.46	114.58	18
A3	3	Internal		1'093.18	175.88	0
B1	1	Internal	South- West	629.39	174.72	41
B2	2	Internal		833.09	174.72	21
B3	3	Internal		1'058.94	174.72	0
C1	1	Internal	North- West	330.33	119.44	28
C2	2	Internal		457.90	119.44	0
D1	1	Internal	North- East	326.00	72.66	33
D2	2	Internal		484.73	72.66	0
E1	1	External	South- East	1'224.43	211.88	0
E2	2	External		1'224.64	211.88	0
F1	1	External	South- West	1'278.63	181.87	0
F2	2	External		1'278.63	181.87	0
F3	3	External		1'278.16	71.8	0
G1	1	External	North- West	793.33	209.92	0
G2	2	External		793.33	209.92	0
G3	3	External		793.31	209.92	0
H1	1	External	North- East	1'537.15	311	0
H2	2	External		1'537.05	311	0
H3	3	External		750.48	143	0

In the diagram below we have resumed the yearly solar irradiation [kWh/m²] for the different floors.

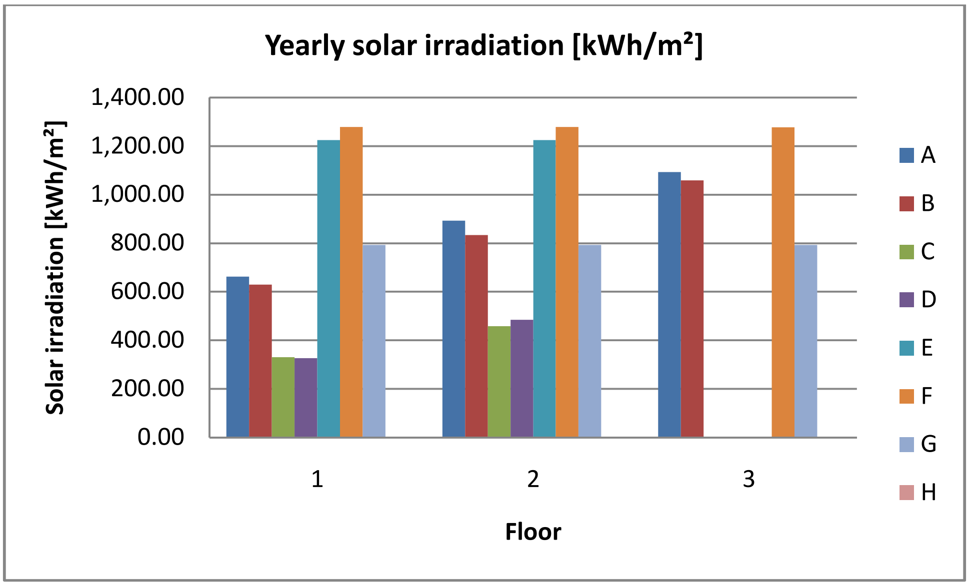


Figure 122 Courtyard house. Yearly solar irradiation [kWh/m²]

As we can see in the table below, there is a major difference between the wall facing the courtyard and the wall facing the outside. The highest difference can be observed on the wall exposed North-East, with a difference of 68 [%]. The lowest difference can be found on the wall facing South-West, with a difference of 27.92 [%]

In the images below we can see the yearly and monthly results for the building.

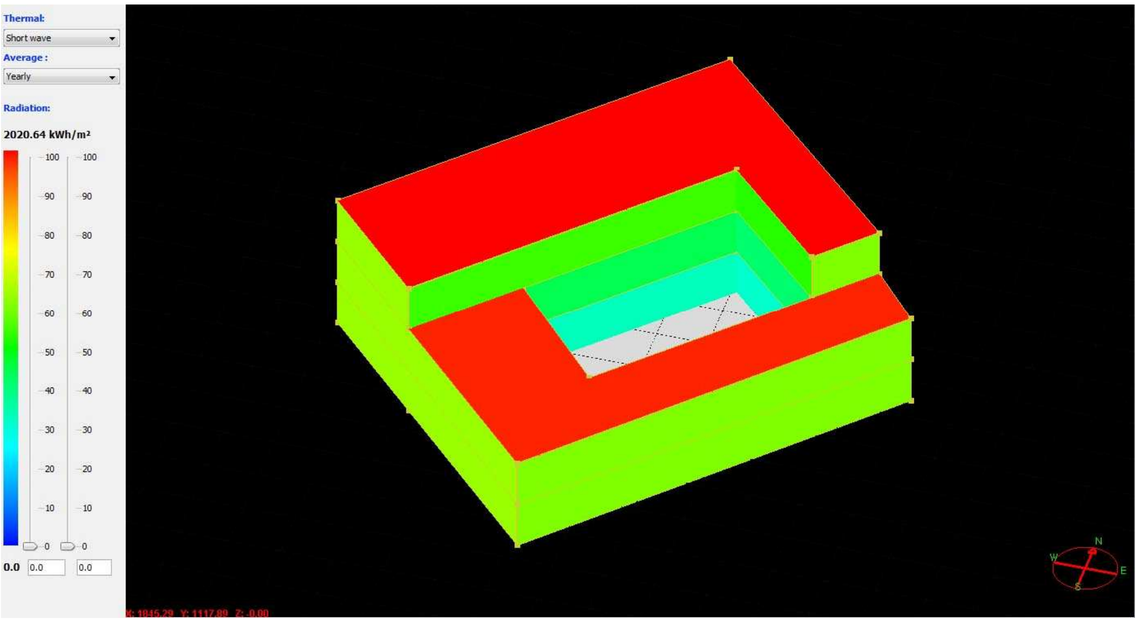


Figure 123 Courtyard house. Yearly results. Max value 2020 [kWh/m²]

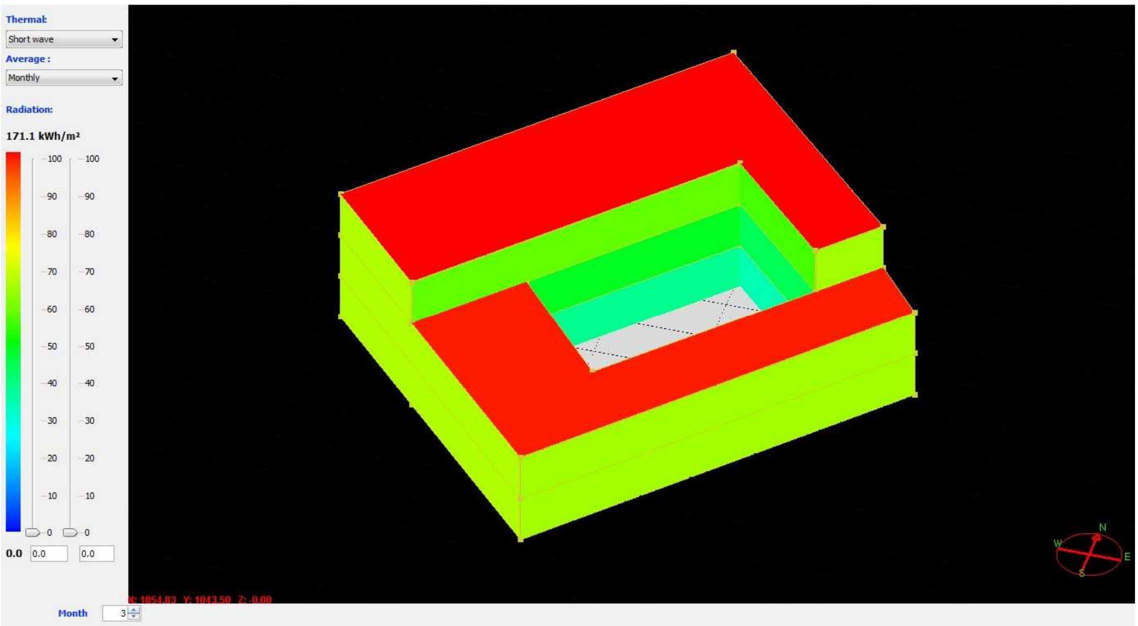


Figure 124 Courtyard house. Monthly results. March. Max value 171 [kWh/m²]

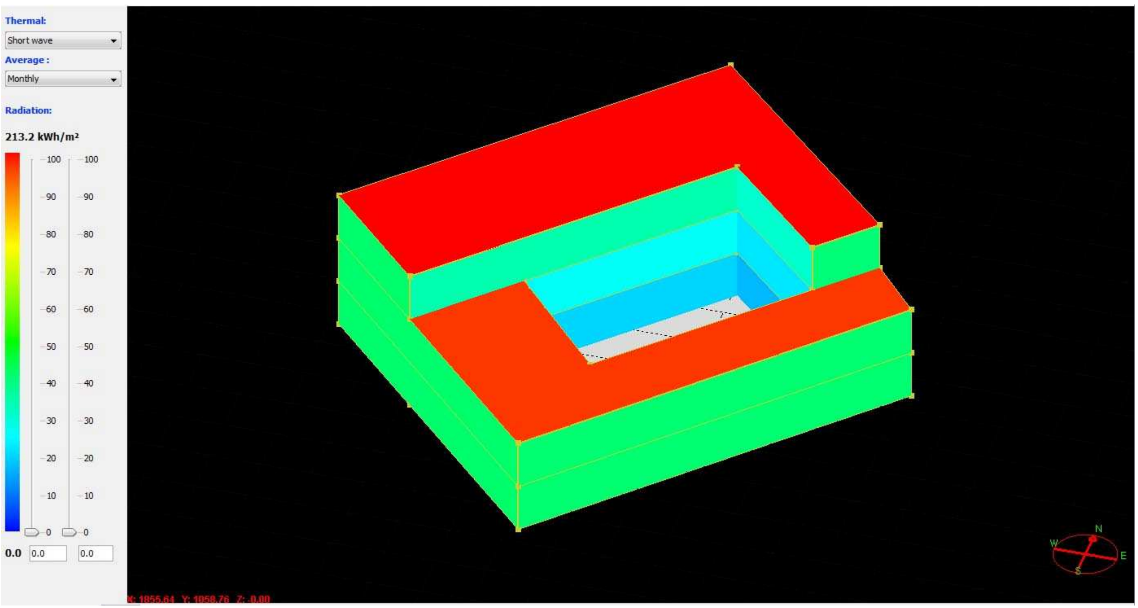


Figure 125 Courtyard house. Monthly results. June. Max value 213 [kWh/m²]

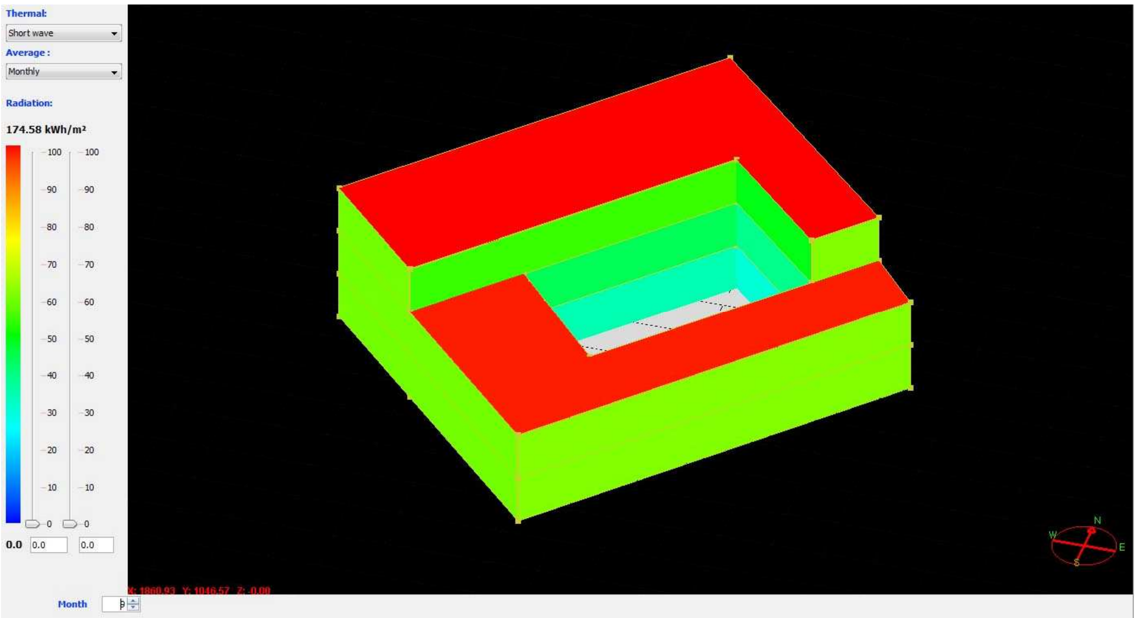


Figure 126 Courtyard house. Monthly results. September. Max value 174 [kWh/m²]

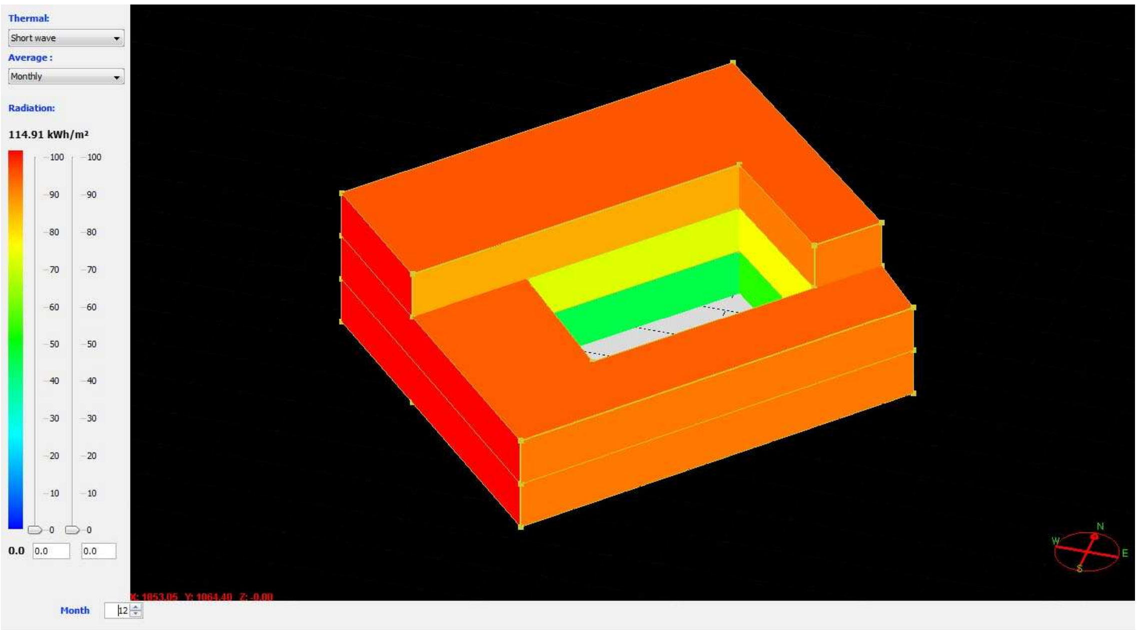


Figure 127Courtyard house. Monthly results. December. Max value 115 [kWh/m²]

4.4 PEDESTRIAN THERMAL COMFORT

4.4.1 WIND FORCE UPON HUMAN BODY

The wind force on a stationary person can be calculated by the formula below:

$$F = \frac{1}{2}\rho u^2 * Ap * Cd$$

Where

F*:* wind force on the body [N]

u*:* wind speed [m/s]

ρ*:* air density [kg/m³]

Ap*:* projected area normal to the wind [m²]

Cd*:* drag coefficient [dimensionless]

The air density depends on the temperature, and as we can see in the Figure below, the air density at 35 [°C] is 1,14 [kg/m³], and 1,12 [kg/m³] at 40 [°C].

Effect of temperature

Temperature	Speed of sound	Density of air	Acoustic impedance
ϑ in °C	c in $m \cdot s^{-1}$	ρ in $kg \cdot m^{-3}$	Z in $N \cdot s \cdot m^{-3}$
+35	351.96	1.1455	403.2
+30	349.08	1.1644	406.5
+25	346.18	1.1839	409.4
+20	343.26	1.2041	413.3
+15	340.31	1.2250	416.9
+10	337.33	1.2466	420.5
+5	334.33	1.2690	424.3
±0	331.30	1.2920	428.0
-5	328.24	1.3163	432.1
-10	325.16	1.3413	436.1
-15	322.04	1.3673	440.3
-20	318.89	1.3943	444.6
-25	315.72	1.4224	449.1

Figure 128 Effect of temperature

The drag coefficient is a parameter that expresses the drag of an object into a fluid; it is connected to the elements to which it refers. For example the drag coefficient of a person in upright position is 1.00- 1.30.

The value Ap, the projected area normal to the wind, is connected to the total surface area, Adu. The ratio Ap/Adu, is a standard value, taken from the article "Acceptable wind speeds in towns"[27], and it is 0.31 for each subject. The total surface area for a standard person, weighing 75 kilos, and measuring 1.80 m, is given by the Du Bois formula:

$$Adu = 0.203 * W^{0.425} * \; h^{0.725}$$

$$Adu = 1.94 \; [m^2]$$

Where

Adu: surface area [m²]

W: body weight [kg]

h: body height [m]

Knowing the surface area, we can define the standard value for Ap, for the person described before:

Ap= 1.94*0.31= 0.60 [m²]

Using the value determined before, we can define F, the wind force on the body, in the climate of Ras Al Khaimah, during the hottest month, that is July, with an average daily mean of 36.37 [°C].

$$F = \frac{1}{2} * \; 1.14 * 3.11^2 * 0.60 * 1.20$$

F= 3.97 [N]

Studying the South wind during the month of August, we obtain a different wind force on the body:

$$F = \frac{1}{2} * \ 1.14 * 4.57^2 * 0.60 * 1.20$$

F= 8.57 [N]

The wind force against the body is 3.97 [N] for the wind from the North-West, and 8.57 [N] for the wind from the South. This simulation has been useful to define the next simulations.

4.4.2 Heat exchange between people and environment

An important aspect of the urban climate is the exchange between people and their environment; this parameter depends on people's attitudes, their movements, their way of clothing and the external climate. We need to define the energy balance of the body, which includes heat loss by convection, conduction, evaporation, or transpiration, and radiation with the external air and neighbouring surfaces. The body maintains a healthy equilibrium between heat gains and heat losses to the environment by convection, conduction and evaporation, or transpiration. It needs to preserve an internal temperature of 37 [°C]. The temperature regulation relies on the blood circulation and the exchange of heat from the skin; but also on active measures taken by a person, such as changing clothes or reducing/increasing activity.

The parameters influencing thermal comfort are defined in the table below.

Table 42 Parameters influencing thermal comfort [28]

Parameters	Symbol	Dimension
Air temperature	θa	[°C]
Mean radiant temperature	θrt	[°C]
Air velocity relative to the subject	ϑ	[m/s]
Water vapour partial pressure	ρ	[Pa]
Metabolic activity of the subject	M	[W]
Mechanical work of the subject	W	[W]
Skin area	A	[m²]
Specific metabolic activity	m= M/A	[W/m²]
Specific mechanical work	w= W/A	[W/m²]
Thermal resistance of clothing	R	[m²K/W]
Clothing	H	[clo]= R/0.155
Clothed fraction	f	

For the simulation with Citysim, the main characteristics are the air temperature, the skin area and the thermal resistance of clothing.

Table 43 Mean metabolic rate for various activities (EN- ISO 7730)[28]

Activity	Heat emission		
	[met]	[W/m²]	[W/person]
Reclining	0.8	46	83
Seated, relaxed	1.0	58	104
Sedentary activity (office, dwelling, school, laboratory)	1.2	70	126
Standing light activity (shops, laboratory, light industry)	1.6	93	167
Standing, medium activity (domestic or machine work)	2.0	116	209
Walking at 4km/h	2.8	162	292

The thermal resistance, Rc, of clothing is expressed in the table below.

Table 44 Some standard clothing with their thermal resistance expressed in phisical units and in Clo (clothing) units[28]

Clothing	[clo]	[m²K/W]	[m² deg C/W]
Naked, standing	0.0	0.0	
Shorts, bathing suit	0.1	0.015	
Summer clothing: panties, shirt with short sleeves, light trousers or skirt, socks, shoes	0.5	0.08	0.08
Underpants, boiler suit, socks, shoes	0.7	0.11	
Panties, shirt, trousers or skirt, vest, jacket, socks or stocking, shoes	1.0	0.15	
Underwear with long sleeves and legs, shirt, trousers, vest, jacket, coat, socks or stockings, shoes	1.5	0.23	

We can assume that considering the climate conditions in Ras al Khaimah, clothing used in the campus will be mostly summer clothing, with a thermal resistance of 0.08 [m²K/W]. The thermal conductivity is 1/R= 4.16 [W/m²K].As we can see in the figure below, the optimal internal temperature in an office building, with an activity of 1.2 [Met], and summer clothing with a value of 0.5 [Clo], can be assumed 26 [°C], with a difference of +- 1.5 [°C]. During the winter the internal temperature can be of 24 [°C], with winter-Arab clothes of 0.70 [Clo].

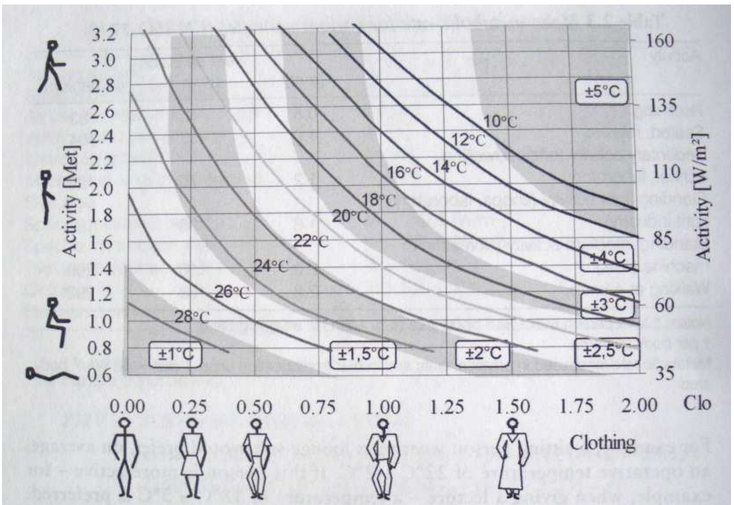


Figure 129 Optimal operative temperature for various clothing and activities[28]

4.4.3 HEAT BALANCE OF HUMAN BODY AND CONDITIONS OF THERMAL COMFORT

The equation of Humphreys[27] gives some advice to define the human comfort in indoor and outdoor conditions, including the solar radiation.

$$Tb - Ta = \frac{M}{Adu} * Rb + k * \frac{M}{Adu} * Rc + \left(k * \frac{M}{Adu} + S\right) * (4.2 + 13u^{0.5}) \quad ^{-1}$$

Where

Tb: Body temperature, 37 [°C]

Ta: Air temperature [°C]

M/Adu: Metabolic rate of heat production per square meter of body surface [W/m²]

k: Proportion of metabolic heat dissipated by means or other than evaporation, about 0.8

Rb: Thermal resistance of the body tissues [m²deg C/W]. According to Humphreys 0.04 [m²deg C/W] is the onset of sweating and 0.09 [m²deg C/W] is the onset of shivering.

Rc: Thermal resistance of clothing [m² deg C/W]. Popular unit [Clo]: 1Clo= 0.155 [m² deg C/W]

S: Solar heat input per square meter of body surface [W/m²]. Maximum value about 120 [W/m²]

u:Wind speed [m/s]

$(4 * 2 + 13u^{0.5})^{-1}$: Thermalresistance between clothing and surroundings [m² deg C/W]

Analysing the weather in Ras Al Khaimah, we can define the equation below:

Tb: 37 [°C]

Ta: 43.18 [°C], July average daily max

M/Adu:162 [W/m²], walking at 4km/h

k: 0.8

Rb: unknown *[*m²deg C/W]

Rc: 0.08 [m² deg C/W], summer clothing: panties, shirt with short sleeves, light trousers or skirt, socks, shoes

S:120 [W/m²], as maximum value

u: 3.11 [m/s], July wind speed max

The equation gives as a result the thermal resistance of the body tissues Rb= -0.25, which means transpiration.

CONCLUSION

The result means that is necessary to reduce the external temperature because there is no human comfort under these conditions. According to Humphreys[27], the values that guarantee thermal comfort are Rb between0.04 and 0.09 [m²deg C/W]. The ways to improve comfort are*:*

- To reduce the solar radiation, with shadows*.*
- To reduce the external temperature, with natural ventilation and shadows*.*
- To increase the wind speed, with a correct building disposition and the use of wind towers and solar towers*.*

From the diagrams below, extracted from the article “Acceptable wind speeds in towns”[27], we can see that the comfort regions for pedestrians in full shade or full sun are connected with the wind speed. The metabolic rate of heat production per square meter of body surface used in the diagrams corresponds to 100 [W/m²], as people walking slowly.

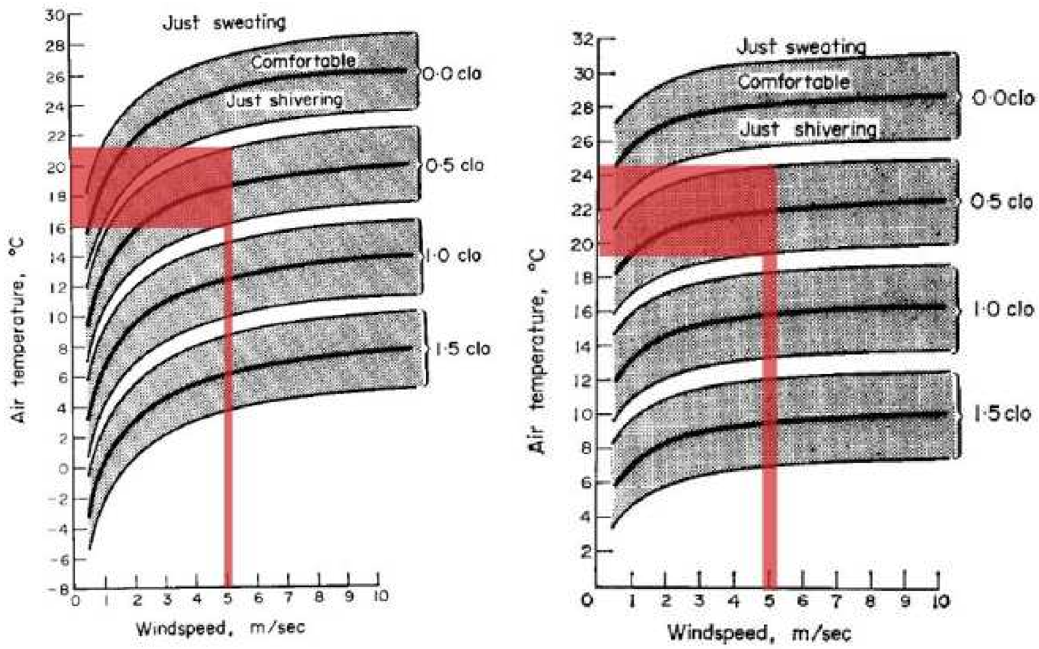


Figure 130 Left: Comfort conditions for strolling in full sun[27]. Right: Comfort conditions for strolling in shade[27]

As we can notice from the diagrams, the influence of wind speed is higher in lower winds, for example in full sun an increase of the wind speed from 0.5 to 5.00 [m/s], needs to be accompanied by a temperature increase of 9 [°C], to maintain a comfortable body temperature. In addition, to guarantee a comfortable temperature, in the shadow, with 0.50 [Clo], we need to guarantee a temperature between 18 and 24 [°C]. But defining that 5 [m/s] is the mean value of the wind speed, to guarantee a comfortable breeze to pedestrians, we can define a temperature of 16 to 21 [°C] as the comfortable one in full sun, and a temperature from 19 to 25 [°C] in strolling shade.

4.4.4 MODELLING OF PEDESTRIAN COMFORT ON URBAN CANYON

As we have said before, the mean temperature in an urban street canyon must be between19and 25 [°C], with a mean wind speed of 5 [m/s].The main object of this paragraph is to simulate with Citysim the pedestrian comfort in an urban canyon. We have define the human body as a cylindrical building, of 1.50 [m] height, and a diameter of 0.17 [m], as defined in the article "Physical modelling of pedestrian energy exchange within the urban canopy"[3]. The cylindrical building was positioned in the centre of the canyon.

Skin temperature: 35 [°C]

Skin albedo: 0.35

Skin emissivity: 0.90

The pedestrian energy balance is described in the figure below, which shows the radiative and convective exchange from the environment to the body.

$$\mathrm{Rn} = (\mathrm{Kdir} + \mathrm{Kdif} + \alpha\mathrm{hKh} + \alpha\mathrm{vKv})(1 - \alpha\mathrm{s}) + \mathrm{Ld} + \mathrm{Lh} + \mathrm{Lv} - \varepsilon\sigma Ts^4$$

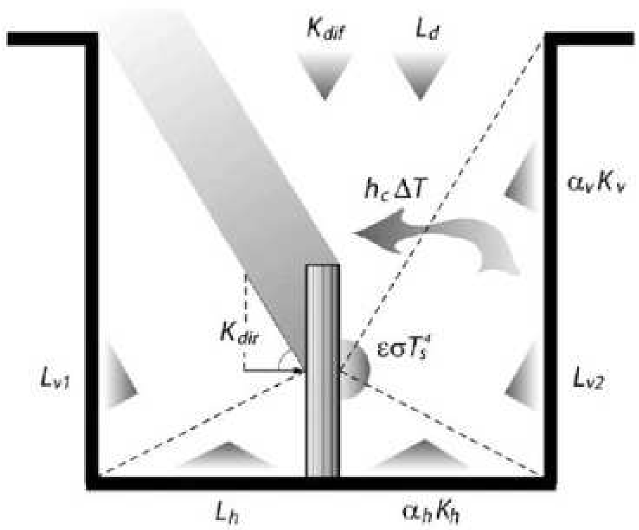


Figure 131 Schematic description of the pedestrian energy exchange model[3]

Where

Rn: the instantaneous balance of net all wave radiation

Kdir: direct component of solar radiation incident on the cylindrical face

Kdif: diffuse components of solar radiation incident on the cylindrical face

αhKh: Incident fluxes of short wave radiation diffusely reflected from horizontal canyon face

αvKv: Incident fluxes of short wave radiation diffusely reflected from vertical canyon face

αs: Body surface albedo, 0.35

Ld: absorbed downward long wave sky radiation

Lh: absorbed long wave radiation fluxes emitted from horizontal surface

Lv: absorbed long wave radiation fluxes emitted from vertical surface

ε: body surface emissivity

σ: Stefan- Boltzmann constant

Ts: the mean body surface temperature [K]

The geometry of the space has an important role in the urban climate. As we can read in the article "Influence of urban geometry on outdoor thermal comfort in a hot dry climate: A study in Fez, Marocco" [29], the main elements to define the urban geometry and climate are the ratio between the height and the distance between buildings. These elements are related to solar radiation, wind speed and the sky view factor. The study was carried out in the city of Fez, assessing the thermal comfort by the PET, Physiologically Equivalent Temperature, a comfort index that takes into account temperature, radiation, humidity and wind speed.

As we can read in the results, buildings in the old town, called Medina, are characterized by an extreme compactness, with buildings from2 to 4 stores, and a courtyard in the centre; the streets are narrow, with deep urban canyons, and irregular. By contrast, the new town, la nouvelle Ville, was designed for cars, with large streets, and a regular pattern of buildings. The article investigates two canyons, one in the old city, a deep canyon with a H/W ratio of 9.7, and a shallow canyon in the new town, with a ratio of 0.6.

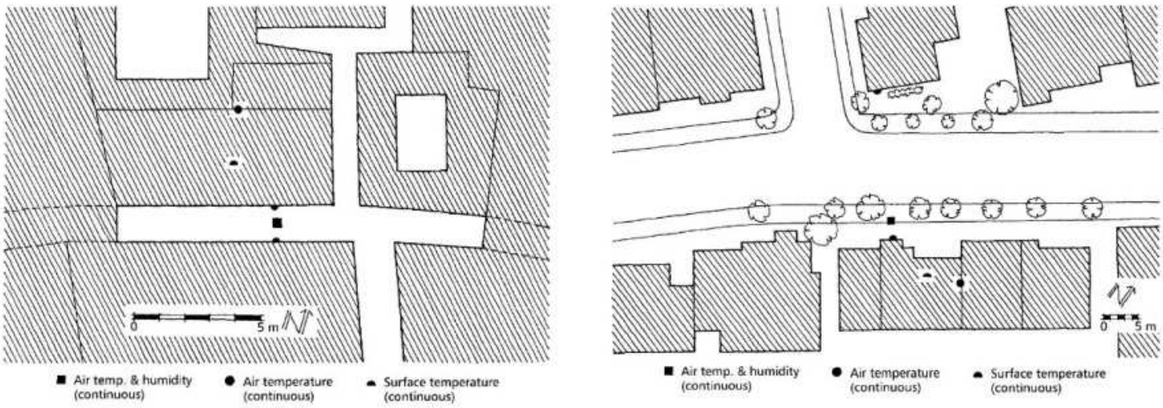


Figure 132 Plant view of the old Medina in Fez, and the nouvelle ville[29]

Analysing the results, we can affirm that deep canyons create a better climate, ensuring a constant temperature during the day, and always lower than in a shallow canyon. This is thanks to the shadow that cools the street, and the air is not warmed up, and this difference of temperature assures that the warm air does not enter the canyon. By night the roof temperature cools down, ensuring natural ventilation in the street.

Concluding the study demonstrates that the air temperature is lower in deep canyons, than in shallow ones. Furthermore the street orientation has no significant influence on the air temperature. As we can see in the diagrams, deep canyons provide a more even climate during the summer and during the winter. The difference of temperature in deep canyons, in summer months, varies between 23.8 and 30 [°C], (ΔT: +6.2 [°C]) , with the highest temperature at 15.00 [hours]; whereasΔT in shallow canyons is +15.00 [°C], with a maximal temperature of 36 [°C], during the afternoon, and a minimal temperature of 21 [°C].

The same analysis can be done for the winter period, with a ΔT in deep canyons of +4.00 [°C], and a ΔT in shallow canyons of +10.00 [°C].

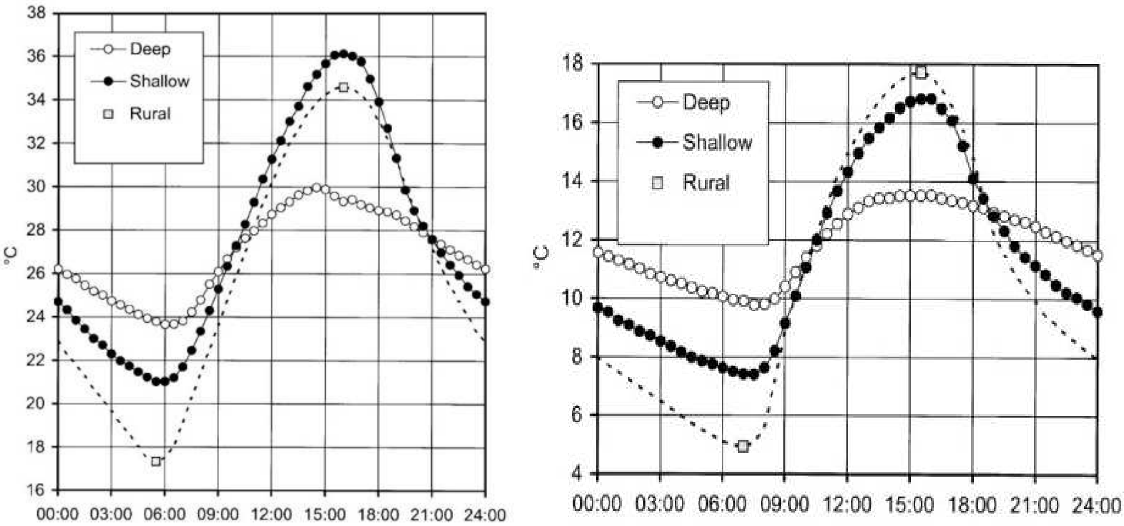


Figure 133 Average air temperature for the summer and winter period in deep and shallow canyons, as well as for rural area[29]

Another interesting element is the radiation upon the wall: the average surface temperature: the deep canyon has a low and stable temperature, thanks to the shadow and the reduction of the solar view factor. By contrast the walls on the shallow canyon have a high variation of temperature, with a value, during the summer months, of 20 [°C] on the NW side.

The same analysis can be made for the humidity, during the hottest months: a difference between 20 [%] and 60 [%] in a shallow canyon, compared to a difference between 35 [%] and 50 [%] in a deep canyon.

Concluding we can say that increasing the H/W ratio, upon a ratio of ≈10, we have a most comfortable temperature, humidity level and radiation upon surface. A climate comfort urban design must have a compact urban form, but with wider streets and more open space, to assure the solar radiation during the winter months. These street must be protected during the summer months, with solar protection for pedestrians achieved through shading trees and shadows projected by upper floors and arcades.

4.4.5 CITYSIM ANALYSIS_ PEDESTRIAN COMFORT

We have decided to create a model with Citysim, to analyse the dimension of streets and courtyards, assuring a correct solar radiation upon surfaces, and pedestrian comfort.

We have created a pedestrian, as a building, with the following value.

Geometry: a cylindrical building, of 1.50 [m] height, and a diameter of 0.17 [m].

Position*:*

for canyon simulation*:* in the middle of the street;

for the building in the courtyard: at 2.00 [m] from the building, and in the centre of the courtyard.

Maximal temperature: 37 [°C]

Minimal temperature: 35 [°C]

We can assume that, considering the climate conditions in Rasal Khaimah, the clothing used in the campus can be mostly summer clothing, with a thermal resistance of 0.08 [m²K/W].

We can define, as an empiric example that the thermal resistance of human body is:

$$R = \frac{1}{8} + 0.08 + \frac{1}{25}$$

R= 0.24 [m²K/W]

And the thermal conductivity is: 1/R= 4.16 [W/m²K]

The wall composition is defined in the table below:

Table 45 Pedestrian thermal comfort. Materials

Name	l [m]	p [Kg/m³]	k [W/mK]	Cp[J/Kg°C]
Glass	0.04	11	0.053	840

Where

l: thickness [m]

p: mass density [Kg/m³]

k: thermal conductivity [W/mK]

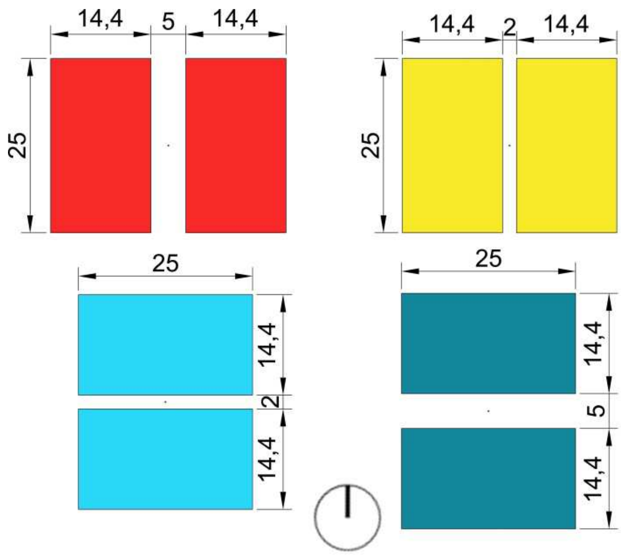
Cp: specific heat [J/Kg°C]

The windows percentage in walls and roofs is 0.00 [%]

Skin albedo:0.35

FIRST ANALYSIS_STREET CANYON

In a first analysis made with CitySim we simulated two buildings of 15.00 [m] height, with a different orientations North-South and East-West, and a different distances in-between, exactly 2.00 and 5.00 [m], as we can see in the image below.



We wanted to define the total solar irradiation on a pedestrian, during the year, and at the summer solstice, the 21st of June, at 12.00 am, considered as the worst situation during the year. It is important to say that every pedestrian has a different conception of thermal comfort, which depends on the age, clothing and movements, but is also connected with temperature and humidity.

For this reason in this chapter we want to analyse the total solar irradiation on pedestrians, starting from the article *"Outdoor human comfort in a urban climate"*[30], that analyses the pedestrian comfort, starting from a collection of dates taken from a questionnaire given to 466 people in Montreal, in a period of 34 days. From this article we can see the relation between the physical measurements and people's preferences. We can say that people prefer a solar irradiation between 200 and 800 [W/m²]. It is important to define that this article refers to Montreal, not to UAE.

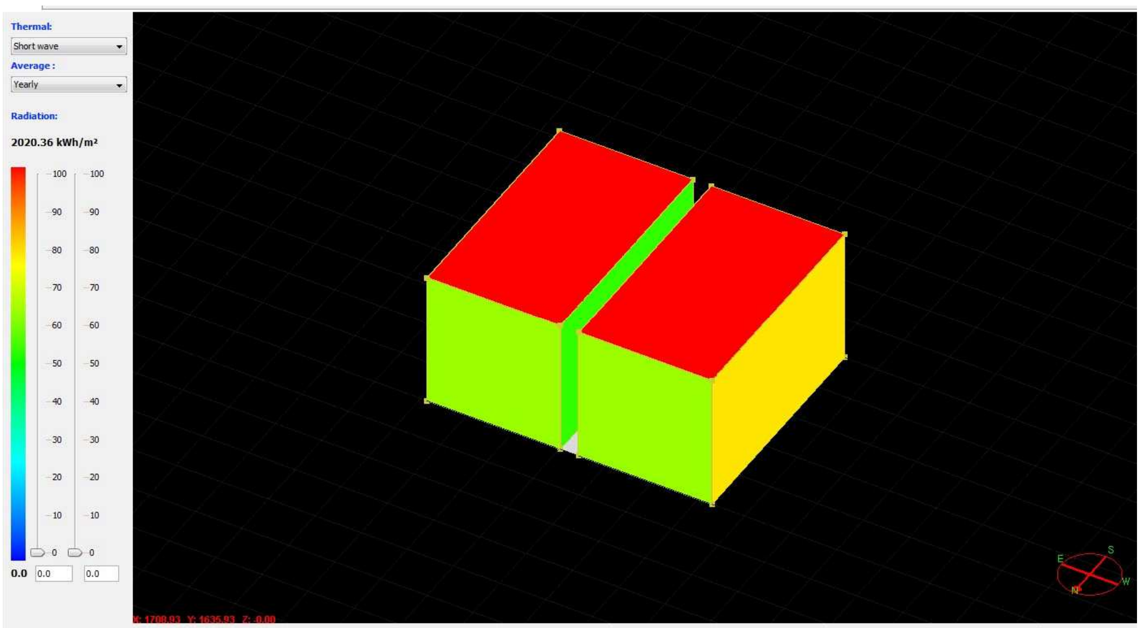


Figure 134 Orientation East-West, distance between buildings 2 [m]. Solar irradiation, yearly results [kWh/m²].

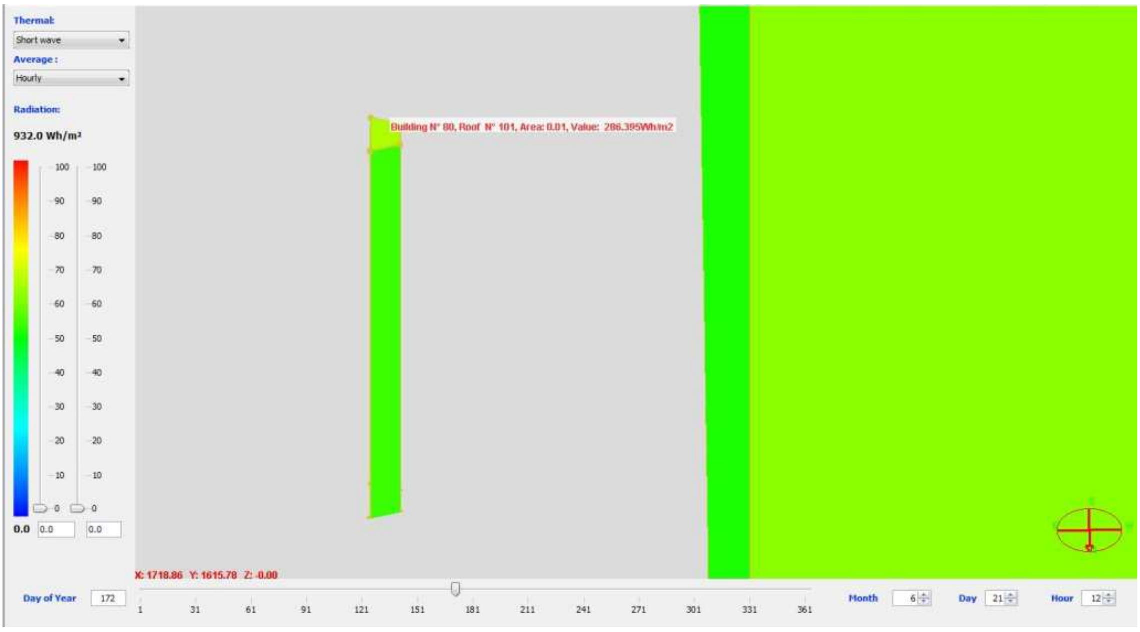


Figure 135 Orientation East-West, distance between buildings 2 [m]. Solar irradiation. Max value 286 [Wh/m²] , 21st of June, 12.00 [h]

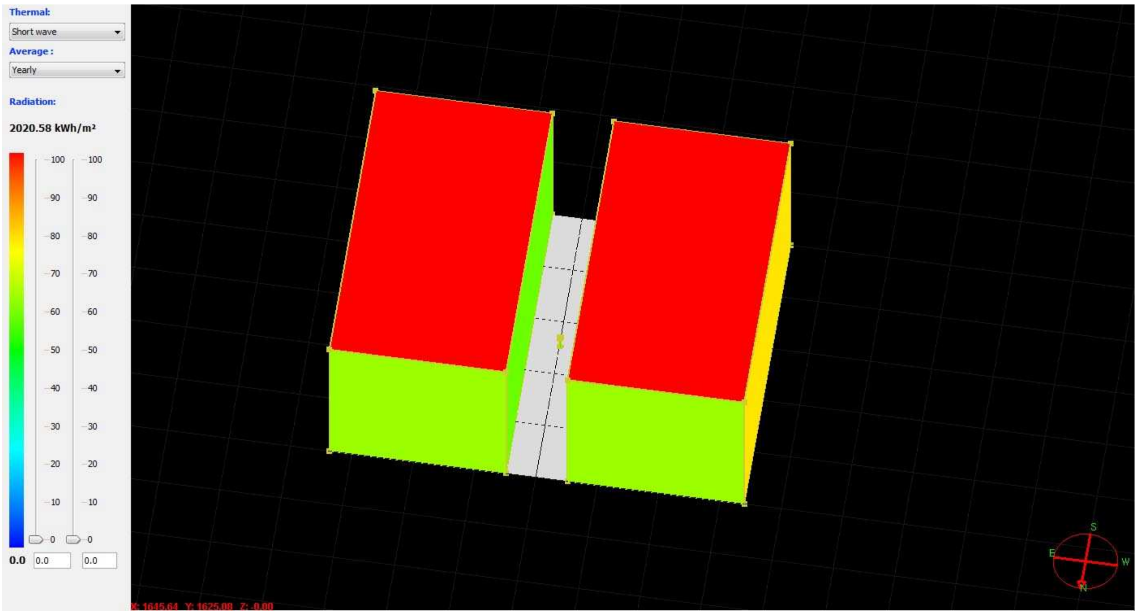


Figure 136 Orientation East-West, distance between buildings 5 [m]. Solar irradiation, yearly results. Max value 2020 [kWh/m²]. North view.

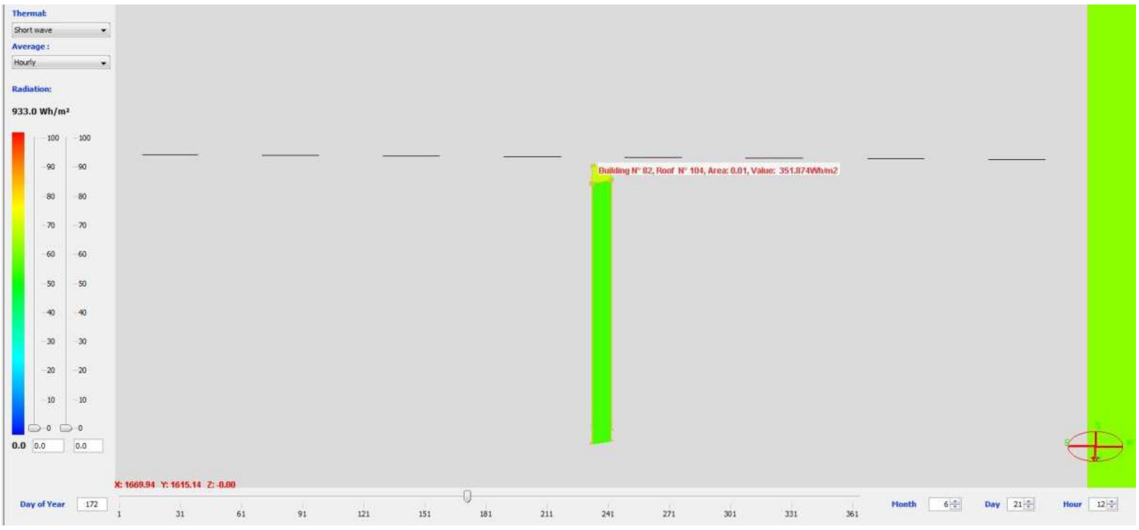


Figure 137 Orientation East-West, distance between buildings 5 [m]. Solar irradiation. Max value 351 [Wh/m²] , 21st of June, 12.00 [h]

Figure 138 Orientation North-South, distance between buildings 2 [m]. Solar irradiation, yearly results. Max value 2020 [kWh/m²]. East view.

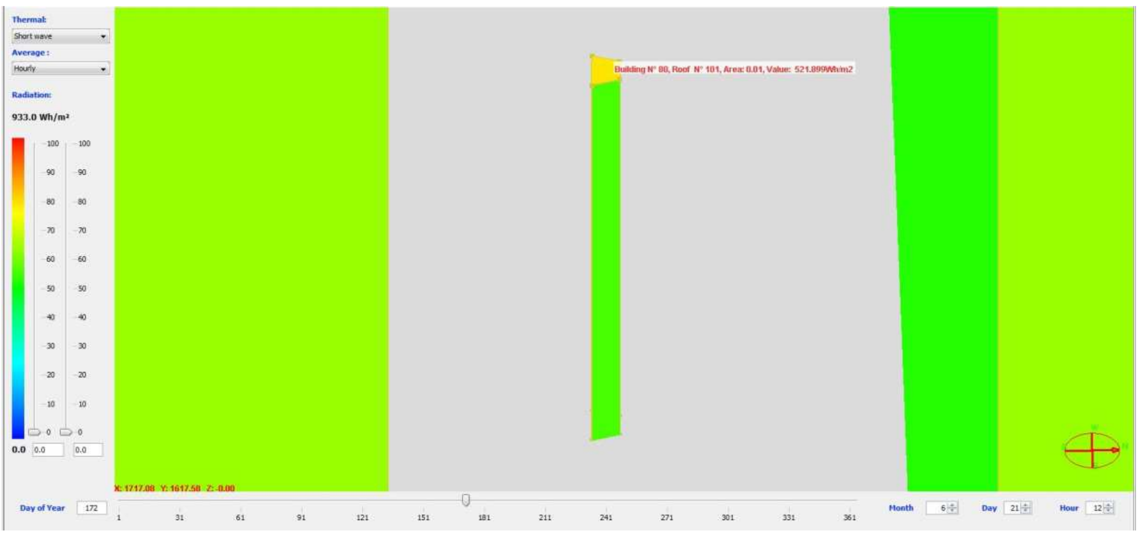


Figure 139 Orientation North- South, distance between buildings 2 [m]. Solar irradiation. Max value 521 [Wh/m²] , 21st of June, 12.00 [h]

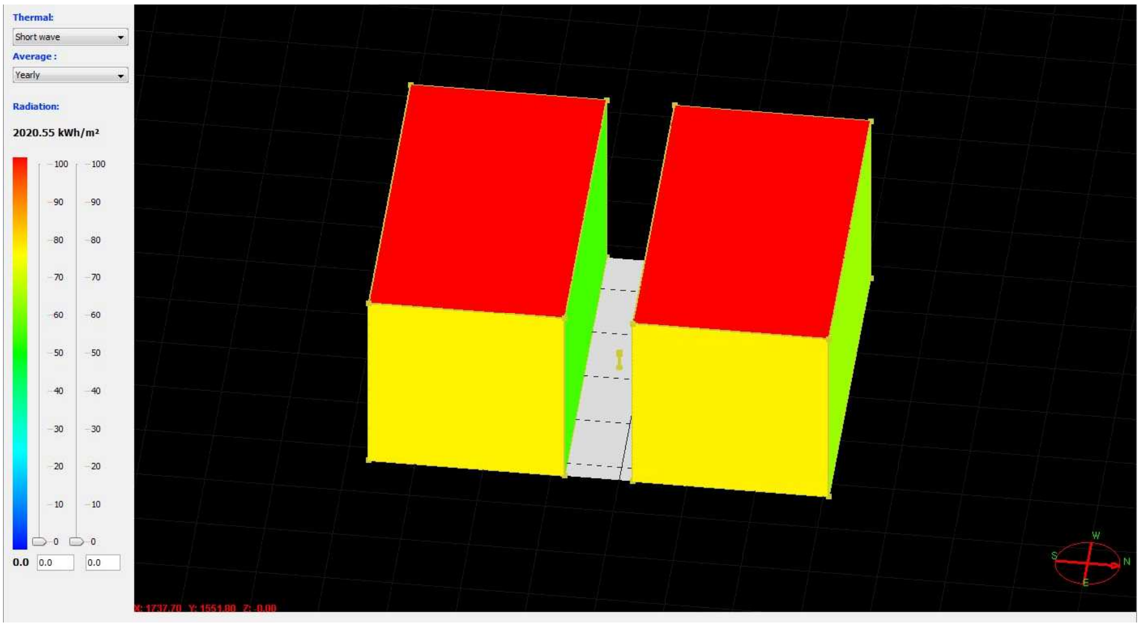


Figure 140 Orientation North- South, distance between buildings 5 [m]. Solar irradiation, yearly results. Max value 2020 [kWh/m²]. East view.

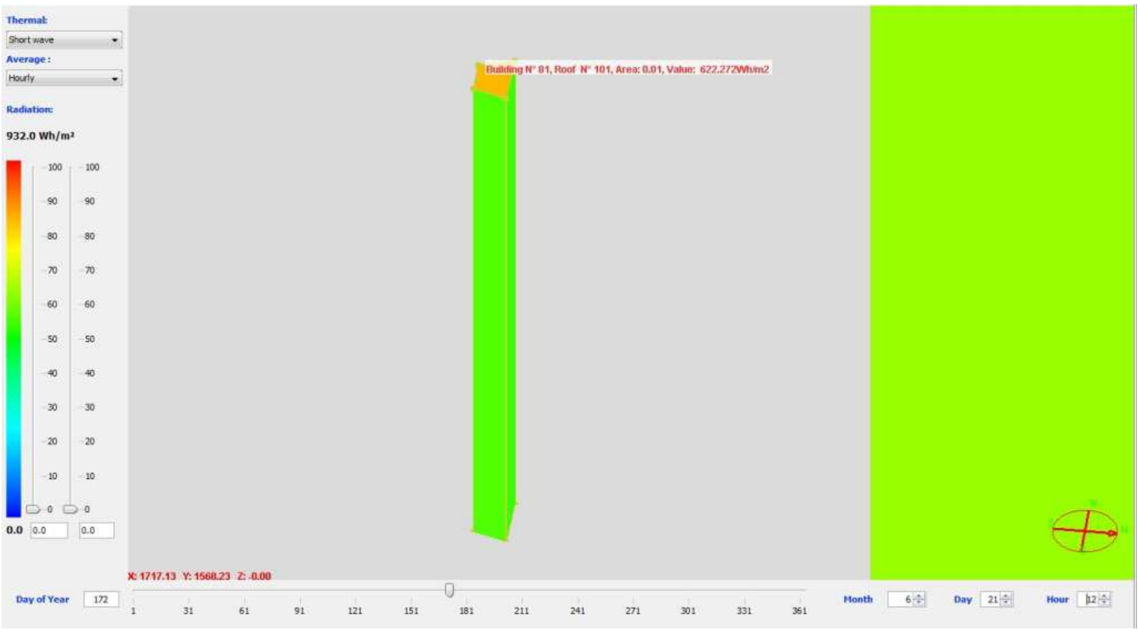


Figure 141 Orientation North- South, distance between buildings 5 [m]. Solar irradiation. Max value 622 [Wh/m²] , 21st of June, 12.00 [h]

As we can see in the images, the maximal value of solar irradiation is on buildings oriented on North-South axes, with a value of 622.27 [Wh/m²] at 12.00 [h] the 21st of June. The minimal value is on the East-West orientation, at a distance of 2 [m], with 286.39 [Wh/m²].

SECOND ANALYSIS_ COURTYARD_SOLAR IRRADIATION

The second analysis wanted to define the solar irradiation upon pedestrians in courtyards. We positioned 5 pedestrians in a courtyard of 23.95* 14.4 [m], as we can see in the image below.

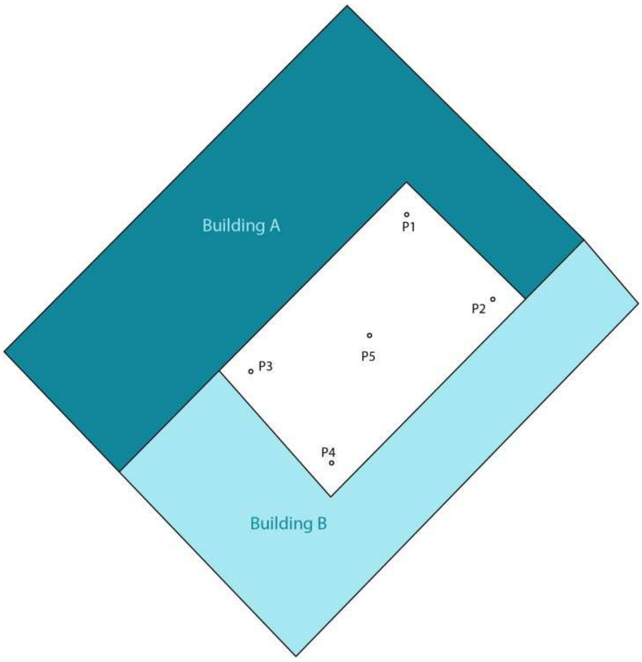


Figure 142 Simulation CitySim: courtyard and pedestrian.

Then we simulated the irradiation upon every pedestrian, demonstrating that every pedestrian has a comfortable climate: indeed the maximal solar irradiation, calculated for the 21st of June at 12.00, is 393.68 [kWh] for pedestrian P2, where the solar irradiation upon roof is 848.32 [kWh] for building A, and 844.28 [kWh] for building B. The maximal difference from the maximal solar irradiation, building A, and the minimal solar irradiation, P4, is 13.85 [%] concerning the yearly solar irradiation, 16.20 [%] the solar irradiation the 21st of June, and 17.39 [%] the solar irradiation the 21st of December.

Table 46 Solar irradiation upon pedestrian.

Pedestrian_building	Yearly solar irradiation [kWh]	21st June [kWh]	21st December [kWh]
P1	734'219.18	148.98	185.16
P2	561'373.43	393.68	72.33
P3	438'273.14	300.69	117.02
P4	279'895.65	137.42	57.92
P5	577'755.97	315.46	145.95
Building A	2'020'309.94	848.32	333.10
Building B	1'973'114.88	844.28	329.49
Difference min-max [%]	13.85	16.20	17.39

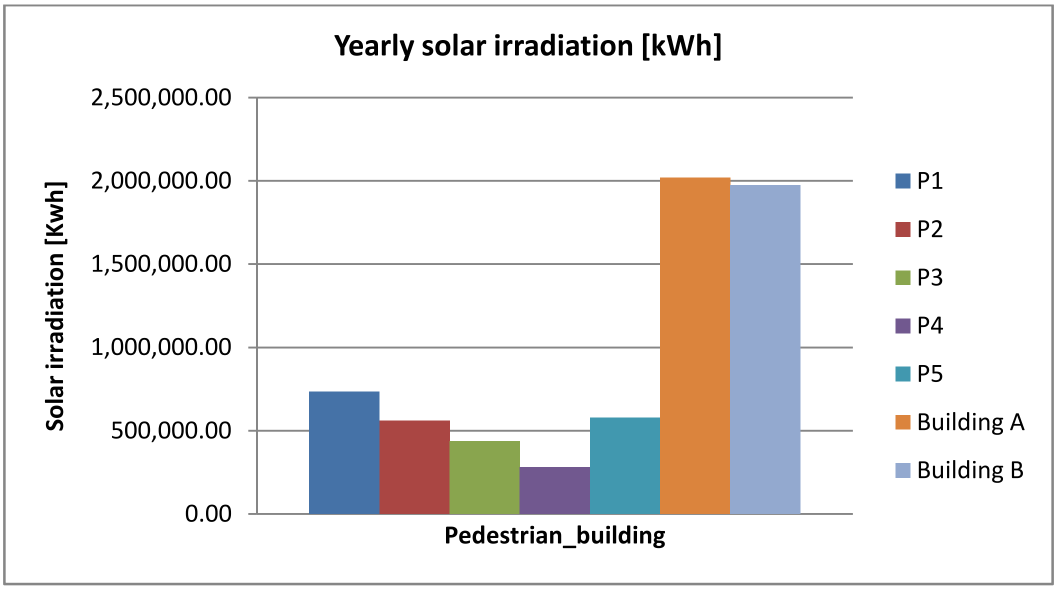


Figure 143 Solar irradiation upon pedestrian [kWh]

THIRD ANALYSIS_ COURTYARD THERMAL COMFORT

Starting from the same model, we defined the pedestrians as buildings, and we defined the cooling needs for every pedestrian. As we can see in the table below, the cooling needs, expressed in [kWh] are reduced to a maximal value of 55 [kWh] in pedestrian P1. That means that a person, without moving, can feel comfortable in the court, and needs just some cool air during the hottest hours of the summer day, as we can see in the graph below.

Table 47 Courtyard pedestrian thermal comfort [kWh]

	Cooling needs [kWh]				
Months	P1	P2	P3	P4	P5
January	-0.17	-0.07	-0.04	0.00	-0.04
February	-0.19	-0.10	-0.08	-0.02	-0.09
March	-1.21	-1.02	-0.87	-0.58	-0.93
April	-2.52	-2.44	-2.48	-1.91	-2.31
May	-6.36	-6.42	-6.62	-6.01	-6.46
June	-9.97	-10.29	-10.41	-9.92	-10.67
July	-12.47	-12.64	-12.56	-12.07	-12.96
August	-10.65	-10.56	-10.67	-9.94	-10.71
September	-6.51	-6.11	-6.12	-5.28	-5.93
October	-3.51	-2.89	-2.49	-1.98	-2.55
November	-1.42	-1.14	-0.77	-0.62	-0.71
December	-0.38	-0.12	-0.09	-0.04	-0.05
Total	-55.36	-53.79	-53.18	-48.39	-53.41

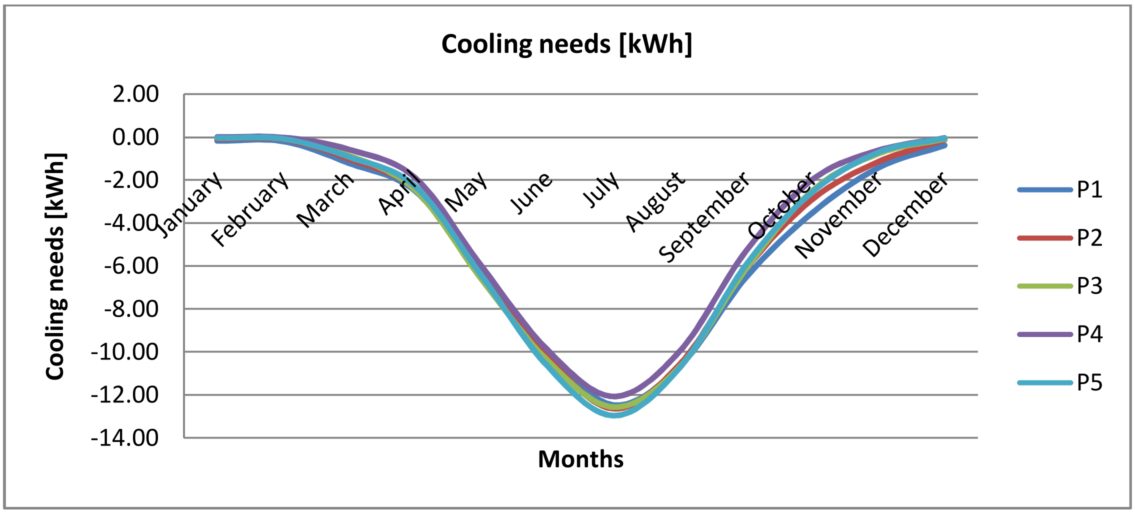


Figure 144 Pedestrian, cooling needs [kWh]

5.0 MASTERPLAN C

The concept of this Masterplan is the Medina. We've defined the urban tissue starting from the "disorder". Indeed the Arab city is created without urban plan, but from the family relationship. For this reason we've first defined a geometrical grid, perpendicular to the main wind direction: the North- West and the South. Then we've defined a central axe, that trace the cancer constellation, where every star is a function, in this case *Decapoda* is laboratory, *Asellus Australis* is the social area and learning centre*, Acubens* is the residence and sport, and finally *Tarf* is the residence.

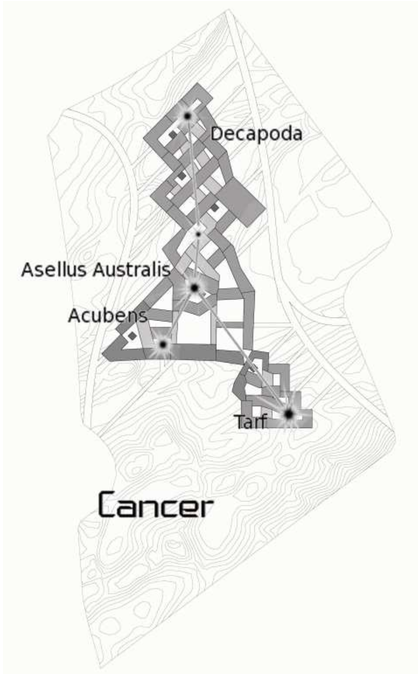


Figure 145 Masterplan C. Concept and panoramic view.

5.1 BIOCLIMATIC PATTERN

- External buildings are higher than internal, creating solar and windy protection.
- Streets cross the building, and are shadowed by them.
- Streets aren't regular, creating privacy and many perspectives during the walk.
- No many windows in building in the South side, to create a protection by the dune created by the South wind.
- Central and protected court, as place of social aggregation.
- Vegetation is external and internal of the campus, protecting from wind [external] and canalizing wind in the building [internal].
- Solar and wind tower.
- Atrium perpendicular at the North- West wind, and wind canyon in every court.
- Courtyard house.

5.1.2 FUNCTIONS

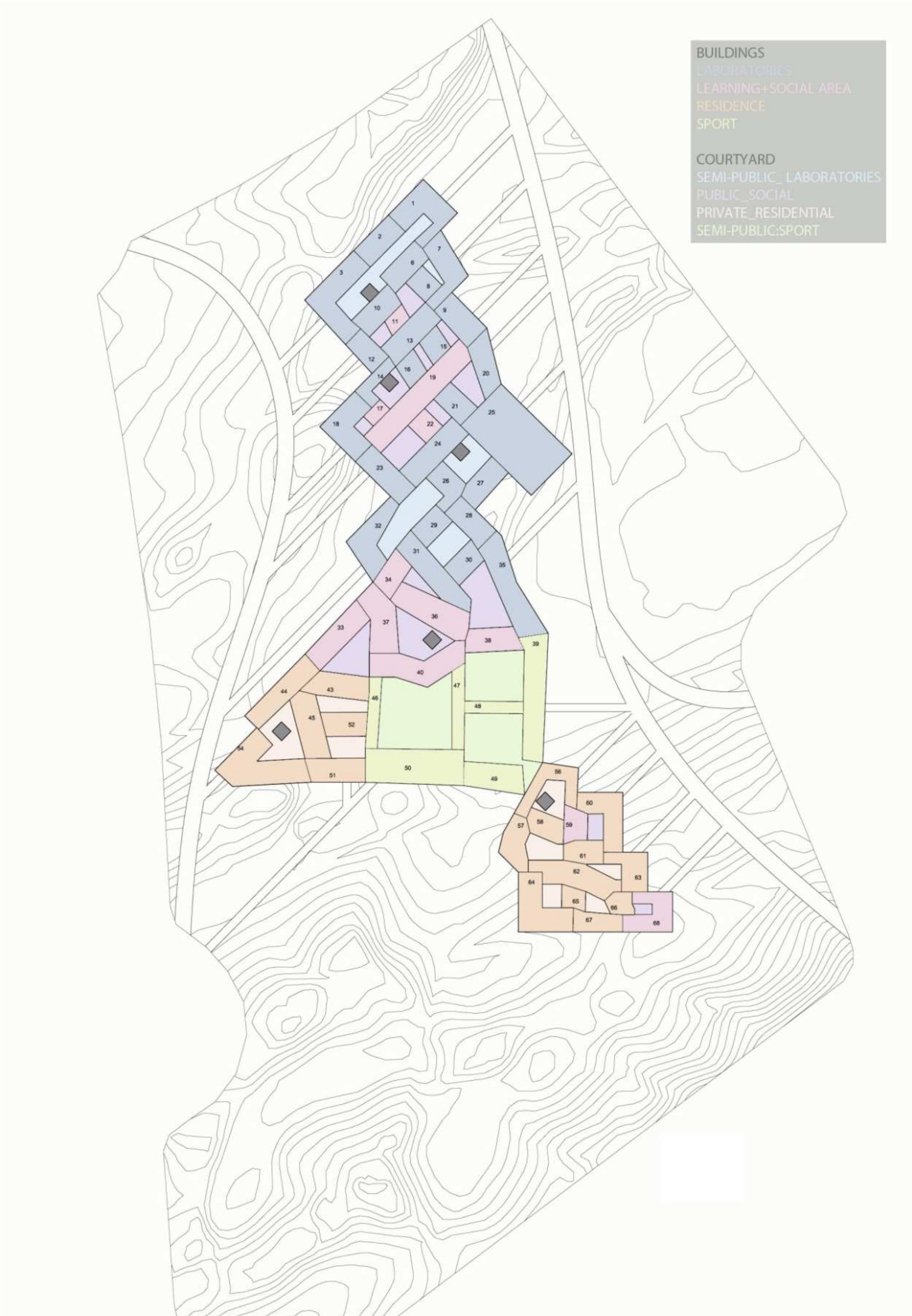


Figure 146 Masterplan C. Functions

As we can see in the table below the total surface respond at the necessity defined by Vigliotti.

Table 48 Function. Total area [m²]

Building	Total area [m^2]	Atrium	Total area [m^2]	Function
1	1691.16	108	1583.16	Laboratory and infrastructure
2	1271.16	107.73	1163.43	Laboratory and infrastructure
3	3245.78	0	3245.78	Laboratory and infrastructure
6	1266.705	0	1266.705	Laboratory and infrastructure
7	1676.17	0	1676.17	Laboratory and infrastructure
8	413.04	0	413.04	Laboratory and infrastructure
9	1371.98	0	1371.98	Laboratory and infrastructure
10	1266.705	0	1266.705	Laboratory and infrastructure
11	206.38	0	206.38	Social area
13	1681.44	0	1681.44	Laboratory and infrastructure
14	772.98	18	754.98	Laboratory and infrastructure
15	392.98	0	392.98	Laboratory and infrastructure
16	391.87	0	391.87	Laboratory and infrastructure
17	168.95	0	168.95	Social area
18	1899.37	35.95	1863.42	Laboratory and infrastructure
19	3503.37	0	3503.37	Learning center
20	1287.23	0	1287.23	Laboratory and infrastructure
21	595.4	0	595.4	Laboratory and infrastructure
22	373.46	0	373.46	Social area
23	1533.56	0	1533.56	Laboratory and infrastructure
24	1971.57	0	1971.57	Laboratory and infrastructure
25	8402.36	0	8402.36	Laboratory and infrastructure
26	668.47	0	668.47	Laboratory and infrastructure
27	1259.46	0	1259.46	Laboratory and infrastructure
28	1240.4	0	1240.4	Laboratory and infrastructure
29	638.08	0	638.08	Laboratory and infrastructure
30	990.96	0	990.96	Laboratory and infrastructure
31	1353	0	1353	Laboratory and infrastructure
32	1913.02	189.57	1723.45	Laboratory and infrastructure
33	1856.64	215.79	1640.85	Social area
34	700.5	0	700.5	Social area
35	2728.85	0	2728.85	Laboratory and infrastructure
36	2303.81	0	2303.81	Learning center
37	1943.32	0	1943.32	Learning center
38	1369.62	0	1369.62	Social area
39	2986.58	0	2986.58	Sport
40	2699.55	0	2699.55	Learning center
43	1481.62	0	1481.62	Residence
44	1947.48	93.54	1853.94	Residence
45	1196.91	0	1196.91	Residence
46	622.8	0	622.8	Sport

Building	Total area [m²]	Atrium	Total area [m²]	Function
47	747.06	0	747.06	Sport
48	767.94	0	767.94	Sport
49	1732.86	0	1732.86	Sport
50	1099.42	0	1099.42	Sport
51	1414.64	0	1414.64	Residence
52	1080.52	0	1080.52	Residence
54	2990.26	0	2990.26	Residence
56	1514.97	0	1514.97	Residence
57	1347.48	0	1347.48	Residence
58	997.11	0	997.11	Residence
59	481.94	0	481.94	Social area
60	1764.94	0	1764.94	Residence
61	948.18	0	948.18	Residence
62	2128.16	0	2128.16	Residence
63	1302.66	0	1302.66	Residence
64	2363.52	0	2363.52	Residence
65	365.36	0	365.36	Residence
66	410.46	0	410.46	Residence
67	1044	0	1044	Residence
68	1633.92	0	1633.92	Social area

VIGLIOTTI

Table 49 Function. Vigliotti's surface [m²]

Function Vigliotti	Area $[m^2]$
Lab+ infrastructure	32'000.00
Learning	8'200.00
Social area	7'000.00
Residence	22'000.00
Sport	20'000.00
Total	89'200.00

MASTERPLAN

Table 50 Function. Masterplan surface [m²]

Function	Area $[m^2]$
Lab+ infrastructure	41'464.45
Learning	10'450.05
Social area	6'575.62
Residence	24'204.73
Sport	7'956.66
Total	90'651.51

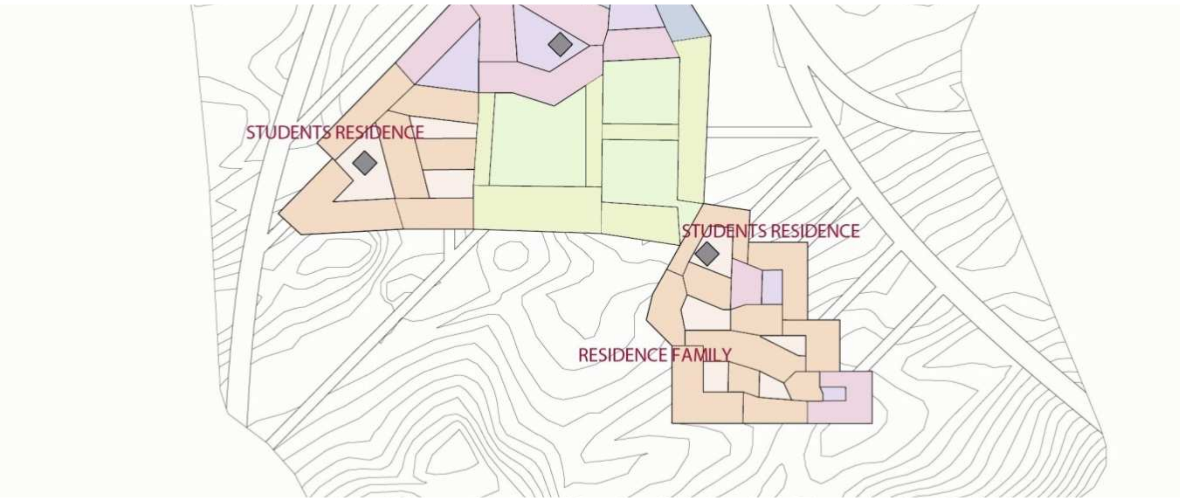


Figure 147 Function. Residence

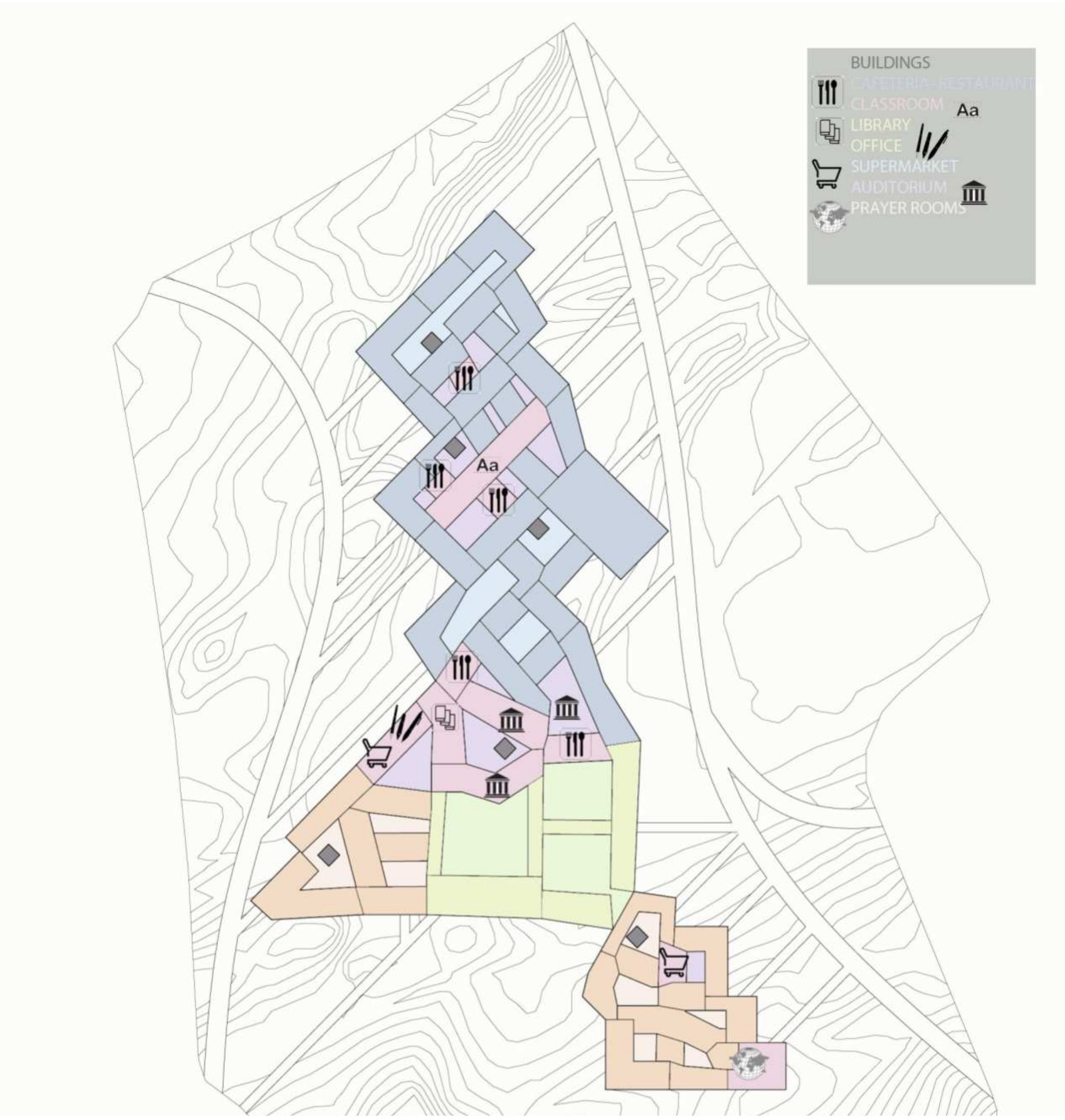


Figure 148 Function. Social area and learning

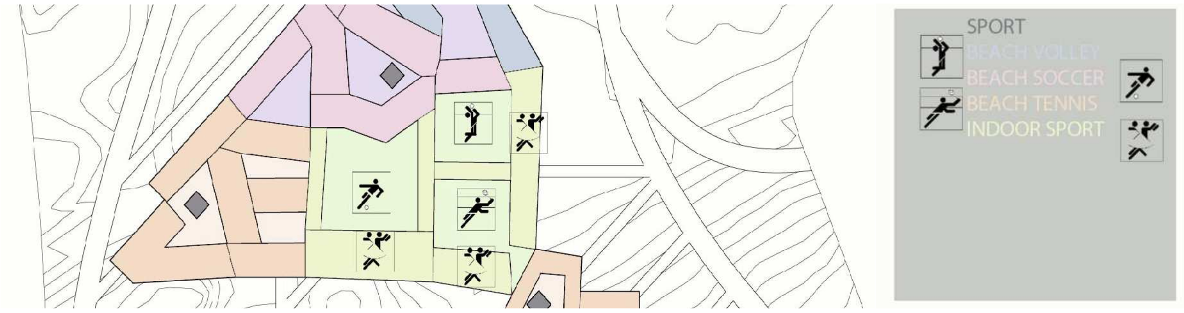


Figure 149 Function. Sport

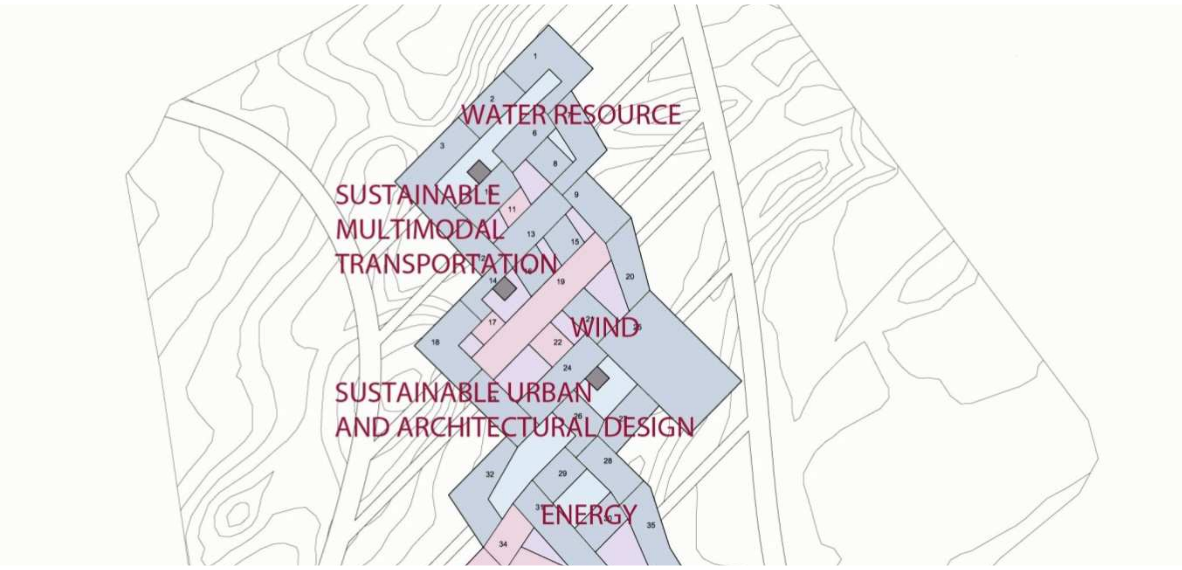


Figure 150 Function. Laboratories

5.1.3 View

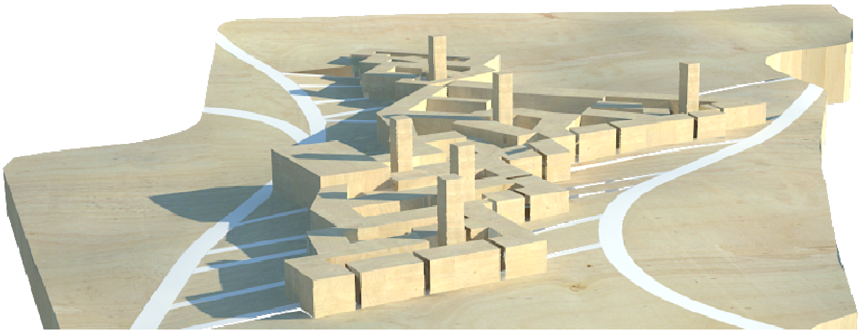


Figure 151 Masterplan C. North view

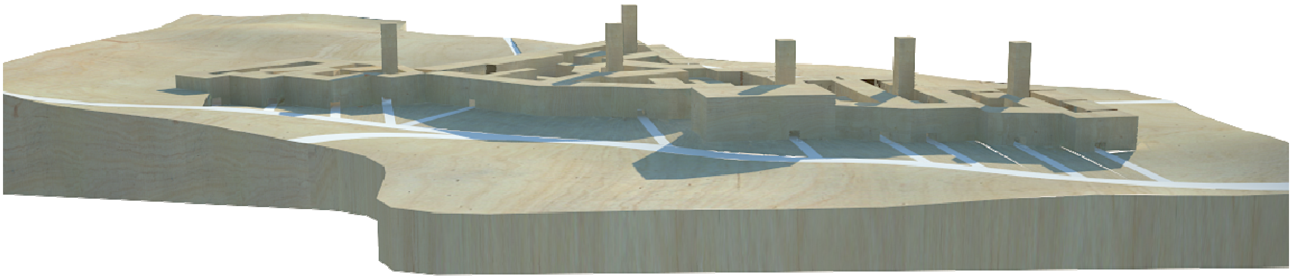


Figure 152 Masterplan C. East view

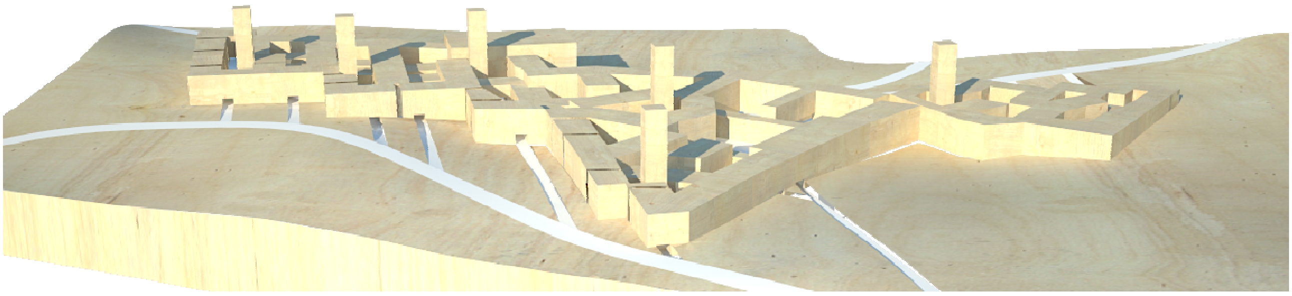


Figure 153 Masterplan C. West view

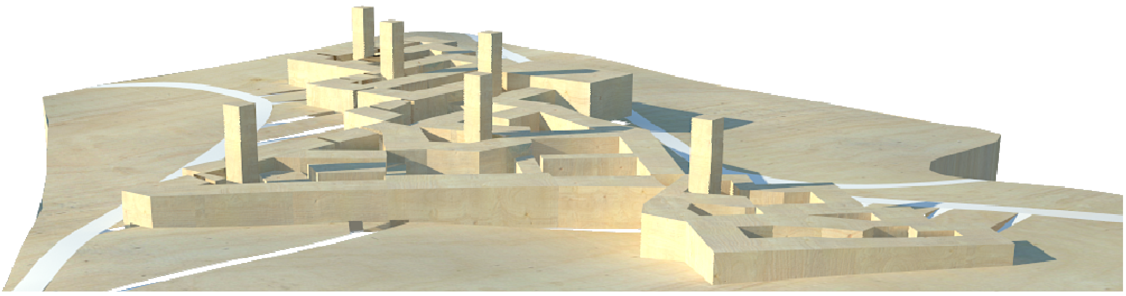


Figure 154 Masterplan C. South view

5.1.4 Images

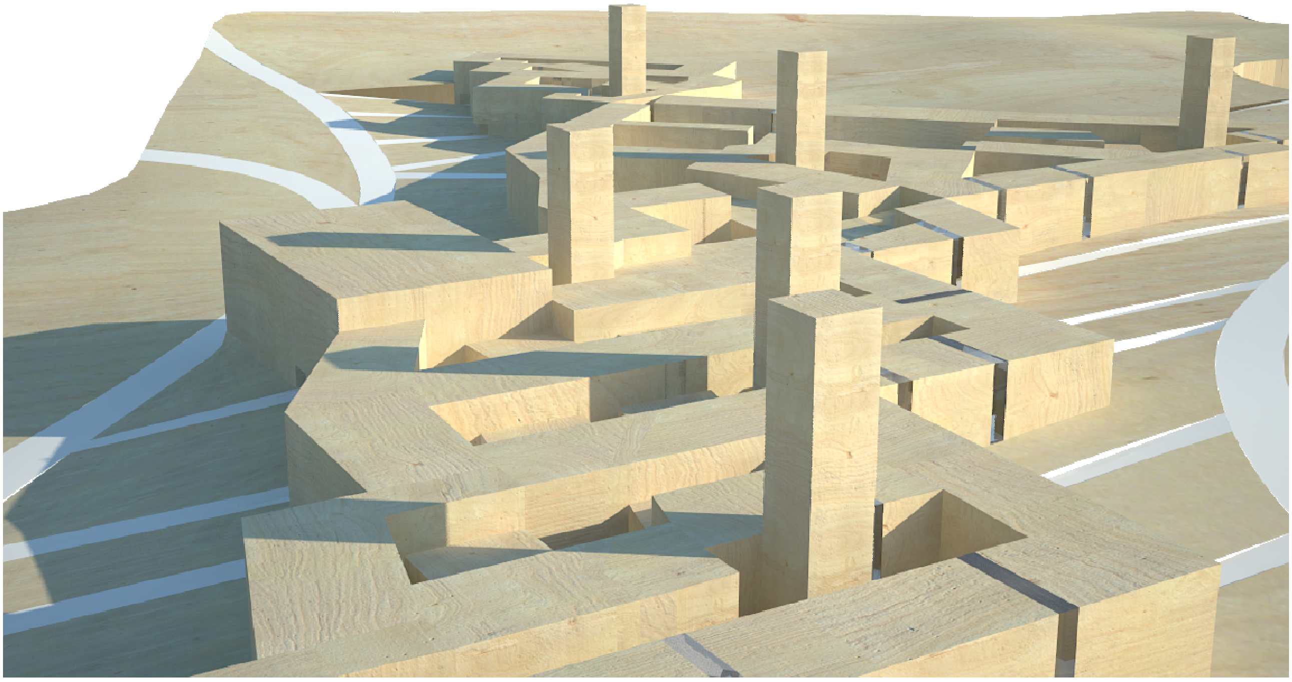


Figure 155 Masterplan C. Central street.

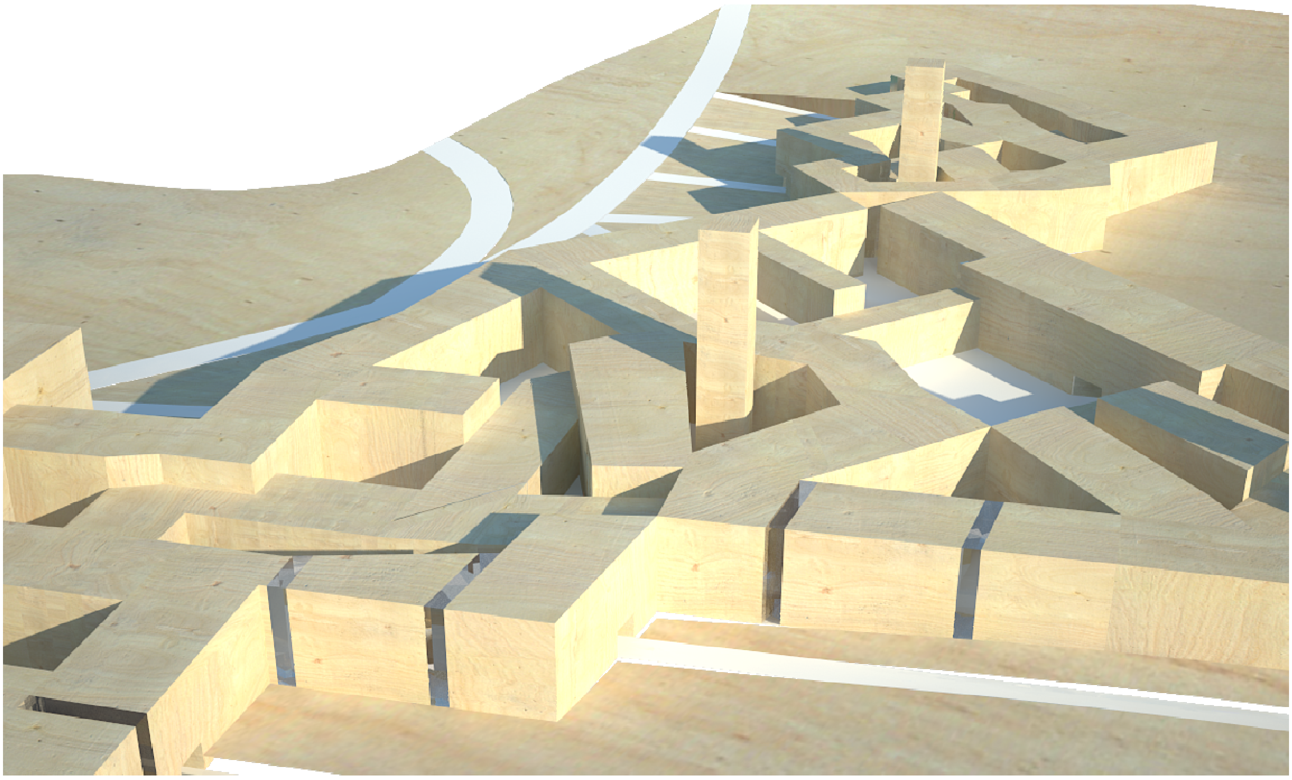


Figure 156 Masterplan C. View of the sport's court

5.1.5 Pedestrian way

We've decided to define four kind of way:

- The main way, passing in courtyard and buildings
- The second way, passing in the buildings.
- The roof way, that can be used also by cycle. Naturally this street can be used just during coldest months, or during the night in the summer months.
- The external way, for pedestrian and emergency vehicle.

Figure 157 Masterplan C. Pedestrian way

The law used to define the fireman access is the "Norme de protection incendie" [31], 2008. In the article 58, « *Accès pour les sapeurs-pompiers »* is written *:* " Les bâtiments, ouvrages et installations doivent garantir un libre accès en tout temps permettant une intervention rapide et efficace des sapeurs-pompiers."

For this reason, every building have an access for the fireman, of 5.00 [m] large, and 4.00 [m] high. Indeed the dimension of a foam tanker is 6.5[m] long, 2.4 [m] large, and 3.0 [m] high.

5.1.6 People's fluxes

As a university campus can be interesting investigate in how people can meet, what are the relationship between the students. As example we've decided to study two hypothetical person, S1 and S2, and we've tried to define their movements during the day, defining two main way to move: by foot and by bicycle, thinking at a pedestrian- cycle street on the roof.

Figure 158 People's flux. S1 8.00 and 10.00 hours

Figure 159 People's flux. S1 12.00 and 18.00 hours

Figure 160 People's flux. S1 22.00 and S2 8.00 hours

Figure 161 People's flux. S210.00 and 12.00 hours

Figure 162 People's flux. S218.00 and 22.00 hours

Figure 163 People's flux and attraction points

CONCLUSION

From this analyse we can define the main way to move in the Masterplan. During the day it can be better to use the main way that cross the building, but during the night the faster way is the roof street. People can meet each other in the campus, thanks to the different street, that cross the central social area. The restaurants and cafeteria are all around the masterplan, increasing the place to meet everywhere. The social area is the main attraction point of the campus, is central, and is the place where everyone need to go. The sport centre is like a filter between the meeting point and the residence, is a place to relax and of meeting.

5.1.7 VEGETATION

The dunes in the Masterplan, as we have defined in the first chapter, are transversal to the main wind directions: the North- West and the South. The dunes are in movement, but there are some elements to limit the displacement, as using vegetation. Collecting to the Australian desert, we've defined some vegetation from the Simpson Desert, as the grass Zygochloaor the Triodia that can live in extremely arid climate. The motivation is not to stop the dunes displacement, but to protect the area around the Campus.

In the courtyard we decided to create gardens, with palms that can live in extremely climate, with watering just in the first two or three years. It can be interesting to have small gardens with Desert ephemerals, Hyacinths and Thumbs, which flourish mainly during the winter and spring season giving the desert an amazing look. During the winter, after rains, a lot of plants emerge from the sand, as Senna plants, Desert Sqashes, Eyelash plants and Blepharis. These plants have developed ways to survive in the arid conditions: some of them store the water in succulent leaves, or absorb water from the humid air; a few have seeds that can survive long dry periods, while others release seeds only after the rainfall.

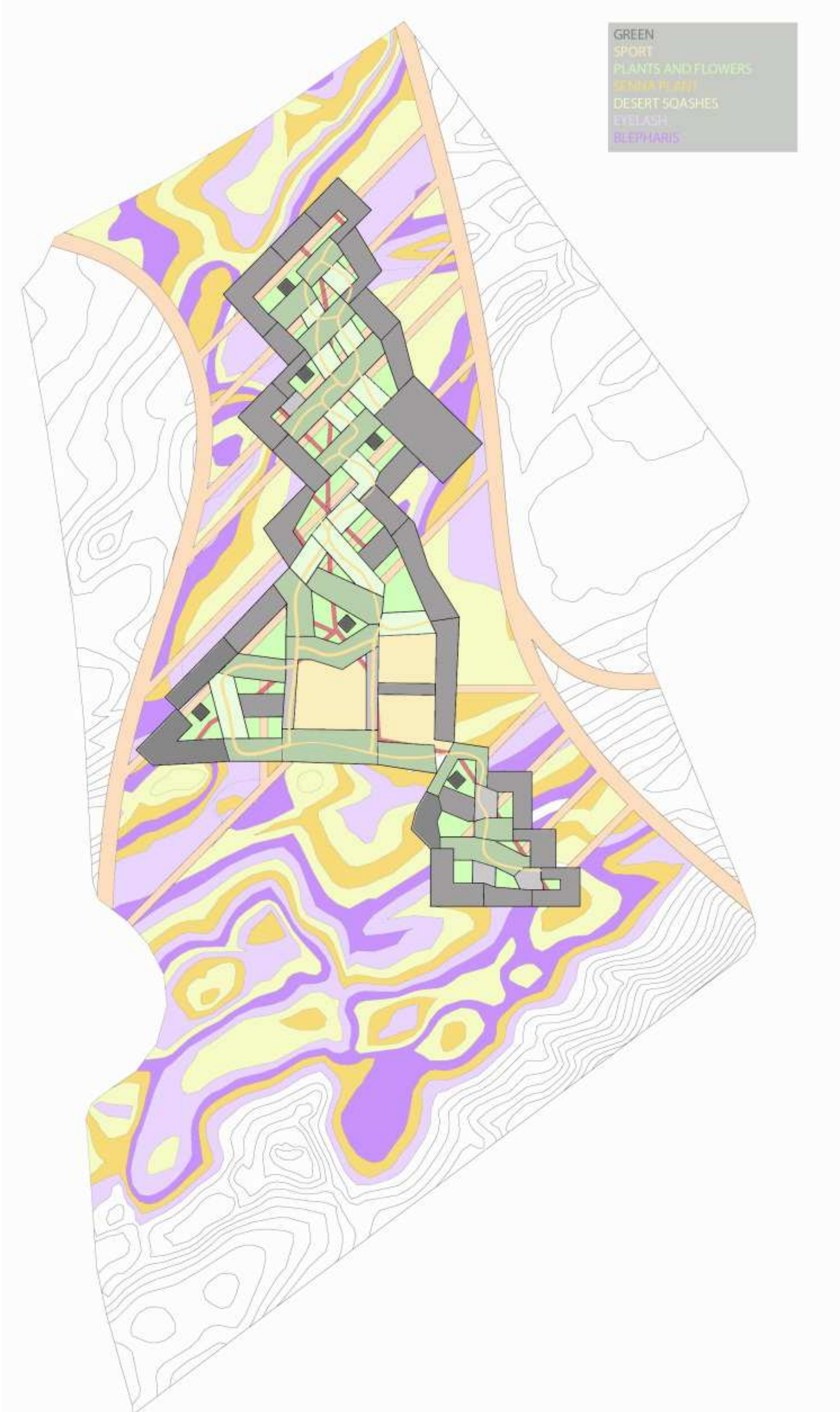


Figure 164 Masterplan C. Vegetation

5.1.8 The sport centre

A sport centre is a place of relax, but also of way of meeting, working in team. For these motivations we've decided to create a big sport centre, outdoor and indoor. With the Arab climate, we've define some activity outdoor, in internal courtyard, that can assure a lower temperature; the main element that define every outdoor sport is the utilisation of the sand: soccer, volleyball and tennis are common sport in Switzerland, but they need a lot of maintenance, and water consumption, as the grass on a football field. In Ras Al Khaimah we need to reduce water consumption, and that's why we've decide to play other sports, similar to the others, but that can be played on sand terrain: beach soccer, beach volley and beach tennis. Sand is a local material, that can be used as we need, it don't' need to be imported, as artificial grass, or red ground for the tennis field. A climbing wall is thought along the courtyard's walls.

Description and dimension

Beach soccer[32]: the football field has a dimension of 37.00*28.00 [m], with a total perimeter of 39.00*30.00 [m], with a safety zone of 2.00 [m] on each side. The goal has a dimension of 5.50*1.50 [m], and a high of 2.20 [m]. The maximal number of player is 5 for each team.

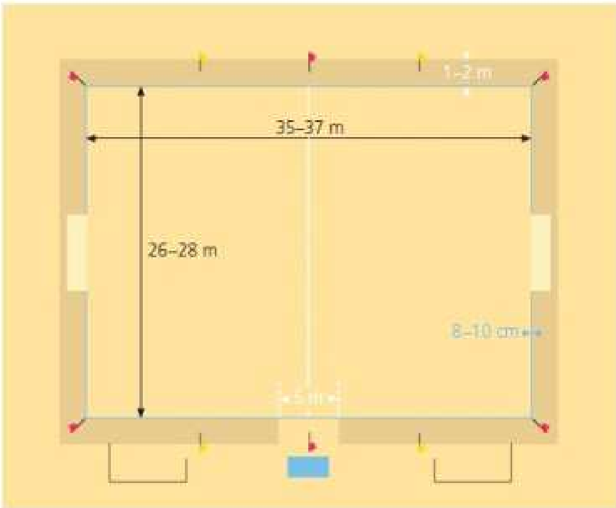


Figure 165 Beach soccer field[32]

Beach volley[33]: the beach volley is a sport team, that's played on a sand field. The dimension of the single field must be of 8.00*16.00 [m], with a net that must be a 2.24 [m] for women, and 2.43 [m] for men. If we want to put together two field, the dimensions became 24.00 *28.00 [m], with a distance between the two of 5.00 [m].

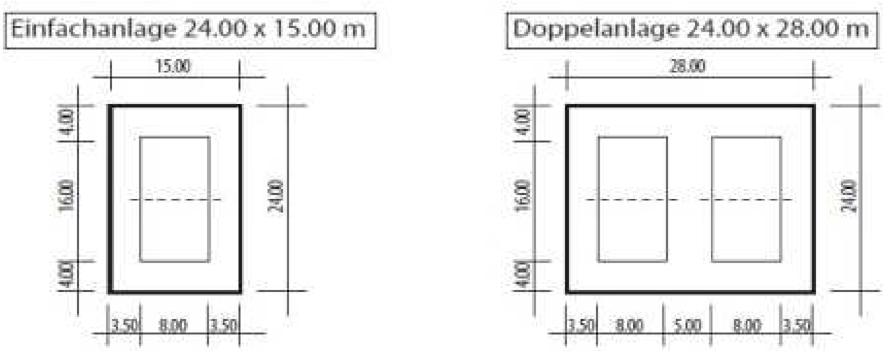


Figure 166Beachvolley's field dimensions[33]

Beach tennis[34]: the court's size is 8.00*16.00 [m], with a safety zone of . The singles court's size is of 5x16m. The net is 1.70m high, positioned on the centre.

In the internal gym, we've decided to put a volleyball field, and a gym.

Description and dimension

Volleyball: the play area must be of 16.00*8.00 [m], with a corridor around the perimeters of 3-4.00 [m], for a total area of 22.00*14.00 [m]. The net must be a 2.24 [m] for women, and 2.43 [m] for men.

5.2 SUSTAINABLE DEVELOPMENT

5.2.1 RECUPERATION OF RAIN WATER

Precipitations are reduced in Ras al Khaimah, as we can see in the table below.

Table 51 Precipitation [mm]

Precipitation [mm]

	Average [mm]	Total [mm]
January	0.06	48.00
February	0.03	20.80
March	0.02	15.70
April	0.00	0.50
May	0.00	0.00
June	0.00	0.00
July	0.00	0.00
August	0.00	0.00
September	0.00	0.00
October	0.00	0.00
November	0.01	4.90
December	0.03	19.40

The rain fall is limited on the winter months, from November to march, with a maximal value of 48.00 [mm] on February. This value confirms the humidity, that is higher in the same months.

What can be interesting is to define how much water can be collected, by the building's roof, referring to E DIN 1989-1: 2000-12. Calculating the total roof surface, we can say that we have totally 38,191.97 [m²] of available roof surface, and a coefficient of draining, connected with the roof characters, in this case with a value of 80 [%] . Knowing that in total we've 109.3 [mm/y] of rain per year. The formula is defined below:

R = S * Vp * Vt

Where

S: total roof surface [m²]
Vp: annual precipitation [mm]

Vt: coefficient of draining, connected with the material. For example: tile is 0,9; concrete 0.8; gravel 0.6 and green roof is 0.4

109.30*38,191.97*0.80= 3,339,505.86 [l]

To define the no potable water needs, we have used the table below:

Purpose	Recommended minimum [litres per person per day]	Percentage
Drinking water, cooking and kitchen	27	17
Sanitation Services	21	13
Bathing	32	20
Toilets	47	29
Washing machine	31	19
Others (car washing, garden..)	4	2
Total	162	100

Table 52 Sia Normative about potable water per day[7]

Where the number of people comes from Vigliotti's Masterplan, as we can read in the table below:

Number of people, from Vigliotti Masterplan	Target 5-7 years	Capacity masterplan 7-10 years
Faculty and scientific staff	50	60
Admin	10	15
Management, services, technical	20	40
PhDstudents	50	70
MScstudents	60	200
Visitingfaculty, scientists, students	25	50
Total	215	435

As we can see in the results, the total daily needs are 70,470.00 [l] for a population of 435 people.

5.2.2 Create water from humidity

As we have defined in the first chapter, in UAE there is a high use of desalinisation, with great problem of Golf's flora and fauna. Also the use of groundwater resource is problematic: Z. S. Rizk andA. S. Alsharhan estimated that the annual recharge for groundwater in the UAE is 21.8 to 32.7 [Mm^3/y], while groundwater abstraction is 880 [Mm^3/y]. As we have seen before, the recuperation of rain water can be an idea, but the value is not considerable, compared with the water needs. That is why, during the humidity analyse, we have thought to use the humidity from the air to create water.

Table 53Masterplan.Relative humidity [%]. Data from Meteonorm

RH Relative humidity [%]	
January	69.76
February	70.01
March	60.37
April	49.30
May	41.10
June	47.00
July	47.60
August	49.73
September	57.58
October	59.52
November	63.49
December	67.29

As we can notice from the upper table, the relative humidity is high, but is important to define the absolute humidity [g/m³], as a value to understand if the humidity can be used to create water.

To define the saturation vapour pressure, we've apply the Clausius-Clapeyron equation, that's:

$$\rho sat = 6.11 * 10.00^{\left(\frac{7.5*t}{237.7+t}\right)}$$

Where:

ρsat: saturation vapour pressure [N/m²]

t: air temperature [°C]

Then we've define the absolute humidity at the vapour saturation, with the formula below:

$$Has = \frac{\rho sat}{0.4617 * t}$$

Where:

Has: absolute humidity at the vapour saturation[g/m³]

ρsat: saturation vapour pressure [N/m²]

t: air temperature [K]

An in the end we've define the absolute humidity, as

$$Ha = Has * Hr$$

Where

Ha: absolute humidity [g/m³]

Has: absolute humidity at the vapour saturation[g/m³]

Hr: relative humidity [%]

As we can read in the table below, absolute humidity [g/m³], is higher during the summer months, with a maximal value of 19.83 [g/m³] in August.

Table 54 Masterplan. Absolute humidity [g/m³]

Absolute humidity [g/m^3]	
January	11.03
February	11.99
March	12.20
April	12.24
May	13.30
June	16.95
July	19.45
August	19.83
September	19.37
October	16.61
November	13.66
December	11.88

The Israeli company, EWA Technology Group, produce an engine that can create water from the air humidity. This concept can be useful in UAE climate, because of the reduced water resource, but the high air humidity. This technology can be apply all around the world, because, except for arid and cold climate, 1 [km³] of air contains from 10 to 40 [tones] of water. The technology adsorbs the atmospherically humidity, and use the solar heat to extract potable water from the air. The idea comes from the study of the MIT professor, in 1993, Reginals E. Newell: he found that in troposphere, the lower 10- 20 [km] of the atmosphere, there are the so called "sky rivers", with flows rate of 165 [million kg/s] of water.

The EWA technology is divided in three phase:

- Absorption of the air humidity: the humidity is removed from the air, thanks to chemical desiccation. The machine can utilize ambient air, even with low relative humidity, as 20 [%], and absolute humidity of 5 [g/m³]
- Desorption of the absorbed water.
- Condensation.

The technology work with different kind of energy source, from biogas and incineration of bioorganic waste. The machine output is:

- to create 1,000 [l] of water, at least 50,000 [m³] of air.
- electric need: 5 [W/l], for example to create 1,000 [l] of water, we need 5 [kW] of electricity. But also 51 [kcal/l].

As we can see in the table below, there are two models that can be used.

Model	Daily water capacity (liters)	Retail Price ($)
Type III 20	10,000	85,000
Type III 40	25,000	125,000

Characteristic	Type III 20	Type III 40
Daily water production	10 m³	20-25 m³
Size (m)	6.0 x 2.5 x 2.5	12.0 x 2.5 x 2.5
Weight (ton)	15	26
Control	Fully automatic	
Maintenance	o Air filters – weekly o Minerals cartridge – according to water consumption (about weekly) o Cassettes replacement/recovery – annually	
Guarantee	One year (including training)	
Extra equipments	Electric generator Diesel/gas heater Water container	
Operations range	Minimum RH - 20% Ambient temperature 4°C to 45°C	

*1kg diesel = 11 kW, 1m³ natural gas = 10 kW

Energy source: Bio-waste plus agricultural waste		
Daily capacity (l/day)	Bio-waste (kg/l) Heat consumption	Electricity consumption (kWh/l)
10,000	0.026	0.00045
25,000	0.022	0.0003
Energy source: Natural Gas [2]		
Daily capacity (l/day)	gas (m³/l) Heat consumption	Electricity consumption (kWh/l)
10,000	0.03	0.00045
25,000	0.024	0.0003
Energy source: Diesel [1]		
Daily capacity (l/day)	Diesel (kg/l) Heat consumption	Electricity consumption (kWh/l)
10000	0.065	0.00045
100000	0.055	0.0003

[1] 1kg diesel = 10,200 kcal or 11 kW
[2] 1m³ natural gas = 8,600 kcal or 10 kW

Figure 167 EWA products [35]

As we can see from the table, with the Type III 40, we can produce 25,000 [l] per day, with a rental price of 125,000 [$]. It can works with bio waste, natural gas and diesel. In total we'd have a production of 9,125,000.00 [l] per year.

Another important element is to define the basic water's need of people, connected to the climate. As we can read in the article "*Basic water requirements for human activities: meeting basic needs*"[36], the basic water requirement for human needs are:

Table 55 Prof.Gleik's water requirement for human needs[36]

Purpose	Recommended minimum [litres per person per day]	Range [litres per person per day]
Drinking water	5	2 to 5
Sanitation Services	20	0 to over 75
Bathing	15	5 to 70
Cooking and Kitchen	10	10 to 50
Total	50	

In Switzerland, as defined in the Sia "*Utilisation rationnelle de l'eau potable dans les bâtiments*"[37] the average water consumption is higher than the one defined before. In the table below we can define a total use of 162 [litres per person per day], but we can delete from this list the voice "Other" and "Toilets", supposing to use recycled water for these use. In total we can have 111 [litres per person per day].

Table 56 Sia Normative about potable water per day[37]

Purpose	Recommended minimum [litres per person per day]	Percentage
Drinking water, cooking and kitchen	27	17
Sanitation Services	21	13
Bathing	32	20
Toilets	47	29
Washing machine	31	19
Others (car washing, garden..)	4	2
Total	162	100

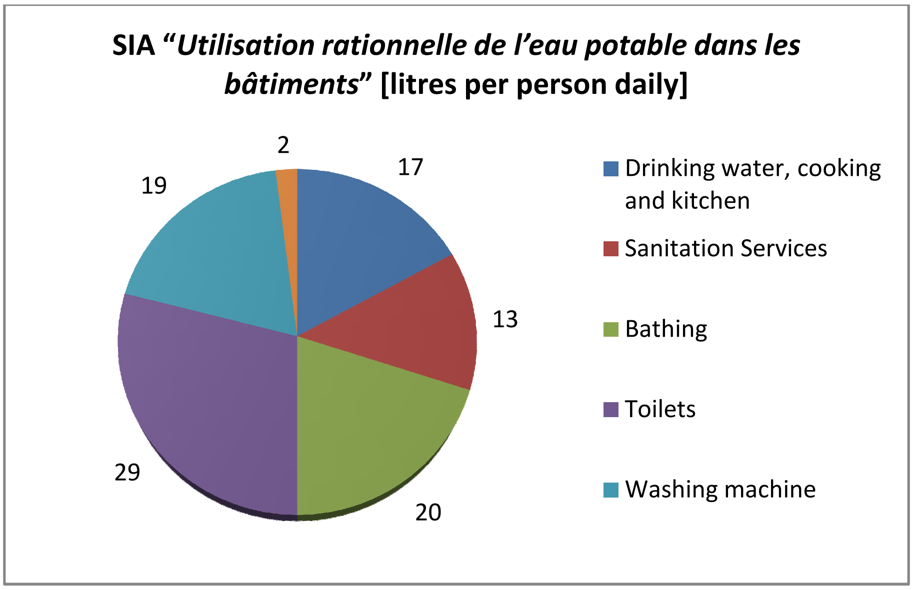


Figure 168 SIA "*Utilisation rationnelle de l'eau potable dans les bâtiments*" [litres per person daily]

Purpose	Recommended minimum [litres per person per day]	Total [litres per day]	Total [litres yearly]	Percentage	Source
Drinking water, cooking and kitchen	27	11,745.00	4,286,925.00	17	EWA Technology
Sanitation Services	21	9,135.00	3,334,275.00	13	EWA Technology
Bathing	32	13,920.00	5,080,800.00	20	EWA Technology
Toilets	47	20,445.00	7,462,425.00	29	Rain water and purification waste water
Washing machine	31	13,485.00	4,922,025.00	19	EWA Technology
Others (car washing, garden..)	4	1,740.00	635,100.00	2	Rain water
Total	162	70,470.00	25,721,550.00	100	

Table 57 Water needs [l] in the campus

Starting with these values, we can say that, with a population of 435 people, we'll need 48,285.00 [l] of potable water per day, and 22,185.00 [l] of no potable water per day. These needs can be covered by 2 machine of the EWA technology, for potable ones, and from the rain water collection and the purification of waste water.

Water	Needs daily [l]	Needs yearly [l]	Source	Yealy [l]	Daily [l]
Potable	48,285.00	17,624,025.00	EWA Technology	18,250,000.00	50,000.00
No potable	22,185.00	8,097,525.00	Rain water	3,339,505.86	
			Purification of waste water	4,739,687.00	

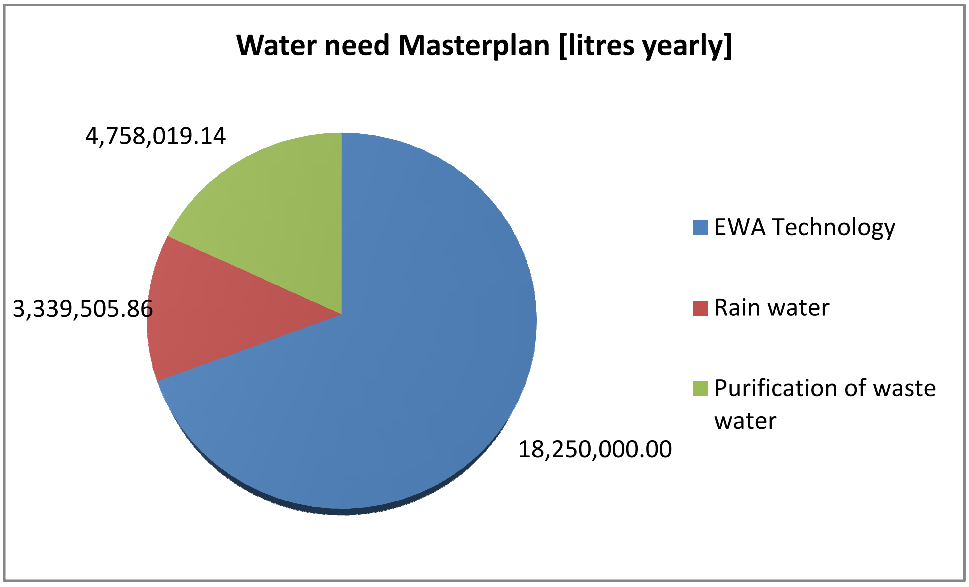


Figure 169 Water needs Masterplan

5.2.3 Wind

As we've seen in the analyses made before, the wind comes, regularly, from North West, and from South during August. For this reason we've decided to use the wind to create energy. As we can see in the graph below, the average wind speed is 2.5- 3 [m/s].

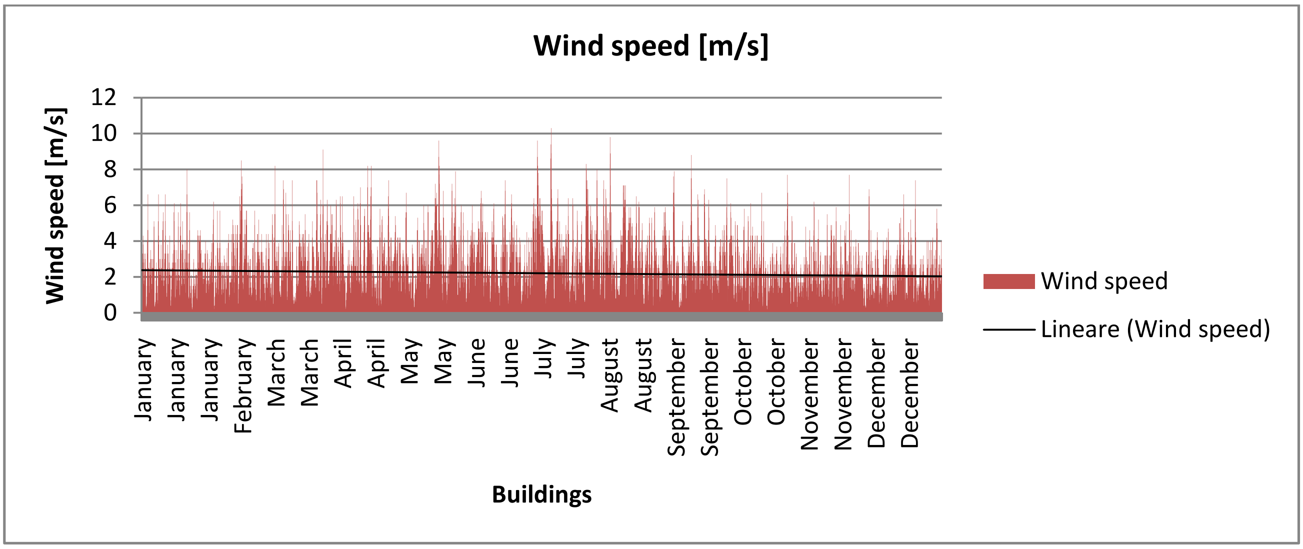


Figure 170 Wind speed [m/s]

5.2.4 Solar Energy

The solar irradiation upon roof is 2015 [kWh/m²], as we can see in the image below. For this reason is interesting to think that a part of the energy can be created by photovoltaic panels. We've decides to put them in the external roofs, with a percentage of 50 [%]. The total area that can be covered by panels is circa 10,000 [m²].

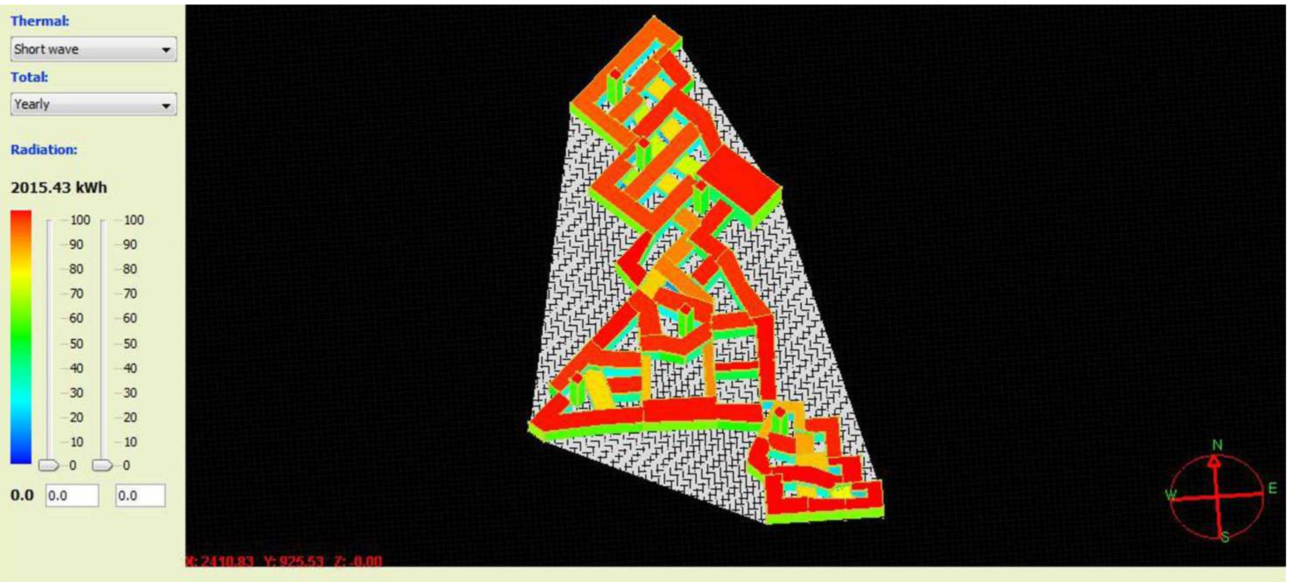


Figure 171Solar irradiation [kWh/m²y]

5.2.5 Wind catcher

Wind catchers are a natural way to ventilate buildings. They appear like a tower on the top of the building, and ensure a natural ventilation of the building, and they are protected against rain. In the commercial market we can find WINDCATCHER X-AIR, distributed by Monodraught Ltd, in the UK. In Masdar the windchatcher are the focus of the central square, rising 45 meters above the square. A PTF membrane carry downward the wind, and a mist generators, on the top, are used to cool the air.

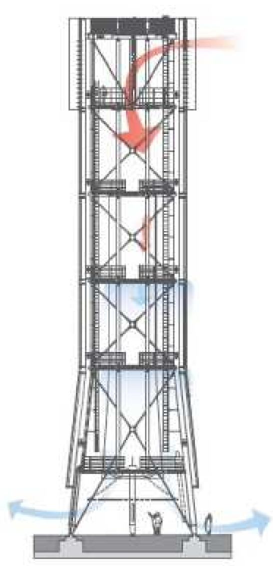
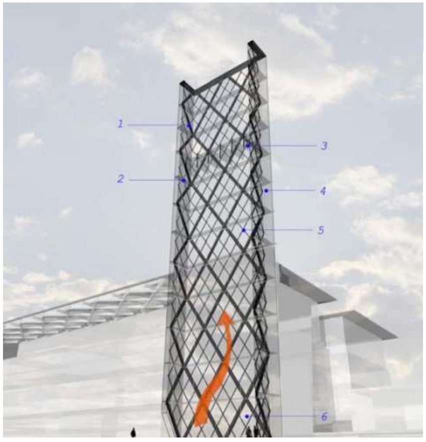


Figure 172 Masdar, wind tower in the central square[25]

5.2.6 SOLAR TOWER

The solar tower is high tower, a natural solution to generate airflow, collecting heated mass of air, and funnelling upward, by a convective vertical flow. The tower is composed by two box, the external one is made with hollow glass, connected from the internal one by a meter large maintenance catwalk system. The internal box is the real concrete structure, closed by glass element. The air is heated by the external hollow skin, creating a greenhouse effect. The internal of the tower is empty, characterized by the air flow convective movement, cooling the internal courtyard. Using the heating from the sun, we can assure a continuous convective flow, also if the wind intensity is not enough.

The solar tower system has been used in the Kaust University Campus, in Saudi Arabia. The tower's dimension has been studied to improve the convective flow, and they are 16.00 *8.00 [m] plan, and 70.00 [m] high.



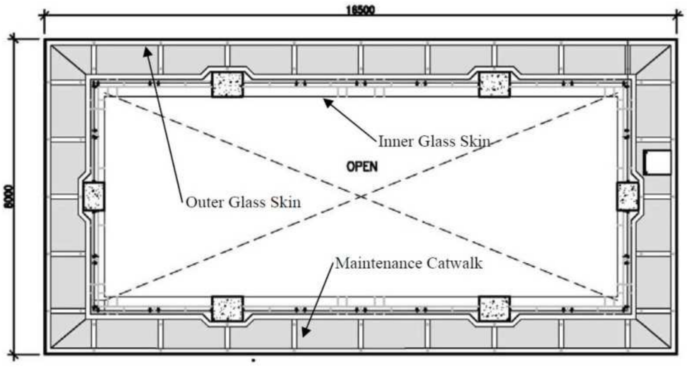


Figure 173 Solar tower in Kaust[38]

5.2.7 SAND BRICK

One topic of the project is to use sand brick, because they are traditional and they've good thermal inertia. Actually we can find different brick on internet, all taken from the concept of creating brick that can be realized with local and traditional materials.

In the three cases analysed the sand is united with different materials, giving the strength.

The sand brick developed by TIS&Partners, a Japanese Studio; the reaction between the silicon and the CO_2, as the formula

$(SiO_2+\alpha)+ CO_2= (SiC+\alpha)+ 2O_2$

give the form, and then infuse the bricks with a binder such as epoxy or urethane, that give the strength to the brick [2.5 times stronger than concrete].

Figure 174 TIS and Partners brick

Another brick was developed by Ginger Krieg Dosier, Assistant Architecture Professor in the American University of Sharjah, in the United Arab Emirates. The brick comes from the elaboration of sand, common bacteria, calcium chloride, and urea. As said Dr.Dosier, concerning the world's pollution, connected with the bricks production "Don't bake the brick; grow it".

Figure 175 The sand brick of Dr. Dosier

At last, but not at least, there are brick made with sand and plastic waste. They're produced by a German industry, not as the project before, that are just experimentation. The name of the product is SIOPLAST, and is made by 70 [%] of sand, and 30 [%] of plastic waste.

The most important elements of the brick are: is three times more wear-resistant than concrete/brick, it has a high thermal insulation, it has duration of 50 years, it doesn't absorb water, and it's recyclable.

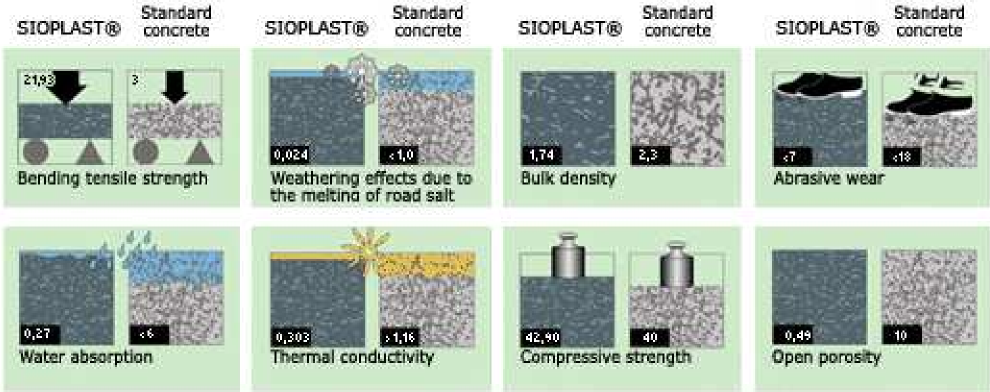


Figure 176 SIOPLAST technology

6.0 SIMULATION WITH CITYSIM

The simulation made with CitySim demonstrates the total energy consumption made by the campus. The first analyse define the total campus, without analysing the people's presence in buildings. The buildings, as first analyse, were defined as polygons, without adding the street and the galleries. The second analyse defines the impact of the emergency exits and the atrium, the third the difference, in energy consumption, of building isolated or with neighbours.

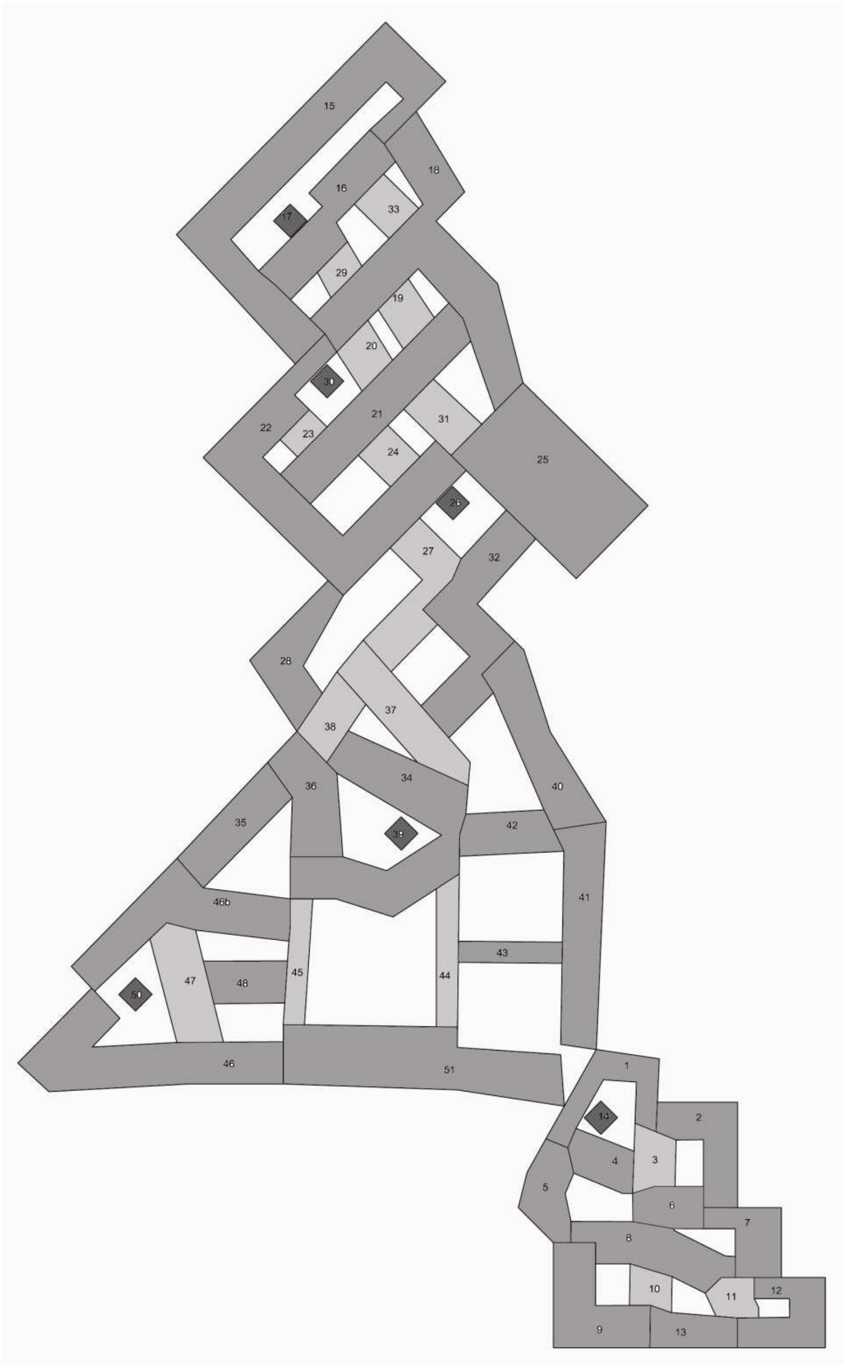


Figure 177 CitySim. Masterplan

6.1 SIMULATION CITYSIM_ FIRST ANALYSE. MASTERPLAN WITHOUT ATRIUM AND EMERGENCY EXITS

The first analysis with CitySim defined the energy consumption of the Masterplan, analysing every buildings. The parameters to classify every building are defined below.

GROUND_ DESERT SAND

Albedo: 0.40 [%]

According to Givoni[7]: 0.60 [%]

BUILDING PROPERTIES

INFILTRATION RATE [PER HOUR]

As said Givoni, in this climate is important to reduce the infiltration rate, because of the hot temperature. For this reason, and starting from the analyse of M. Papadopoulou, the infiltration rate of the building is defined as 0.05, with the actual standards.

In the atrium we have calculated the infiltration rate, connected with the wind and the difference of temperature, in the case of the cross ventilation, using the Ashrae method. This method consists in an empiric equation, which connect the total effective leakage of the building with the wind coefficient.

$$Q = A * \sqrt{a\Delta T + bv_r^2}$$

Where

Q: Flow rate [m^3/h]

A: the total effective leakage area of the building [cm^2]

a: stack coefficient [m^6/h^2cm^4K]

b: wind coefficient [m^4s^2/h^2cm^4]

ΔT: average inside- outside temperature difference [K]

vr: mean wind speed measured at the local weather station [m/s]

The stack coefficient, a, is connected with the number of stores, as we can see in the table below.

Table 58 Stack coefficient[39]

Stack coefficient [m^6/h^2cm^4K]	Number of storey
0.00188	1
0.00376	2
0.00564	3

[7]23. Givoni, B., *Climate considerations in Building and Urban Design*, ed. I.T. Publishing. 1998.

The wind coefficient, b, is defined in the table below.

Table 59 Wind coefficient, b [39]

Shielding class	House height (storeys)		
	One	Two	Three
I	0.00413	0.00544	0.00640
II	0.00319	0.00421	0.00495
III	0.00226	0.00299	0.00351
IV	0.00135	0.00178	0.00209
V	0.00041	0.00054	0.00063

In the case of the atrium, the infiltration flow rate is 3.50 [m³/h].

INTERNAL TEMPERATURE

Tmin [°C]: 5

Tmax [°C]: 26

Target temperature profile: no profile

HVAC: no HVAC

Heating energy converter: no

Start heating date [day]: 1

Stop heating date [day]: 365

Cooling energy converter: Heat pump

Start cooling date [day]: 1

Stop cooling date [day]: 365

Heat tank: standard

Cool tank: standard

Simulate thermal: true

THERMAL REGULATION

HEAT PUMP

Maximum power source [W]: 372,100.00

COP: 4

ηtech: 0.25

Temperature target [°C]: 15

Source: air

WALL PROPERTIES

Short wave reflectance: 0.20

This value is connected to the reflectivity of the wall and the windows; to calculate it we've defined each surface multiplying his area for the ratio, for example, if there is 10% of glass [0% reflectivity] and 90% of wall [light ivory, 68% reflectivity]

[0.1*0.0]+ [0.9*68]= 0.61

It is absolutely important to define a small value of reflectivity, because of the albedo. This is why it was chosen a light pink wall [RAL 3015], with 43.66% reflectivity.

Glazing ratio

The walls are divided in two parts, for the glazing ratio:

- E-W direction, with a 0.30 glazing ratio, on the external wall;
- N-S direction, with a 0.50 glazing ratio, on the wall in courtyard.

Glazing G value [%]: 0.05

The G value is given by the mobile shades, that can reduce the solar gain through a value <0.10.
Glazing U value [W/m²K]: 1.00

Material: U [W/m²K]= 0.2

Table 60 Simulation CitySim. Material

Name	l [m]	p [Kg/m^3]	k [W/mK]	Cp [J/Kg°C]
Plaster	0.02	600	0.29	840
Isolation	0.15	30	0.04	840
Brick	0.12	600	0.25	840
Plaster	0.01	600	0.29	840

Where

l: thickness [m]

p: mass density [Kg/m³]

k: thermal conductivity [W/mK]

Cp: specific heat [J/Kg°C]

ROOF PROPERTIES

Short wave reflectance: 0.20

Glazing ratio: 0.00

Glazing G value [%]: 0.05

Glazing U value [W/m²K]: 1.00

Uvalue [W/m²K]: 0.2

PV ratio: 0.50

FLOOR PROPERTIES

Short wave reflectance: 0.20

Glazing ratio: 0.00

Uvalue [W/m²K]: 0.2

PV ratio: 0.00

SIMULATIONS RESULTS

The results from the "Simulation A" are defined in the table below. The buildings with the maximal energy consumption are n. 43, 44 and 45, because they're situated in the sport court, that means that they are exposed to solar irradiation more than others. The others values are acceptable, because the building have an energy consumption comprise between 20 [kWh/m²y] and 36.90 [kWh/m²y]. As first optimisation, "Simulation B", we've decided to limit the window's percentage in buildings n. 43, 44 and 45, from 50 [%] to 30 [%]. As we can see in the table below, their energy consumption has been reduced of 11- 16 [%]. The total energy consumption for the Masterplan is 2,474 [MWh] or 8,906,400 [MJ] for the first simulation, and 2,460 [MWh] or 8,856,000 [MJ] for the second simulation.

Table 61 First simulation. Simulations results [kWh/m²y] and [MJ/m²]

Building	Simulation A Cooling needs $[\mathrm{kWh/m^2a}]$	Simulation A Cooling needs $[\mathrm{MJ/m^2}]$	Simulation B Cooling needs $[\mathrm{kWh/m^2a}]$	Simulation B Cooling needs $[\mathrm{MJ/m^2}]$	Difference [%]
1	-36.90	-132.85	-36.54	-131.55	0.98
2	-27.97	-100.70	-27.97	-100.69	0.00
3	-26.05	-93.76	-26.05	-93.77	0.00
4	-29.50	-106.20	-29.50	-106.18	0.02
5	-26.19	-94.29	-26.19	-94.29	0.00
6	-17.23	-62.02	-17.23	-62.02	0.00
7	-27.43	-98.74	-27.42	-98.73	0.01
8	-24.78	-89.19	-24.78	-89.20	0.00
9	-24.95	-89.82	-24.95	-89.81	0.01
10	-33.66	-121.17	-33.66	-121.17	0.00
11	-23.70	-85.34	-23.70	-85.33	0.01
12	-31.97	-115.10	-31.97	-115.10	0.00
13	-27.24	-98.06	-27.24	-98.06	0.00
14	Wind tower	Wind tower	Wind tower	Wind tower	Wind tower
15	-26.71	-96.16	-26.71	-96.16	0.00
16	-28.12	-101.24	-28.12	-101.24	0.00
17	Wind tower	Wind tower	Wind tower	Wind tower	Wind tower
18	-23.31	-83.93	-23.31	-83.93	0.00

Building	Simulation A Cooling needs [kWh/m²a]	Simulation A Cooling needs [MJ/m²]	Simulation B Cooling needs [kWh/m²a]	Simulation B Cooling needs [MJ/m²]	Difference [%]
19	-31.44	-113.17	-31.44	-113.17	0.00
20	-31.88	-114.78	-31.88	-114.78	0.00
21	-22.92	-82.51	-22.92	-82.51	0.00
22	-25.52	-91.86	-25.52	-91.86	0.00
23	-32.43	-116.76	-32.43	-116.76	0.00
24	-32.24	-116.08	-32.24	-116.08	0.00
25	-20.32	-73.16	-20.32	-73.15	0.01
26	Wind tower	Wind tower	Wind tower	Wind tower	Wind tower
27	-30.82	-110.94	-30.82	-110.94	0.00
28	-30.73	-110.64	-30.73	-110.63	0.01
29	-32.80	-118.06	-32.80	-118.06	0.00
30	Wind tower	Wind tower	Wind tower	Wind tower	Wind tower
31	-28.80	-103.69	-28.80	-103.69	0.00
32	-25.87	-93.14	-25.87	-93.14	0.00
33	-30.80	-110.87	-30.80	-110.87	0.00
34	-25.26	-90.94	-25.26	-90.94	0.00
35	-27.51	-99.05	-27.51	-99.04	0.02
36	-23.03	-82.93	-23.03	-82.93	0.00
37	-27.31	-98.31	-27.31	-98.31	0.00
38	-21.43	-77.17	-21.43	-77.16	0.01
39	Wind tower	Wind tower	Wind tower	Wind tower	Wind tower
40	-28.42	-102.32	-28.42	-102.32	0.00
41	-28.58	-102.89	-28.58	-102.89	0.00
42	-28.22	-101.60	-28.22	-101.60	0.00
43	-48.12	-173.24	-40.21	-144.77	16.43
44	-48.00	-172.81	-42.01	-151.23	12.49
45	-39.31	-141.52	-34.77	-125.18	11.55
46	-26.49	-95.36	-26.49	-95.36	0.00
46b	-20.45	-73.63	-20.45	-73.63	0.00
47	-27.03	-97.29	-27.02	-97.29	0.00
48	-31.78	-114.39	-31.78	-114.39	0.00
50	Wind tower	Wind tower	Wind tower	Wind tower	Wind tower
51	-24.16	-86.99	-24.17	-87.00	-0.02

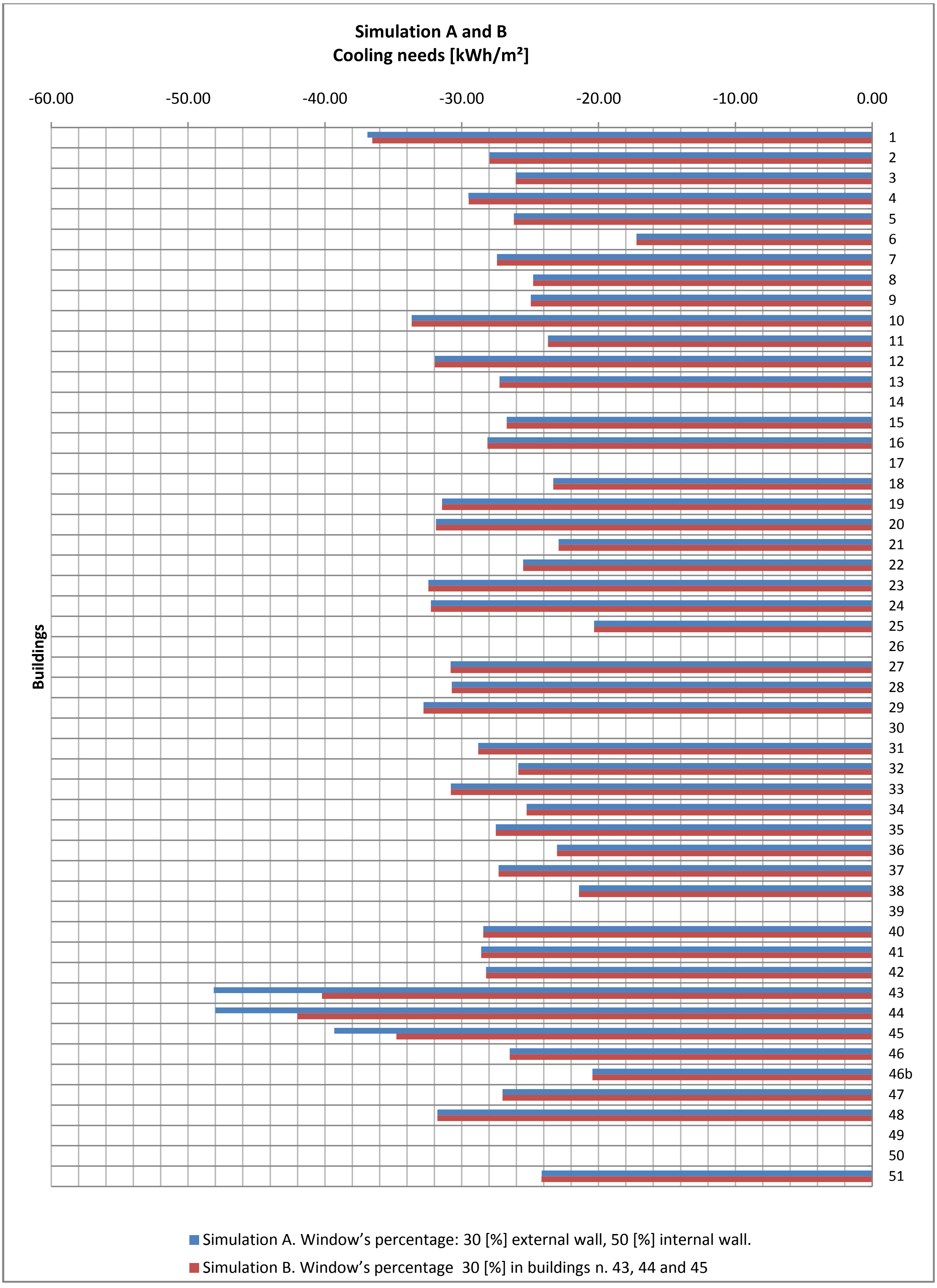


Figure 178 First simulation. Simulation results. Cooling needs per building [kWh/m²y]

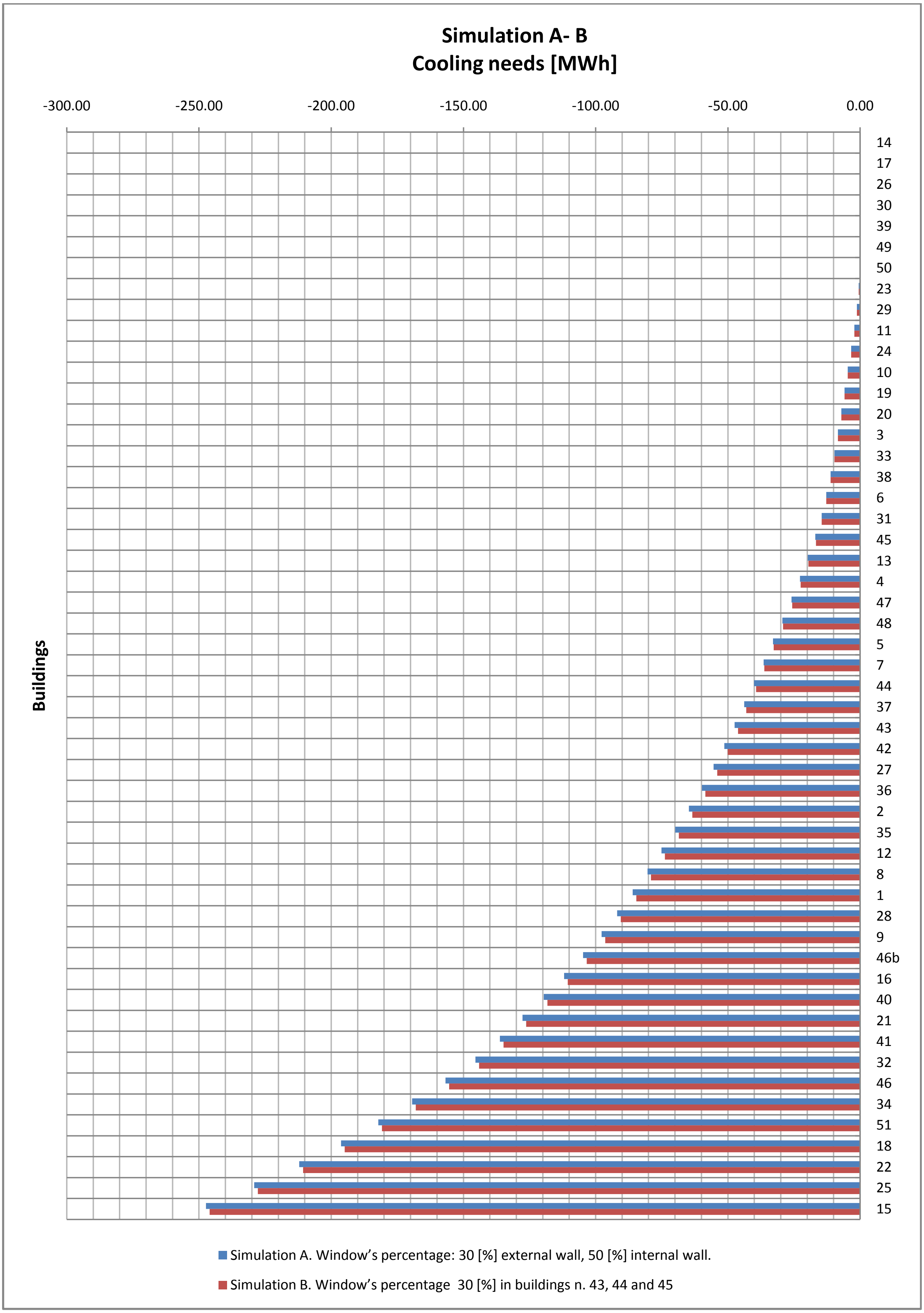


Figure 179 First simulation. Simulation results. Cumulative cooling needs per building [MWh]

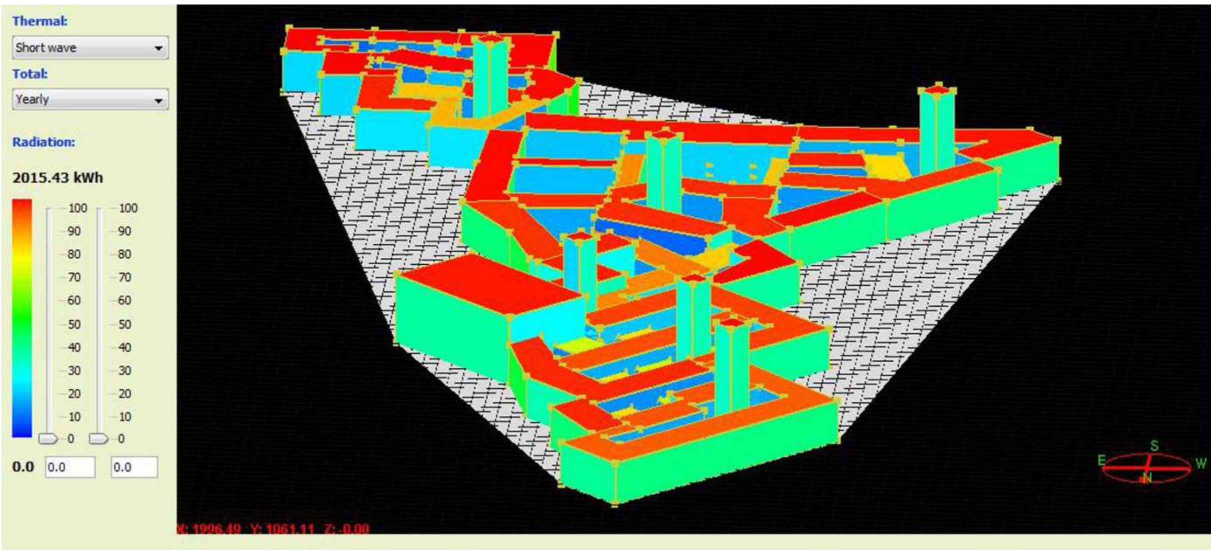


Figure 180 Masterplan. Yearly result. North view. Max value 2015[kWh/m²y]

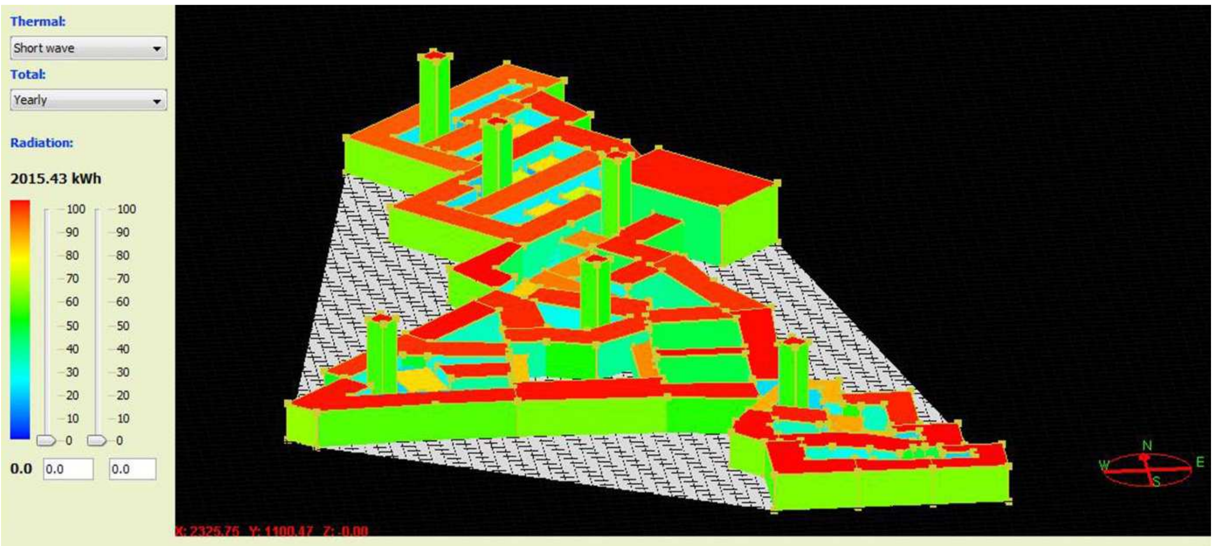


Figure 181 Masterplan. Yearly result. South view. Max value 2015[kWh/m²y]

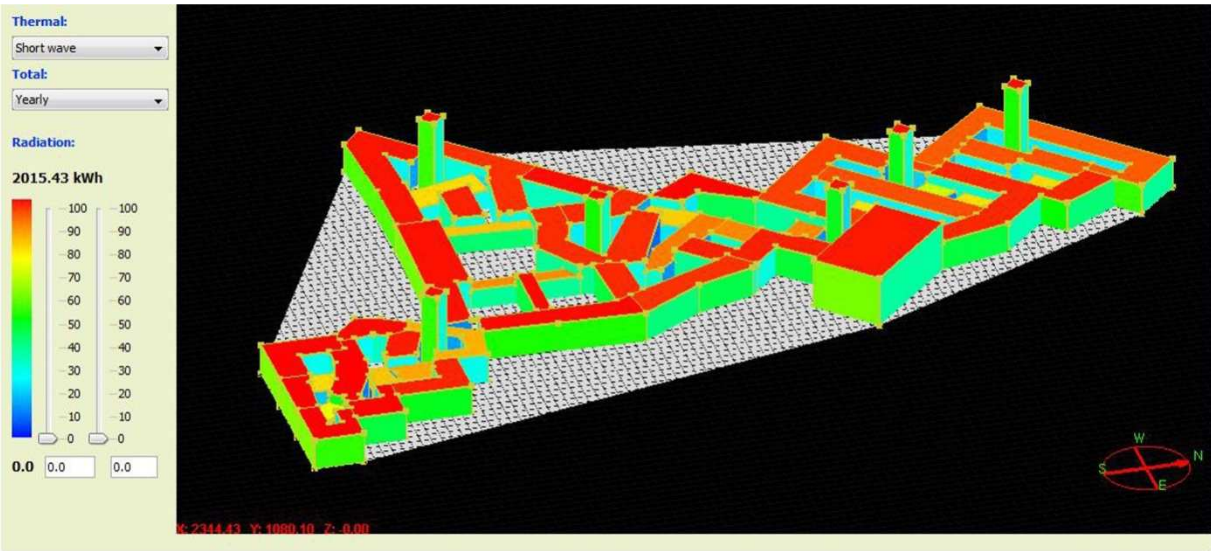


Figure 182 Masterplan. Yearly result.East view. Max value 2015[kWh/m²y]

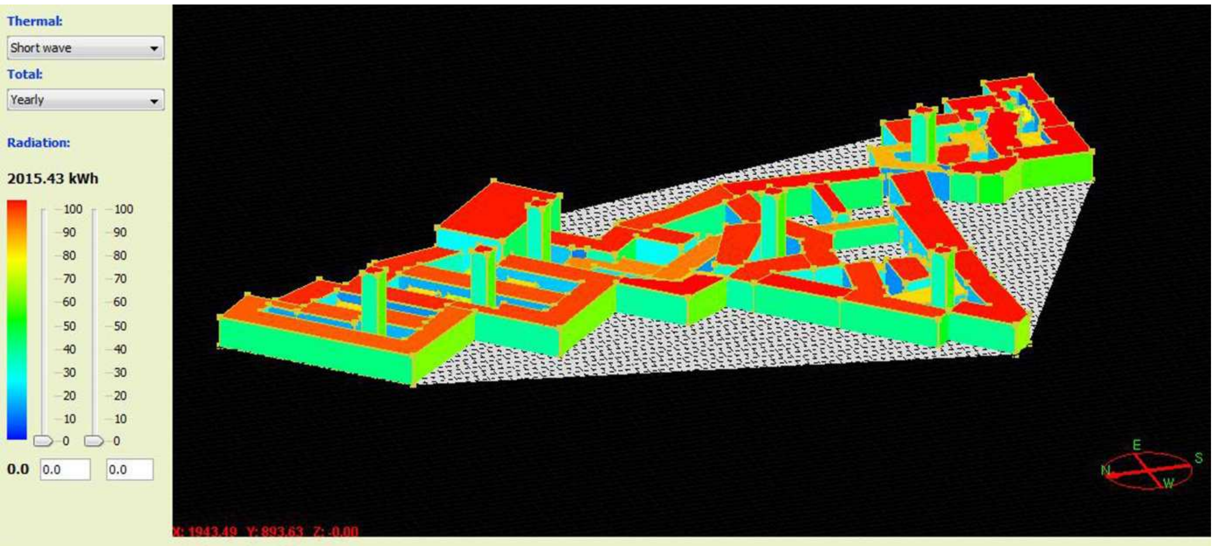


Figure 183 Masterplan. Yearly result.West view. Max value 2015[kWh/m²y]

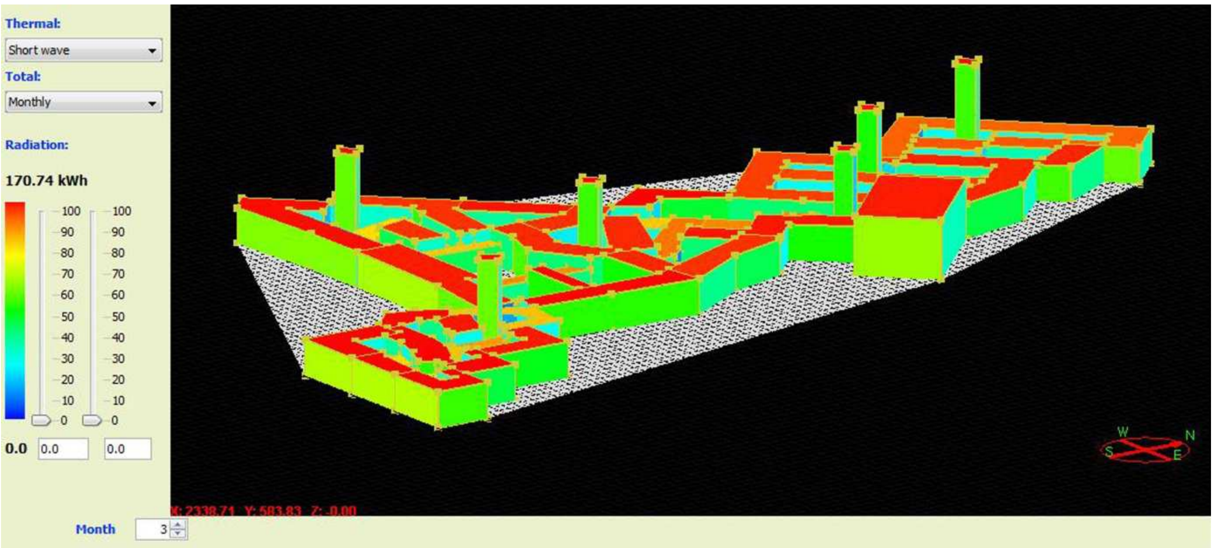


Figure 184 Masterplan. Monthly result. March. Max value 171 [kWh/m²y]

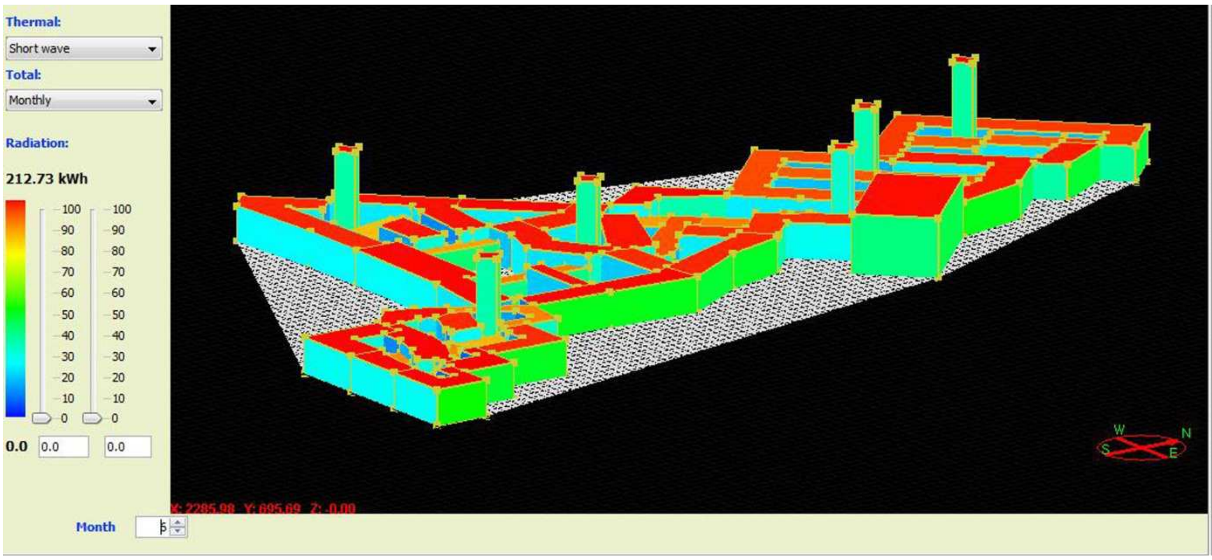


Figure 185 Masterplan. Monthly result. June. Max value 213[kWh/m²y]

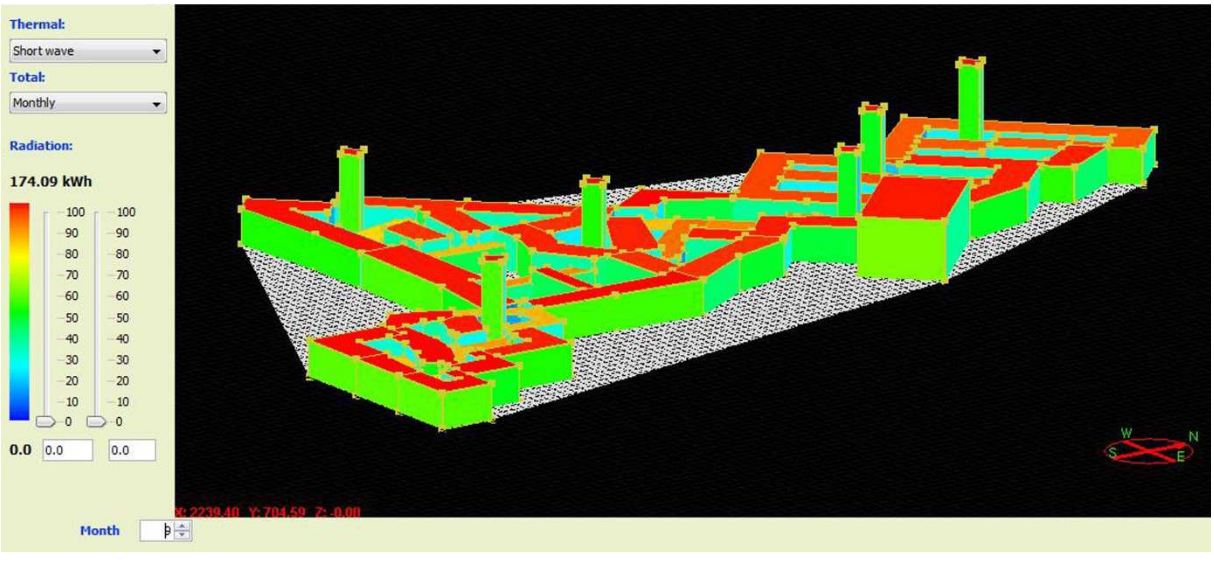


Figure 186 Masterplan. Monthly result. September. Max value 174[kWh/m²y]

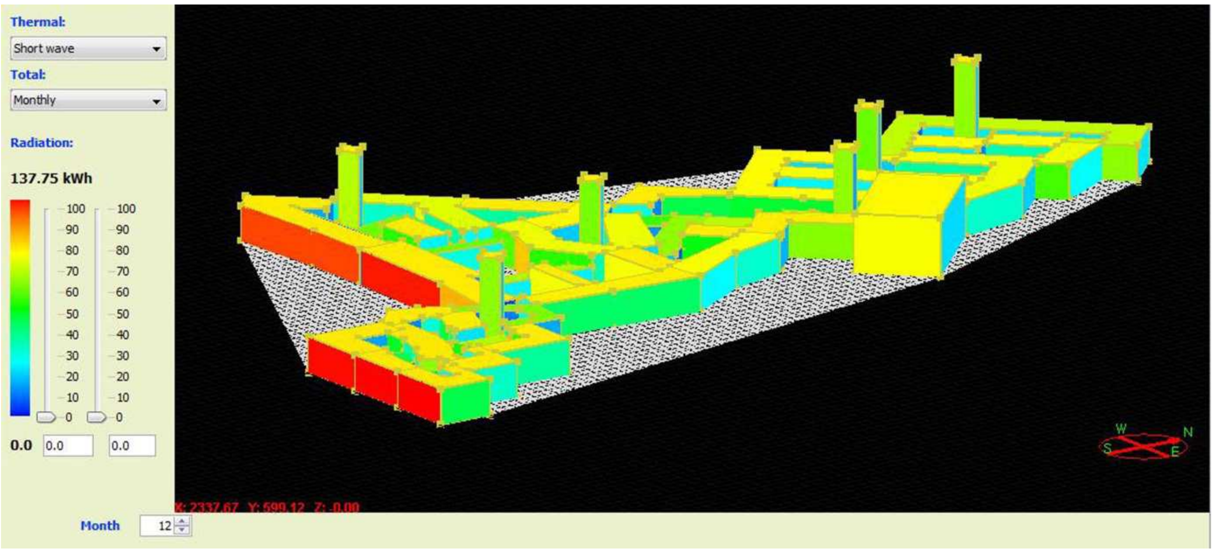


Figure 187 Masterplan. Monthly result. December. Max value 138 [kWh/m²y]

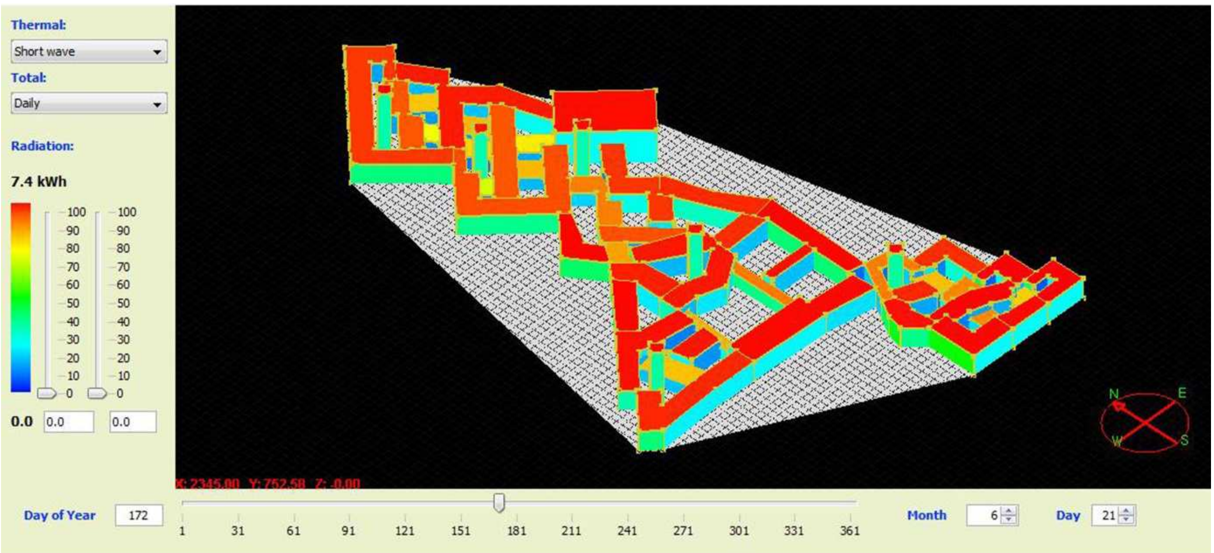


Figure 188 Masterplan. Daily result.21 June. Max value 7[kWh/m²y]

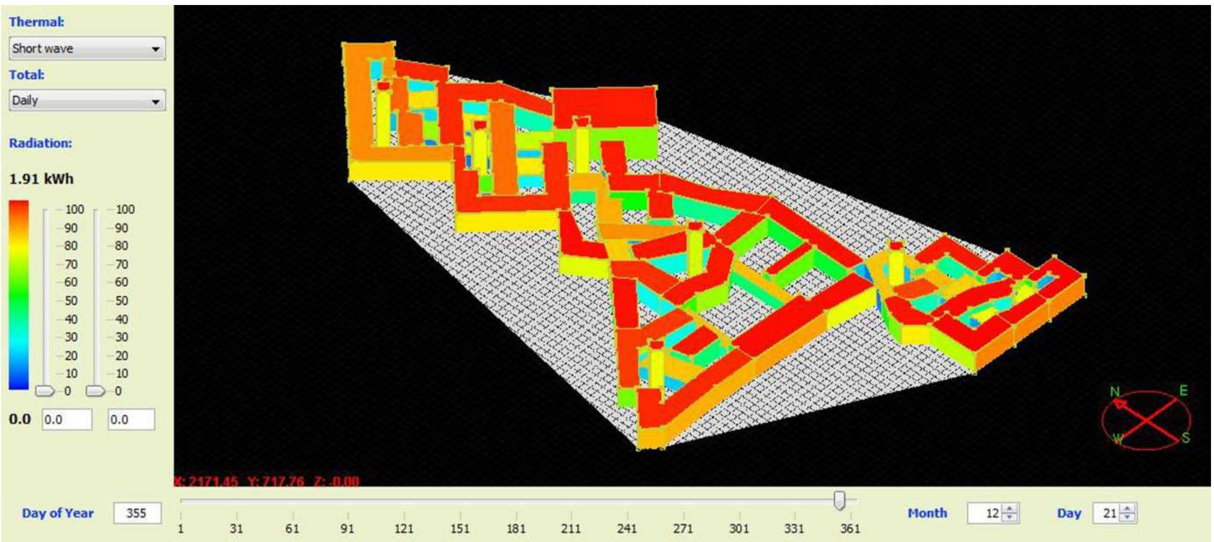


Figure 189 Masterplan. Daily result.21 December. Max value 2[kWh/m²y]

6.1.1 Second analysis. Impact of emergency exits

Another element that's part of the Masterplan is the presence of emergency exits, that cross the buildings. We decided to start the analyse with a single building, simulating it as an independent building without neighbouring. The building chosen was part of the residential area: building n.2. It was simulated with and without the crossing street, and we've seen that there is a reduction in the energy consumption with the crossing street, probably because of the higher windows percentage, overlooking at the corridor. The energy consumption, for cooling needs, without the emergency street is 32.40[kWh/m²y], and with the passage is 31.08 [kWh/m²y], with a difference of - 4 [%].Thanks to this simulation, we can assure that the emergency streets can participate positively on the total energy consumption of the building. Another element that we can see in the figures below, is the solar irradiation on the wall facing to the street: we have a notable reduction on the solar irradiation, giving a better climatic conditions on the internal room.

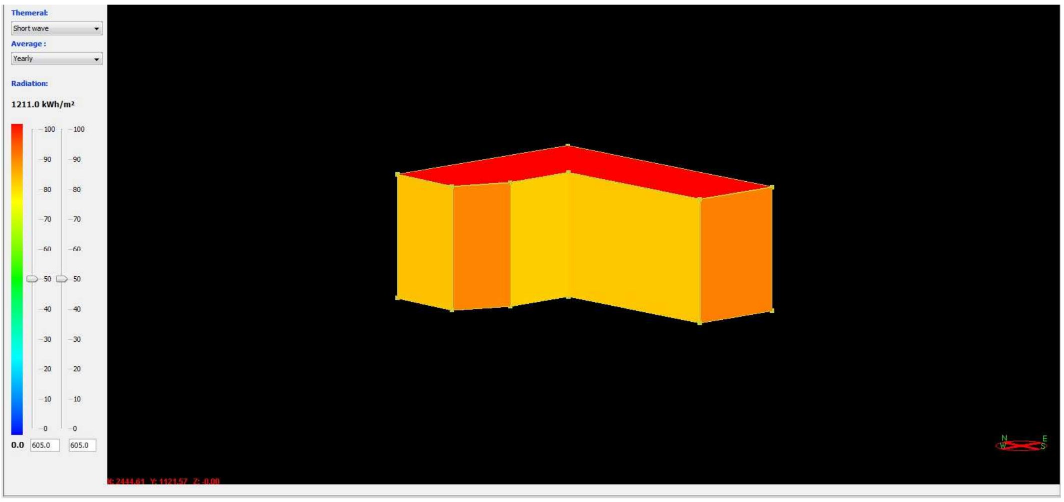


Figure 190 Building n.2 without crossing street. Yearly solar irradiation results [kWh/m²y]

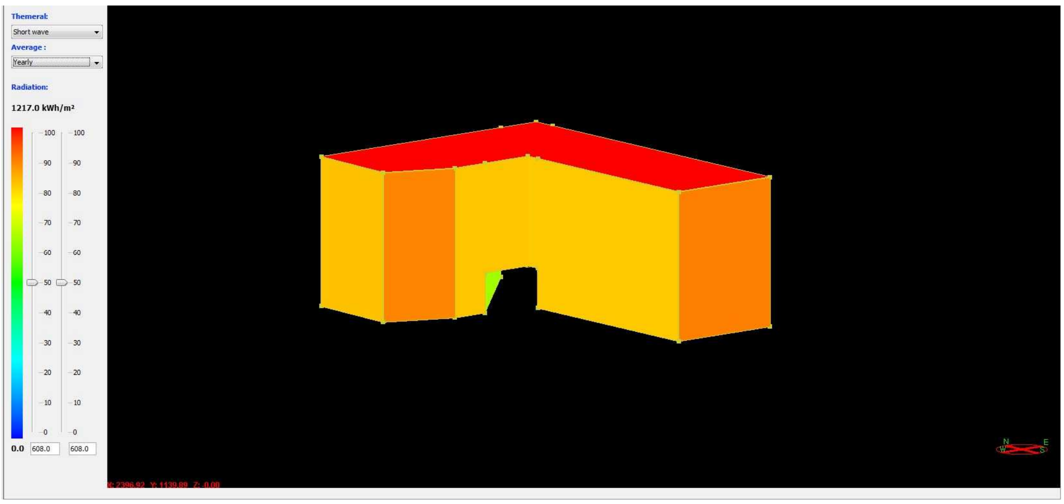


Figure 191 Building n.2 with crossing street. Solar irradiation, annual results. Max value: 1217.00 [kWh/m²y]

6.1.2 Third analysis. Impact of urban texture and isolate building

The next simulation wanted to define the percentage of different energy consumption on the same building, n.15, with and without neighbour's buildings. The result indicates the importance of the neighbour buildings: the total energy consumption for cooling needs is 26.71 [kWh/m²y], instead of 28.17 [kWh/m²y] for the isolated building, with a difference, expressed in percentage, of 5 [%].

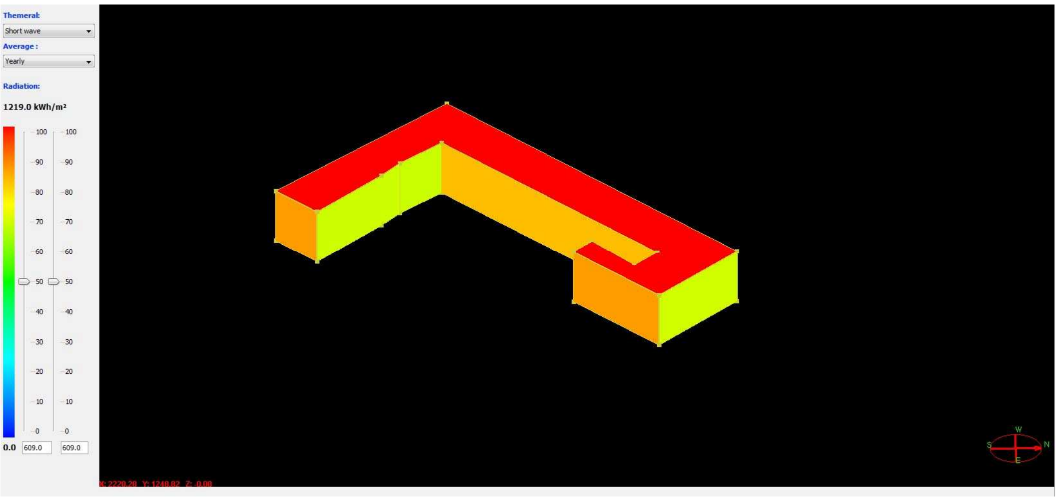


Figure 192Building n. 15. Solar irradiation, annual results. Max value: 1219.00 [kWh/m²y]

The total difference on cooling needs is expressed in the table below.

Table 62 Building n.15, cooling needs [kWh/m²y]

Building n.15	Cooling needs [kWh/m²y]
With neighbour buildings	-26.71
Isolated building	-28.17

6.2 SIMULATION CITYSIM_ MASTERPLAN WITHOUT PEOPLE

As last simulation we've defined the entire Masterplan with emergency exits and atrium. In the first simulation we've defined the Masterplan including the atrium and the emergency exits. As we can see in the results, these two elements ameliorate the total energy consumption of the Masterplan. In the second analyse wanted to define the influence of the windows percentage upon the Masterplan, to define the best position of the windows, and their percentage.

Below we've defined the element that characterizes every simulation:

Simulation C. Window's percentage: 30 [%] for all wall.

Simulation D. Window's percentage: 30 [%] external wall, 50 [%] internal wall.

Simulation E. Window's percentage: 25 [%] external wall, 45 [%] internal wall.

Simulation F. Window's percentage: 20 [%] external wall, 40 [%] internal wall.

Simulation G. Window's percentage: 20 [%] external wall, 40 [%] internal wall and 30 [%] in building n. 19, 20, 23, 24, 29,31, 33, 43, 44, 45.

The buildings with higher energy consumption are n. 19, 20, 23, 24, 29, 31 and 33, that are the buildings in the middle of the courtyard, but crossed by the exit emergency, that means that they have 1 and 2 floors. The others are n. 43, 44 and 45, that are in the sport court. After this analyse we've decided to use a 30 [%] of windows in this buildings, knowing that in the buildings n. 19, 20, 23, 24, 29, 31, 33 the floor is elevated, and with a 30 [%] of glass.

Simulation G: window's percentage: 20 [%] external wall, 40 [%] internal wall, and 30 [%] in building n. 19, 20, 23, 24, 29,31, 33, 43, 44, 45.

In the table below we've decided to compare the different simulations, to see the influence of the different window's percentage, as an attribute to increment the energy efficient of the building.

Table 63 Simulation without people. Simulations results [kWh/m²y]

Building	Simulation C Energy consumption per building [kWh/m²]	Simulation D Energy consumption per building [kWh/m²]	Simulation E Energy consumption per building [kWh/m²]	Simulation F Energy consumption per building [kWh/m²]	Simulation G Energy consumption per building [kWh/m²]
1	-35.62	-39.00	-37.25	-35.51	-35.52
2	-30.89	-33.58	-32.32	-31.07	-31.07
3	-28.78	-33.53	-32.33	-31.15	-31.15
4	-24.55	-28.91	-27.81	-26.73	-26.73
5	-25.73	-26.76	-26.01	-25.28	-25.28
6	-24.72	-29.47	-28.27	-27.09	-27.09
7	-26.98	-29.43	-28.34	-27.26	-27.26
8	-29.40	-35.26	-33.78	-32.32	-32.32
9	-24.12	-25.14	-24.41	-23.69	-23.69
10	-29.11	-33.23	-32.20	-31.15	-31.15
11	-21.45	-23.62	-23.06	-22.52	-22.52
12	-33.71	-36.90	-35.36	-33.82	-33.82
13	-25.21	-27.10	-26.11	-25.12	-25.12
14	Wind tower	Wind tower	Wind tower	Wind tower	Wind tower
15	-25.67	-27.66	-26.26	-25.30	-25.69
16	-29.70	-35.42	-33.99	-32.57	-32.57
17	Wind tower	Wind tower	Wind tower	Wind tower	Wind tower
18	-23.76	-25.96	-25.11	-24.28	-24.28
19	-33.45	-40.06	-38.41	-36.75	-33.50
20	-33.97	-40.66	-38.97	-37.31	-34.04
21	-21.46	-24.75	-23.92	-23.09	-23.09
22	-23.47	-25.86	-25.00	-24.15	-24.15
23	-43.73	-53.48	-51.01	-48.57	-43.77
24	-35.18	-41.52	-39.92	-38.32	-35.17
25	-16.59	-17.18	-16.75	-16.31	-16.31
26	Wind tower	Wind tower	Wind tower	Wind tower	Wind tower
27	-29.99	-34.32	-33.22	-32.14	-32.14
28	-32.83	-33.78	-32.60	-31.43	-31.42
29	-41.22	-49.97	-47.73	-45.52	-41.15
30	Wind tower	Wind tower	Wind tower	Wind tower	Wind tower
31	-29.25	-34.01	-32.80	-31.60	-29.26
32	-24.00	-26.12	-25.36	-24.60	-24.61
33	-36.09	-43.64	-41.76	-39.92	-36.27
34	-23.99	-27.77	-26.81	-25.87	-25.87
35	-23.20	-24.83	-24.09	-23.35	-23.35
36	-22.99	-26.06	-25.16	-24.27	-24.27

Building	Simulation C Energy consumption per building [kWh/m²]	Simulation D Energy consumption per building [kWh/m²]	Simulation E Energy consumption per building [kWh/m²]	Simulation F Energy consumption per building [kWh/m²]	Simulation G Energy consumption per building [kWh/m²]
37	-27.69	-31.84	-30.79	-29.75	-29.76
38	-20.96	-23.12	-22.57	-22.03	-22.03
39	Wind tower	Wind tower	Wind tower	Wind tower	Wind tower
40	-25.81	-27.37	-26.59	-25.82	-25.82
41	-33.16	-36.44	-35.25	-34.07	-34.07
42	-24.99	-28.61	-27.71	-26.81	-26.80
43	-43.00	-50.71	-48.74	-46.82	-42.99
44	-43.16	-48.60	-47.22	-45.86	-43.16
45	-40.42	-45.97	-44.58	-43.19	-40.44
46	-25.52	-28.37	-27.37	-26.39	-26.39
47	-26.13	-29.40	-28.57	-27.75	-27.74
48	-30.44	-36.40	-34.89	-33.39	-33.39
50	Wind tower	Wind tower	Wind tower	Wind tower	Wind tower
51	-24.26	-26.46	-25.63	-24.79	-24.79
52	-29.10	-31.59	-30.47	-29.35	-29.35

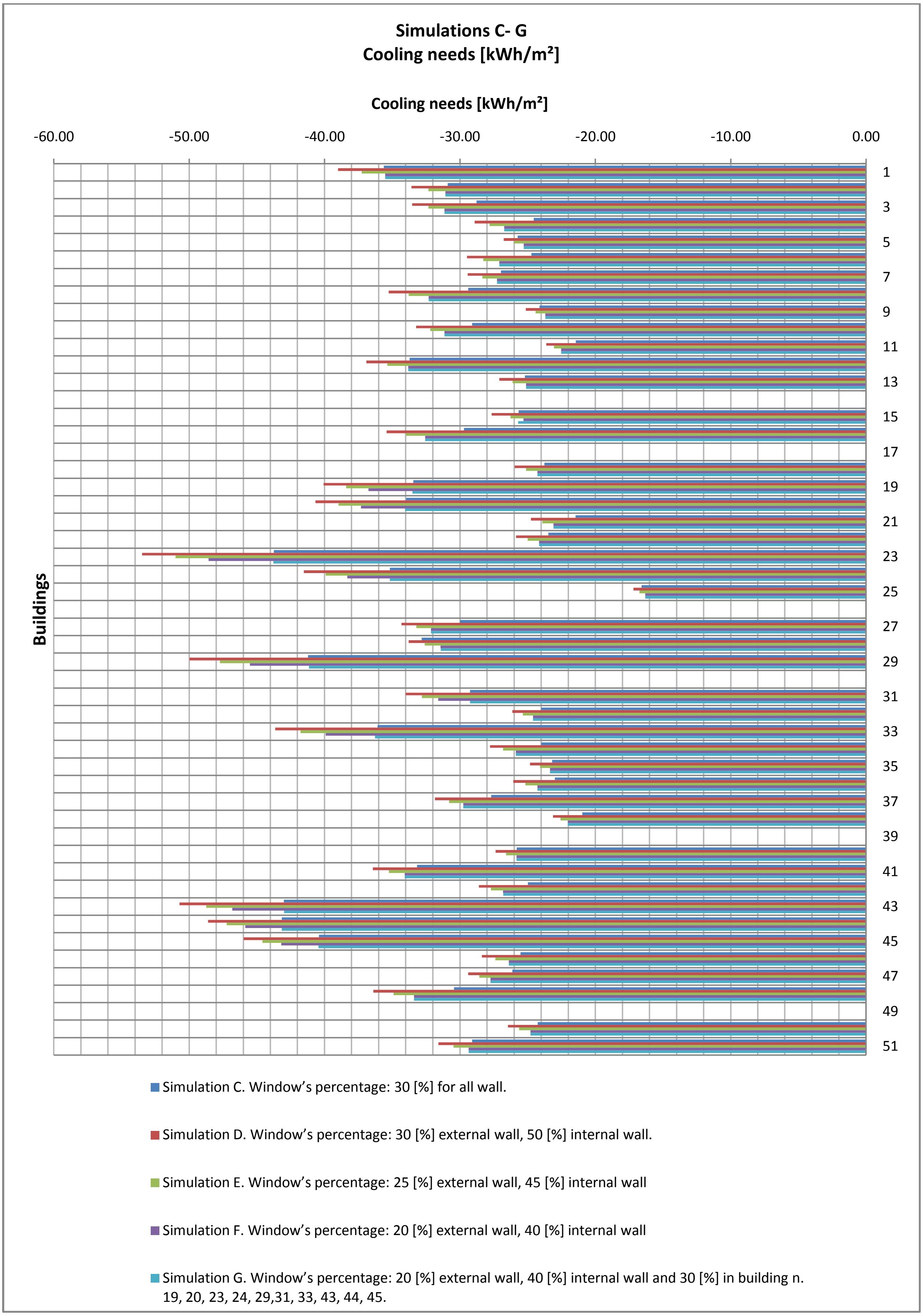


Figure 193 Masterplan simulation. Simulation results. Cooling needs per building [kWh/m²y].

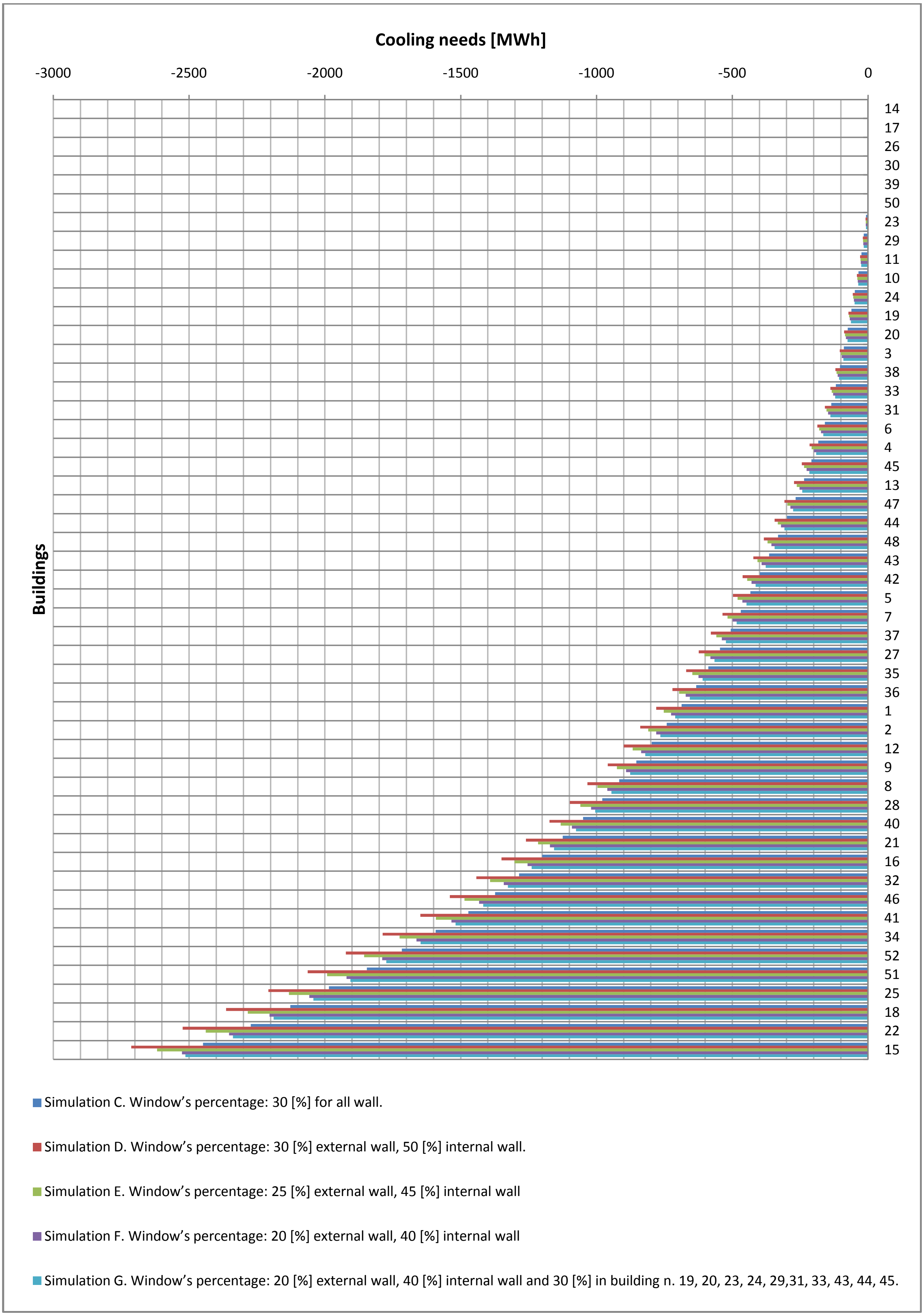


Figure 194 Masterplan simulation. Cumulative cooling needs per building [MWh]

6.3 SIMULATION CITYSIM_ MASTERPLAN WITH PEOPLE

The number of occupants is connected with the function of every building, but also with the net surface. For these reason we've defined the typical function for every building, starting from Ashrae template, and then we've fix the number of people, per square meter, of every building. In the end we've settle new number of people, starting from the SIA 2024, as the sum of people and the electric consumption.

6.31 SIA 2024_OCCUPANCY PROFILE

Occupancy profile as taken from SIA 2024.The schedule provide information about occupancy assumptions for different building type [as school, residential, etc.], and information concerning the energy power of the electronics. For each occupancy schedule, are provided hourly value, from 0.00 to 24.00 hours, on x axes. The total number of people, in percentage, is defined on the y axes; 1 is the total people number, based on the number of occupant for each building type.

It was defined seven kinds of building, for the different function of the university: auditorium, gym, library, office, residential, restaurants and school. As we can see in the table below, every function has a different energy consumption [W/m²]:

Table 64 Power density for every function [W/m²]

Function	Power density $[\mathrm{W/m^2}]$
Auditorium	4
Gym	2
Library	2
Office	7
Residence	2
Restaurant	2
School	4

For every function we've defined the normalized curve, and the correct number of people. The tables and graphs below explain the analyse. For every function we've used the SIA2024 occupancy profile and energy consumption, defined hourly value for weekdays and weekends. Then we've addiction the two value, finding the correct number of people in the building, thinking as the energy consumption of the electronics can be studied as a person. In the example of the auditorium, we've a total number of people of 24, but including the power density we arrive to 28 people.

AUDITORIUM

Table 65 Auditorium: occupancy profile_weekdays

Auditorium_Weekdays	Hours	Occupancy	(ON) Occupancy * Number of people	90 [W]* ON
	1	0	0	0
	2	0	0	0
	3	0	0	0
	4	0	0	0
	5	0	0	0
	6	0	0	0
	7	0	0	0
	8	0.2	4.8	432
	9	0.6	14.4	1296
	10	1	24	2160
	11	1	24	2160
	12	0.2	4.8	432
	13	0.2	4.8	432
	14	1	24	2160
	15	1	24	2160
	16	0.6	14.4	1296
	17	0.2	4.8	432
	18	0	0	0
	19	0	0	0
	20	0	0	0
	21	0	0	0
	22	0	0	0
	23	0	0	0
	24	0	0	0

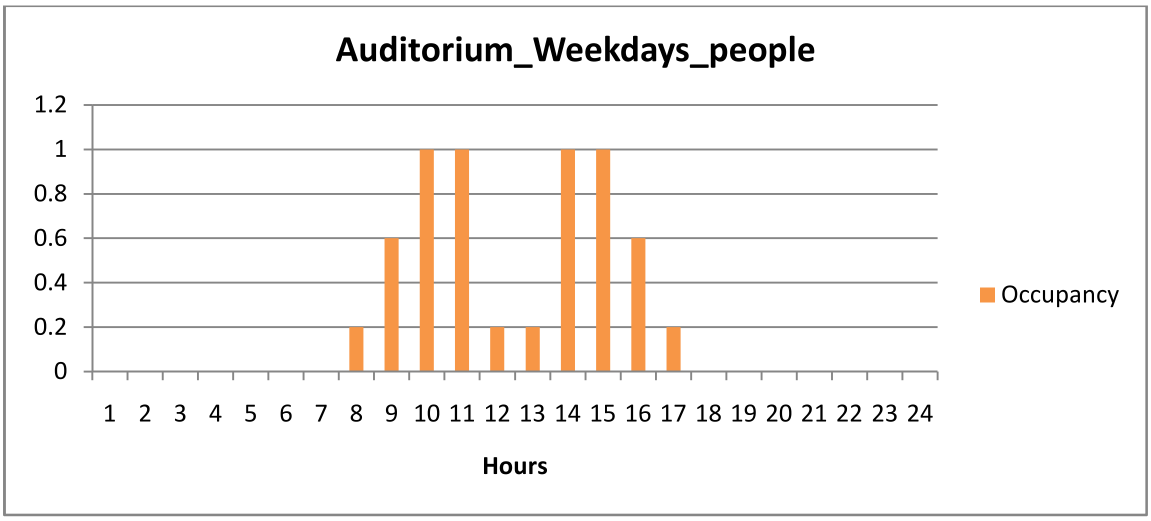


Figure 195 Auditorium: occupancy profile_weekdays

Table 66 Auditorium: energy consumption_weekdays

Auditorium_Weekdays	Hours	Distribution	(ED) consumption Distribution	Energy *	Surface [m²]* ED
	1	0	0		0
	2	0	0		0
	3	0	0		0
	4	0	0		0
	5	0	0		0
	6	0	0		0
	7	0	0		0
	8	0.2	0.8		75.784
	9	0.6	2.4		227.352
	10	1	4		378.92
	11	1	4		378.92
	12	0.2	0.8		75.784
	13	0.2	0.8		75.784
	14	1	4		378.92
	15	1	4		378.92
	16	0.6	2.4		227.352
	17	0.2	0.8		75.784
	18	0	0		0
	19	0	0		0
	20	0	0		0
	21	0	0		0
	22	0	0		0
	23	0	0		0
	24	0	0		0

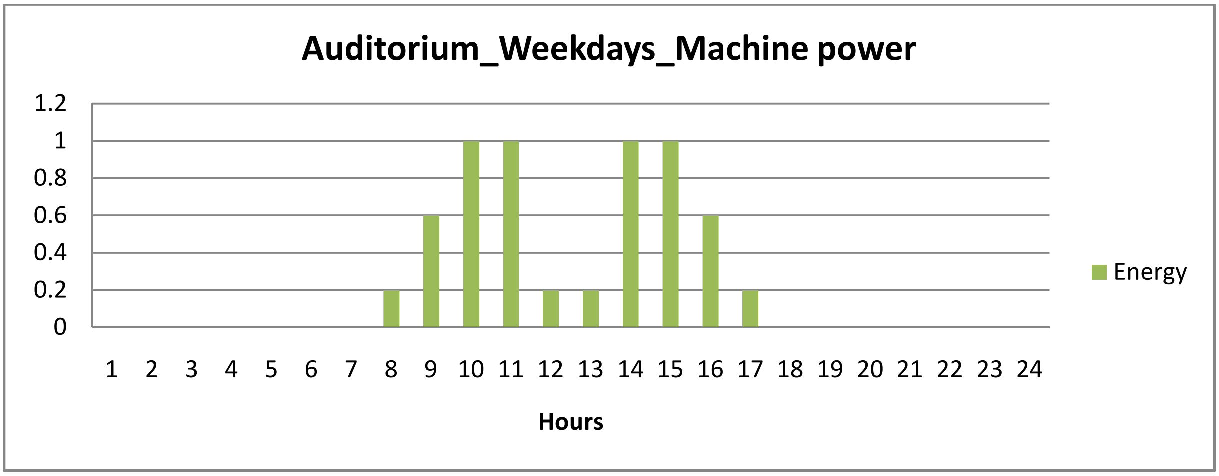


Figure 196 Auditorium: energy consumption_weekdays

Table 67 Auditorium: people occupancy and energy consumption_weekdays

Auditorium_Weekdays	Person [W]	Energy consumption [W]	(PE) Person + Energy Consumption [W]	PE /90[W]= number of person	Number person/n. person max
	0	0	0	0	0.00
	0	0	0	0	0.00
	0	0	0	0	0.00
	0	0	0	0	0.00
	0	0	0	0	0.00
	0	0	0	0	0.00
	0	0	0	0	0.00
	432	75.784	507.784	6	0.20
	1296	227.352	1523.352	17	0.60
	2160	378.92	2538.92	28	1.00
	2160	378.92	2538.92	28	1.00
	432	75.784	507.784	6	0.20
	432	75.784	507.784	6	0.20
	2160	378.92	2538.92	28	1.00
	2160	378.92	2538.92	28	1.00
	1296	227.352	1523.352	17	0.60
	432	75.784	507.784	6	0.20
	0	0	0	0	0.00
	0	0	0	0	0.00
	0	0	0	0	0.00
	0	0	0	0	0.00
	0	0	0	0	0.00
	0	0	0	0	0.00
	0	0	0	0	0.00

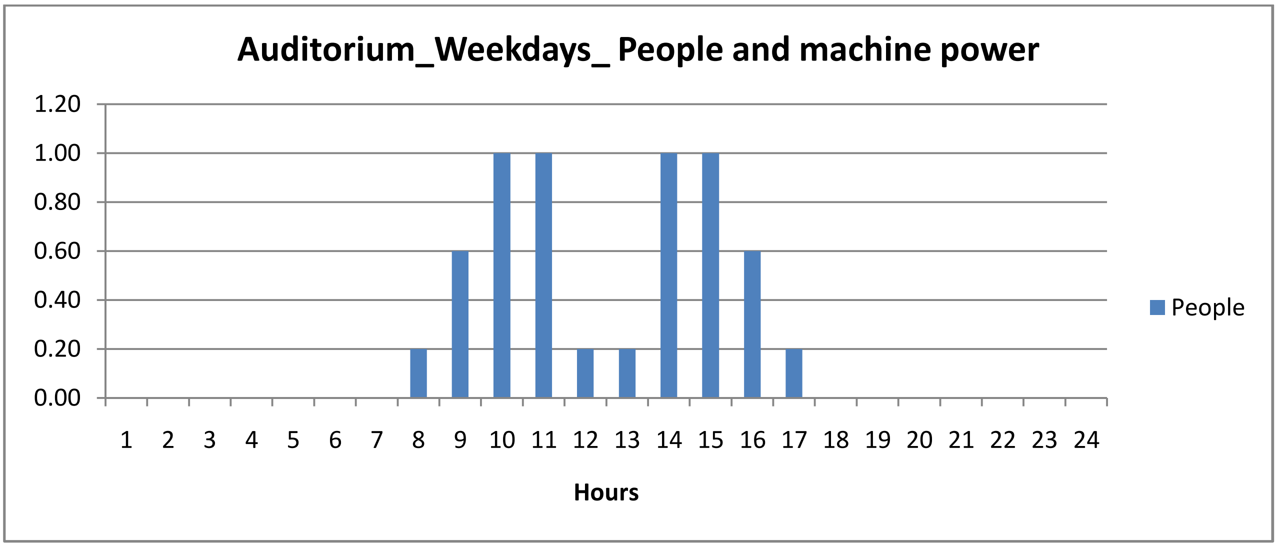


Figure 197 Auditorium: people occupancy and energy consumption_ weekdays

As we can see in the example of the auditorium, we've suppose 24 people in the building, but then we've find that the maximal number of people can be of 28, in this case the total graphs doesn't change, because of the similar value in occupancy and machine power, but in the case of restaurant we can notice an interesting difference between the two models. For every building we've apply the correct occupancy profile and energy consumption, to obtain the dates below. The graphs define the Occupancy profile, including people and machine, for every typology of building.

AUDITORIUM

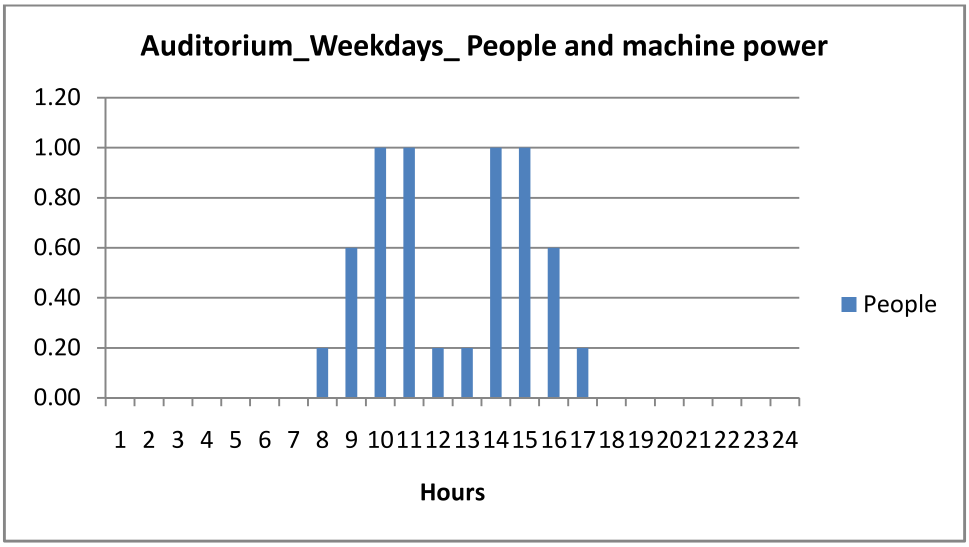


Figure 198 Auditorium: occupancy profile_weekdays

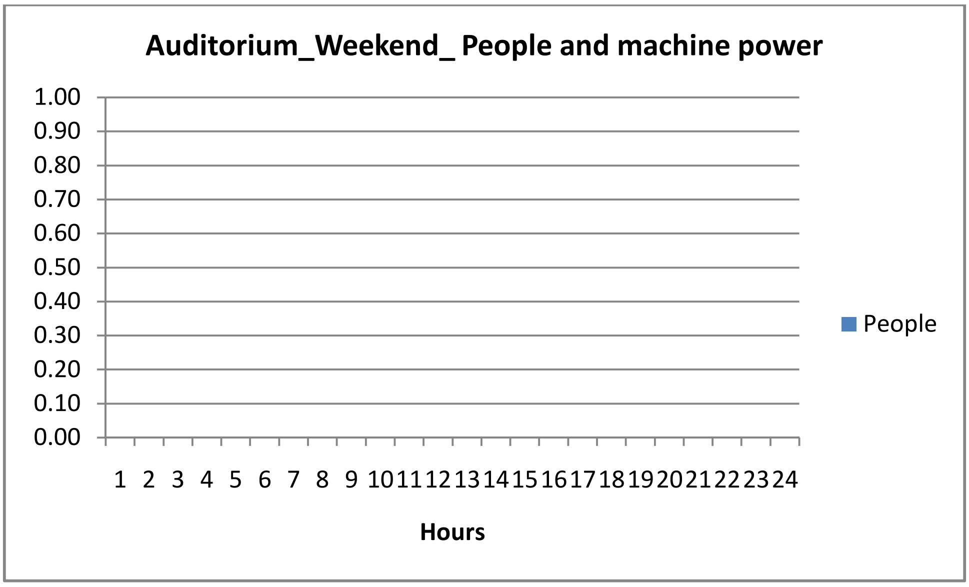


Figure 199 Auditorium: occupancy profile_weekend

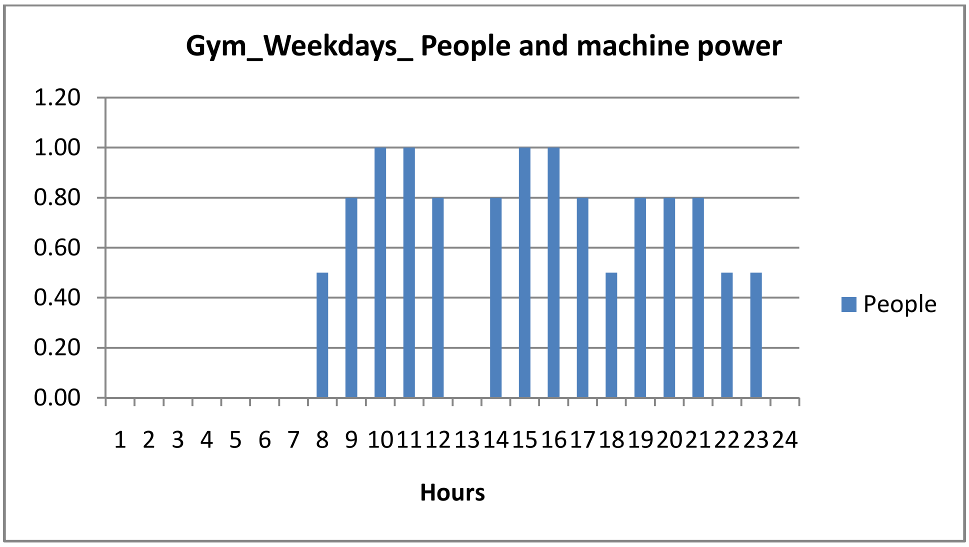


Figure 200 Gym: occupancy profile_weekdays

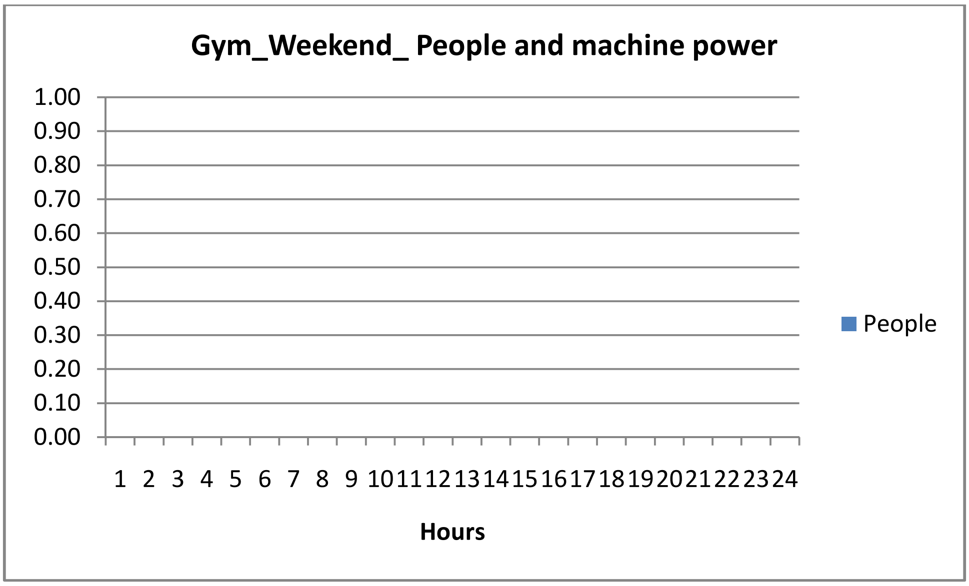


Figure 201Gym: occupancy profile_weekend

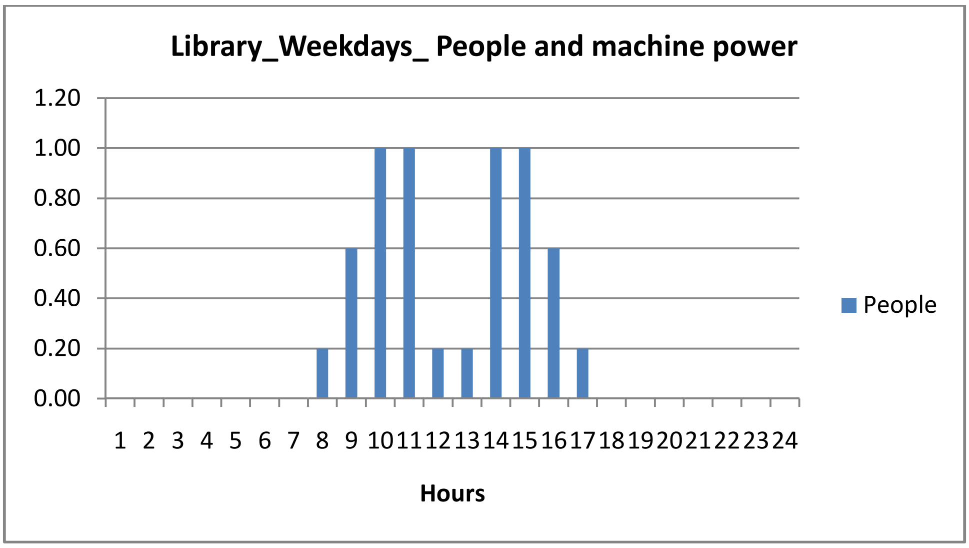


Figure 202 Library: occupancy profile_weekdays

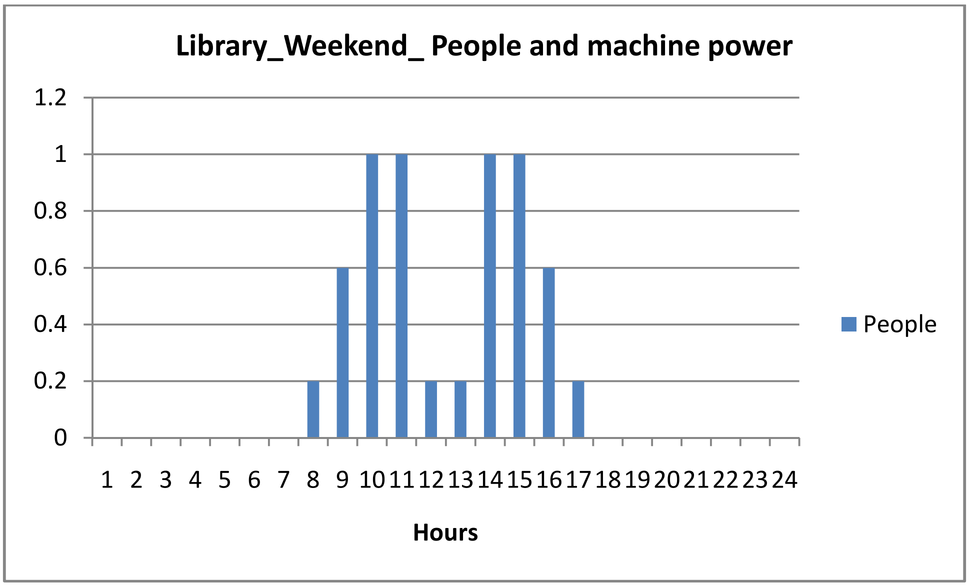


Figure 203 Library: occupancy profile_weekend

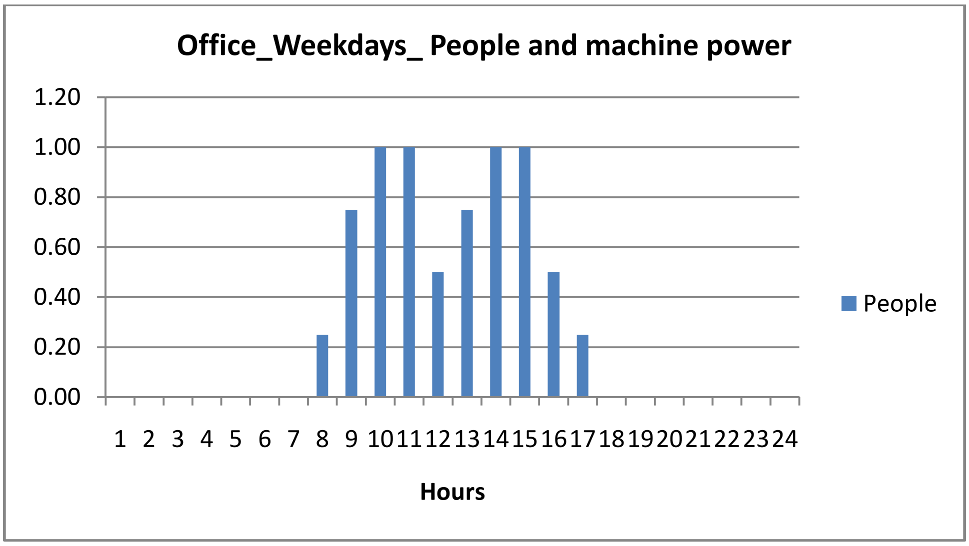


Figure 204 Office: occupancy profile_weekdays

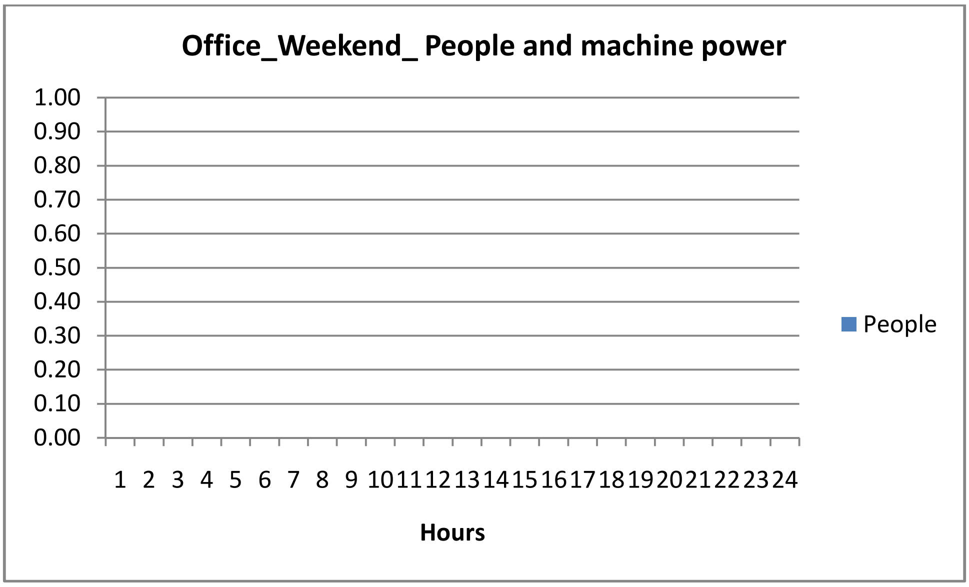


Figure 205 Office: occupancy profile_weekend

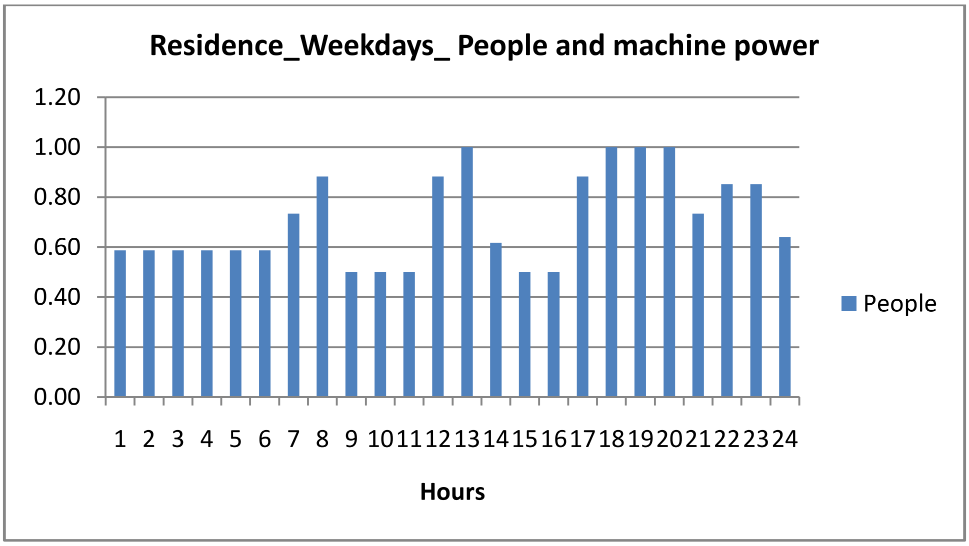


Figure 206 Residence: occupancy profile_weekdays

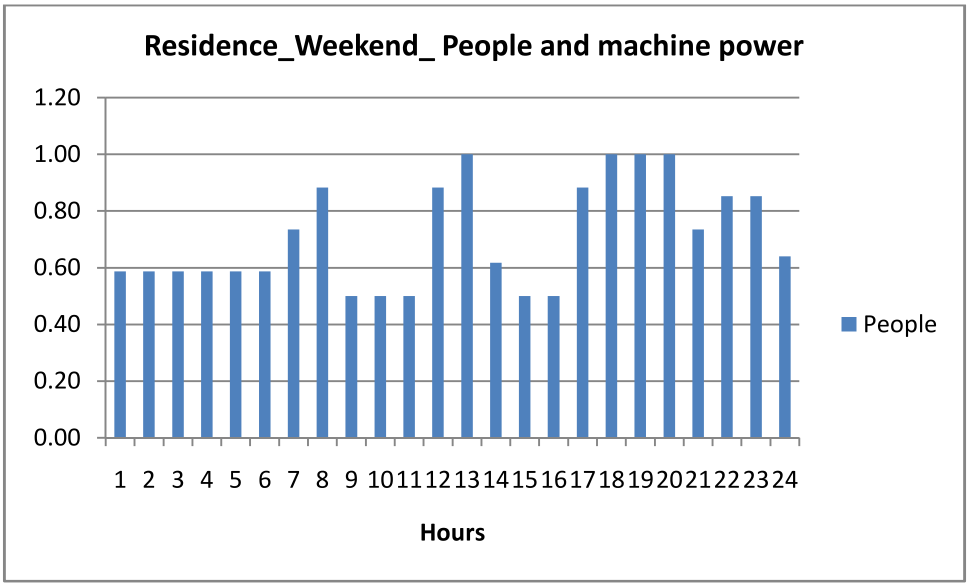


Figure 207 Residence: occupancy profile_weekend

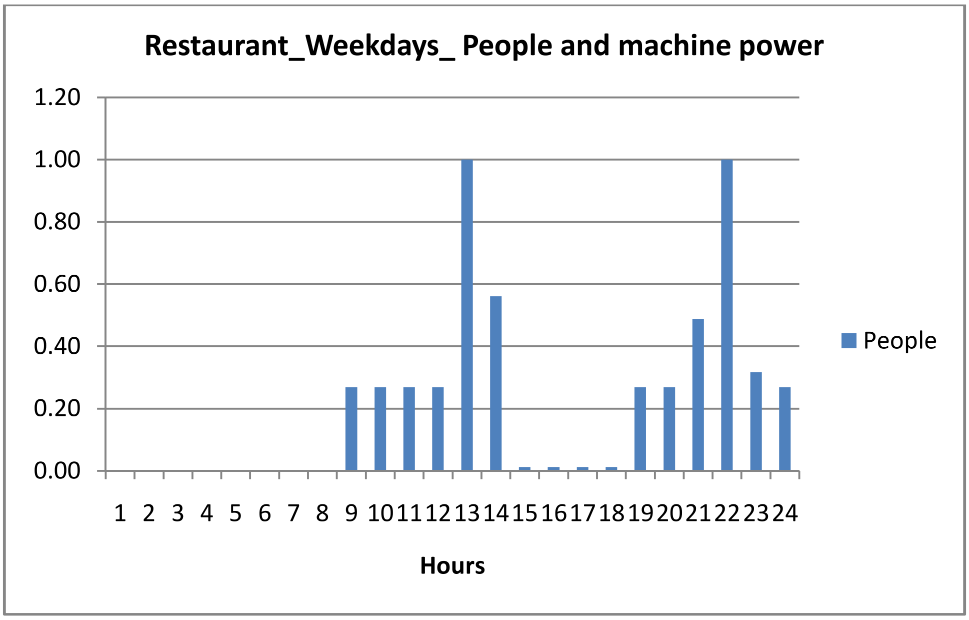


Figure 208 Restaurant: occupancy profile_weekdays

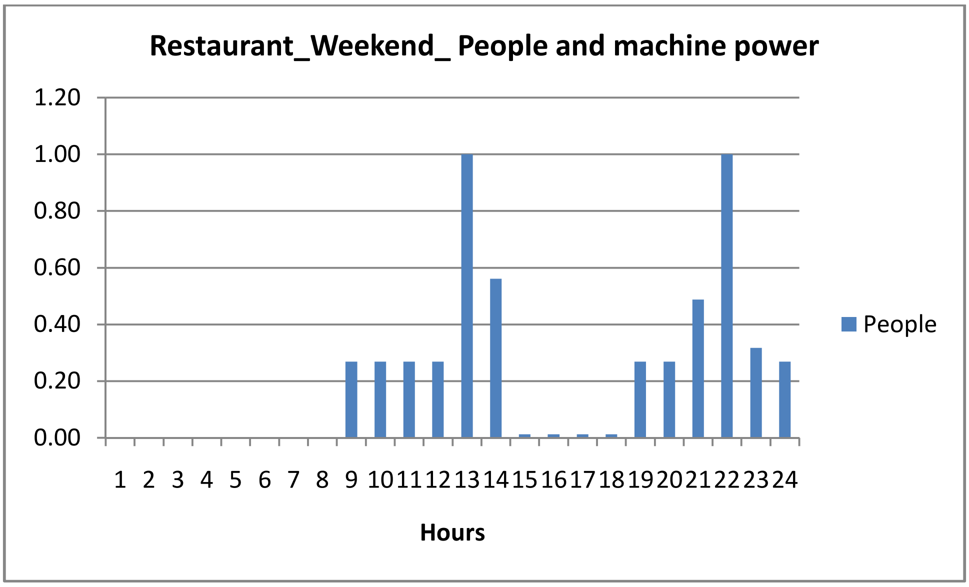


Figure 209 Restaurant: occupancy profile_weekend

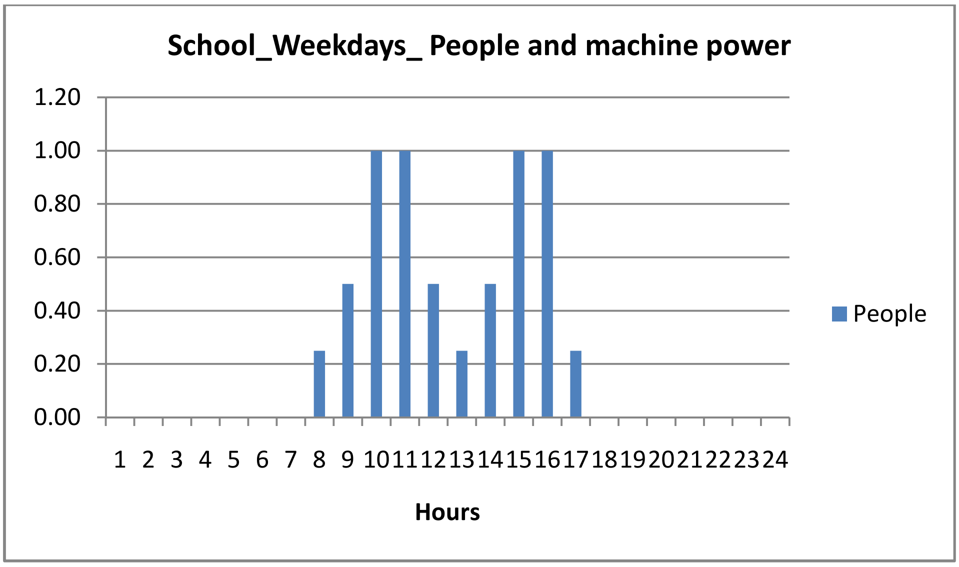


Figure 210 School: occupancy profile_weekdays

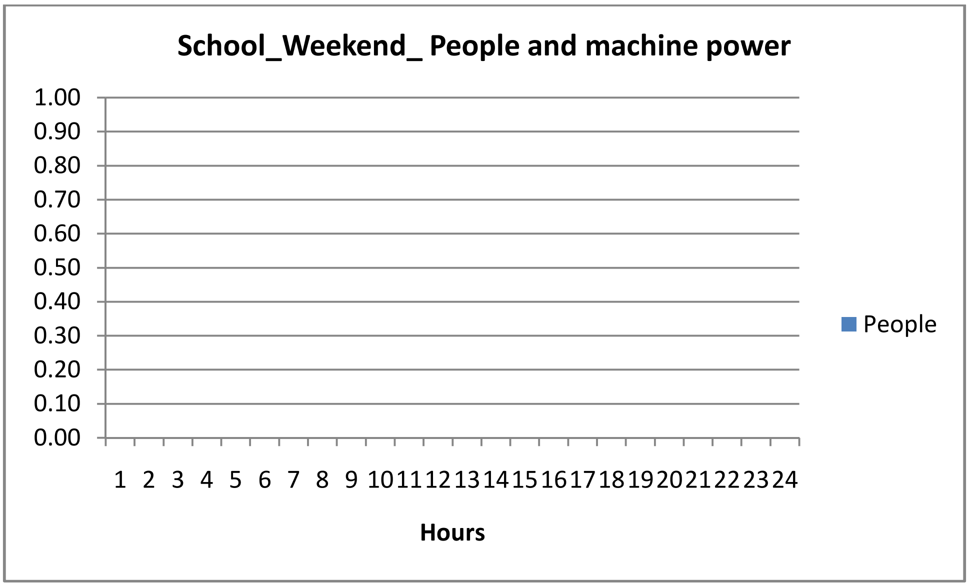


Figure 211 School: occupancy profile_weekend

In the table below are resumed all the calculation connected with the total number of people in every building. The column “total people” means the people per square meter of every function, the column “total people correct” means the total number of people plus the power density.

Building	Area [m²]	Floor	Total area [m²]	Net area [m²]	Function	Function	Occupancy schedule	People [m²]	Total people	Total people correct
1			1514.97	757.485	Residence	Female student lodging	Residential	0.025	19	31
1a	379.05	3	1137.15	568.575				0.025	14	24
1b	55.32	2	110.64	55.32				0.025	1	2
1c	89.06	3	267.18	133.59				0.025	3	5
2			1764.94	882.47	Residence	Female student lodging	Residential	0.025	22	37
2a	207.54	3	622.62	311.31				0.025	8	13
2b	88.01	2	176.02	88.01				0.025	2	4
2c	322.1	3	966.3	483.15				0.025	12	20
3			481.94	240.97	Social area	Cafeteria-restaurant	Restaurant	0.35	84	72
3a	204.24	2	408.48	204.24				0.35	71	61
3b	73.46	1	73.46	36.73				0.35	13	11
4	332.37	3	997.11	498.555	Residence	Married family lodging	Residential	0.025	12	21
5	449.16	3	1347.48	673.74	Residence	Married family lodging	Residential	0.025	17	29
6			948.18	474.09	Residence	Married family lodging	Residential	0.025	12	21
6a	41.67	2	83.34	41.67				0.025	1	3
6b	288.28	3	864.84	432.42				0.025	11	18
7			1302.66	651.33	Residence	Married family lodging	Residential	0.025	16	27
7a	92.84	3	278.52	139.26				0.025	3	5
7b	65.82	2	131.64	65.82				0.025	2	3
7c	297.5	3	892.5	446.25				0.025	11	19
8			2128.16	1064.08	Residence	Married family lodging	Residential	0.025	27	45
8a	579.44	3	1738.32	869.16				0.025	22	37
8b	75.7	2	151.4	75.7				0.025	2	3
8c	79.48	3	238.44	119.22				0.025	3	5
9	787.84	3	2363.52	1181.76	Residence	Married family lodging	Residential	0.025	30	50
10	182.68	2	365.36	182.68	Residence	Married family lodging	Residential	0.025	5	8
11	205.23	2	410.46	205.23	Residence	Married family lodging	Residential	0.025	5	9
12			1633.92	816.96	Social area	Prayer rooms and other	Assembly	0.25	204	241
12a	84.14	3	252.42	126.21		Prayer rooms and other	Assembly	0.25	32	38
12b	55.38	2	110.76	55.38		Prayer rooms and other	Assembly	0.25	14	16
12c	423.58	3	1270.74	635.37		Prayer rooms and other	Assembly	0.25	159	187
13	348	3	1044	522	Residence	Married family lodging	Residential	0.025	13	22
14	64			0				Wind tower		

15			6946.67	3311.53				0.035	116	299
15a	236.33	3	708.99	354.495				0.035	12	32
15b	71.82	2	143.64	71.82				0.035	3	7
15c	68.46	2	136.92	68.46				0.035	2	6
15d	243.51	3	730.53	365.265				0.035	13	33
15e	36	3	108	54				Atrium	0	0
15f	387.81	3	1163.43	581.715				0.035	20	52
15g	35.96	3	107.88	53.94			Office	Atrium	0	0
15h	454.64	3	1363.92	681.96				0.035	24	62
15i	35.91	3	107.73	53.865	Lab+infrastr ucture	Laboratory		Atrium	0	0
15j	278.61	3	835.83	417.915				0.035	15	38
15k	62.44	2	124.88	62.44				0.035	2	5
15l	307.05	3	921.15	460.575				0.035	16	41
15m	164.59	3	493.77	246.885				0.035	9	23
15n	35.91	3	107.73	53.865				Atrium	0	0
16	844.47	3	2533.41	1266.705	Lab+infrastr ucture	Industry short-term hosting	Office	0.035	44	114
17	64			0				Wind tower		
18			6010.34	3005.17				0.035	105	271
18a	223.77	3	671.31	335.655				0.035	12	30
18b	75.37	2	150.74	75.37				0.035	3	7
18c	1125.24	3	3375.72	1687.86	Lab+infrastr ucture	Laboratory	Office	0.035	59	152
18d	81.81	2	163.62	81.81				0.035	3	7
18e	238.78	3	716.34	358.17				0.035	13	33
18f	78.87	2	157.74	78.87				0.035	3	7
18g	258.29	3	774.87	387.435				0.035	14	35
19			392.98	196.49				0.035	7	18
19a	158.93	2	317.86	158.93	Lab+infrastr ucture	Laboratory	Office	0.035	6	15
19b	75.12	1	75.12	37.56				0.035	1	3
20			391.87	195.935				0.035	7	18
20a	160.21	2	320.42	160.21	Lab+infrastr ucture	Laboratory	Office	0.035	6	15
20b	71.45	1	71.45	35.725				0.035	1	3
21	1167.79	3	3503.37	1751.685	Learning	Classroom	School	0.25	438	413
22			6195.24	3016.68				0.035	106	272
22a	136.68	3	410.04	205.02				0.035	7	18
22b	18.04	3	54.12	27.06				Atrium	0	0
22c	207	3	621	310.5				0.035	11	28
22d	35.92	3	107.76	53.88				Atrium	0	0
22e	342.42	3	1027.26	513.63	Lab+infrastr ucture	Laboratory	Office	0.035	18	46
22f	72.05	2	144.1	72.05				0.035	3	7
22g	208.07	3	624.21	312.105				0.035	11	28
22h	72.04	2	144.08	72.04				0.035	3	7
22i	1020.89	3	3062.67	1531.335				0.035	54	138

23			168.95	84.475	Social area	Cafeteria-restaurant	Restaurant	0.35	30	26
23a	48.59	2	97.18	48.59				0.35	17	15
23b	71.77	1	71.77	35.885				0.35	13	11
24			373.46	186.73	Social area	Cafeteria-restaurant	Restaurant	0.35	65	57
24a	71.92	1	71.92	35.96				0.35	13	11
24b	150.77	2	301.54	150.77				0.35	53	46
25	2100.59	4	8402.36	1050	Lab+infrastructure	Laboratory	Office	0.035	37	95
26	64			0				Wind tower		
27			1305.59	652.795	Lab+infrastructure	Laboratory	Office	0.035	23	59
27a	133.21	2	266.42	133.21				0.035	5	12
27b	71.99	1	71.99	35.995				0.035	1	3
27c	483.59	2	967.18	483.59				0.035	17	44
28			1913.02	861.725	Lab+infrastructure	Industry short-term hosting	Office	0.035	30	78
28a	27.53	3	82.59	41.295				Atrium	0	
28b	208.28	3	624.84	312.42				0.035	11	28
28c	35.66	3	106.98	53.49				Atrium	0	
28d	234.79	3	704.37	352.185				0.035	12	32
28e	72.83	2	145.66	72.83				0.035	3	7
28f	82.86	3	248.58	124.29				0.035	4	11
29			206.38	103.19	Social area	Cafeteria-restaurant	Restaurant	0.35	36	31
29a	73.8	1	73.8	36.9				0.35	13	11
29b	66.29	2	132.58	66.29				0.35	23	20
30	64			0				Wind tower		
31			595.4	297.7	Lab+infrastructure	Laboratory	Office	0.035	10	26
31a	261.54	2	523.08	261.54				0.035	9	23
31b	72.32	1	72.32	36.16				0.035	1	3
32	1187.83	3	3563.49	1781.745	Lab+infrastructure	Laboratory	Office	0.035	62	160
33			413.04	206.52	Lab+infrastructure	Laboratory	Office	0.035	7	19
33a	107.27	2	214.54	107.27				0.035	4	10
33b	71.98	1	71.98	35.99				0.035	1	3
33c	63.26	2	126.52	63.26				0.035	2	6
34			4986.03	2493.015	Learning	Grand Auditorium	Auditorium	0.25	623	735
34a	90.16	2	180.32	90.16				0.25	23	27
34b	433.6	3	1300.8	650.4				0.25	163	192
34c	94.73	2	189.46	94.73				0.25	24	28
34d	1105.15	3	3315.45	1657.725				0.25	414	488

35			1856.64	928.32	Social area	Admin, IT, management services, first aid	Office	0.035	29	74
35a	36.66	3	109.98	54.99				Atrium	0	0
35b	325.59	3	976.77	488.385				0.035	17	44
35c	35.27	3	105.81	52.905				Atrium	0	0
35d	221.36	3	664.08	332.04				0.035	12	30
36			1943.32	971.66	Learning	Library	Library	0.1	97	119
36a	228.92	3	686.76	343.38				0.1	34	42
36b	96.92	2	193.84	96.92				0.1	10	12
36c	354.24	3	1062.72	531.36				0.1	53	65
37			1353	676.5	Lab+infrastr ucture	Laboratory	Office	0.035	24	
37a	276.73	2	553.46	276.73				0.035	10	25
37b	68.96	1	68.96	34.48				0.035	1	3
37c	330.92	2	661.84	330.92				0.035	12	30
37d	68.74	1	68.74	34.37				0.035	1	3
38	350.25	2	700.5	350.25	Social area	Cafeteria-restaurant	Restaurant	0.35	123	106
39	64			0				Wind tower		
40			2728.85	1364.425	Lab+infrastr ucture	Laboratory	Office	0.035	48	
40a	220.96	3	662.88	331.44				0.035	12	30
40b	76	2	152	76				0.035	3	7
40c	637.99	3	1913.97	956.985				0.035	33	86
41			2986.58	1493.29	Sport	Indoor sport	Gym	0.33	493	
41a	577.88	3	1733.64	866.82				0.33	286	305
41b	65.23	2	130.46	65.23				0.33	22	23
41c	374.16	3	1122.48	561.24				0.33	185	197
42	456.54	3	1369.62	684.81	Social area	Cafeteria-restaurant	Restaurant	0.35	240	207
43	255.98	3	767.94	383.97	Sport	Indoor sport	Gym	0.33	127	136
44	373.53	2	747.06	373.53	Sport	Indoor sport	Gym	0.33	123	131
45	311.4	2	622.8	311.4	Sport	Indoor sport	Gym	0.33	103	110
46			3437.47	3390.7	Residence	Male student lodging	Residential	0.025	42	70
46a	210.14	3	630.42	315.21				0.025	8	13
46b	31.18	3	93.54	46.77				Atrium	0	0
46c	410.79	3	1232.37	616.185				0.025	15	26
46d	86.75	2	173.5	86.75				0.025	2	4
46e	435.88	3	1307.64	653.82				0.025	16	27
47			1196.91	598.455	Residence	Male student lodging	Residential	0.025	15	26
47a	64.21	1	64.21	32.105				0.025	1	2
47b	566.35	2	1132.7	566.35				0.025	14	24

48			1080.52	540.26	Residence	Female student lodging	Residential	0.025	14	23
48a	172.63	3	517.89	258.945				0.025	6	11
48b	72.38	2	144.76	72.38				0.025	2	3
48c	139.29	3	417.87	208.935				0.025	5	9
50	64			0				Wind tower		
51			5319.09	2659.545	Sport	Indoor sport	Gym	0.33	878	937
51a	214.17	3	642.51	321.255				0.33	106	113
51b	141.15	2	282.3	141.15				0.33	47	50
51c	1464.76	3	4394.28	2197.14				0.33	725	774
52			4283.06	2141.53	Residence	Female student lodging	Residential	0.025	54	90
52a	112.31	3	336.93	168.465				0.025	4	7
52b	117.65	2	235.3	117.65				0.025	3	5
52c	1064.41	3	3193.23	1596.615				0.025	40	67
52d	71.72	2	143.44	71.72				0.025	2	3
52e	124.72	3	374.16	187.08				0.025	5	8

Table 68 The total number of people in every building

In this simulation we want to define the incidence of people presence in the buildings. We've taken the same value as in "Simulation G", but we've defined the number of people and the presence as we have explained before.

SIMULATIONS RESULTS

The results from the simulation are defined in the table below. As we can see the building that have a higher energy consumption, connected with the people presence, are the ones as restaurants, gym, and auditorium. The buildings with the maximal energy consumption are n. 41, 43, 44 and 45, because they're situated in the sport court, that means that they are exposed to solar irradiation more than the others. The total energy consumption for the Masterplan is 5,731.06 [MWh] or 20,631,816 [MJ] for the first simulation with people, and 2,513.07 [MWh] or 9,047,052 [MJ] for the simulation without people. The difference between the two model is higher, and rise to 80.46 [%] in building n.51, gym. The minimal difference is in residential building.

Table 69Simulation with people. Simulations results [kWh/m²y]

Building	Simulation H Energy consumption per building [kWh/m^{2}y] with people	Simulation G Energy consumption per building [kWh/m^{2}y] without people	Difference [%]
1	-44.97	-35.52	21.02
2	-40.74	-31.07	23.74
3	-113.55	-31.15	72.57
4	-36.61	-26.73	26.98
5	-35.34	-25.28	28.46
6	-37.41	-27.09	27.60
7	-36.80	-27.26	25.92
8	-42.21	-32.32	23.44
9	-33.57	-23.69	29.45
10	-41.25	-31.15	24.49
11	-32.55	-22.52	30.81
12	-114.75	-33.82	70.52
13	-35.00	-25.12	28.23
14	Wind tower	Wind tower	0.00
15	-46.23	-25.30	45.29
16	-54.64	-32.57	40.40
17	Wind tower	Wind tower	0.00
18	-46.36	-24.28	47.63
19	-55.25	-33.50	39.36
20	-55.89	-34.04	39.09
21	-87.36	-23.09	73.57
22	-45.86	-24.15	47.33
23	-126.24	-43.77	65.33
24	-118.23	-35.17	70.25
25	-21.41	-16.31	23.84
26	Wind tower	Wind tower	0.00
27	-54.01	-32.14	40.50
28	-51.15	-31.42	38.57
29	-121.65	-41.15	66.18
30	Wind tower	Wind tower	0.00
31	-50.06	-29.26	41.55
32	-46.87	-24.61	47.51
33	-57.89	-36.27	37.35
34	-108.74	-25.87	76.21
35	-42.75	-23.35	45.38
36	-55.22	-24.27	56.05
37	-51.57	-29.76	42.31
38	-107.64	-22.03	79.53
39	Wind tower	Wind tower	0.00
40	-47.78	-25.82	45.96
41	-133.67	-34.07	74.51

Buildin g	Simulation H Energy consumption per building [kWh/m²y] with people	Simulation G Energy consumption per building [kWh/m²y] without people	Difference [%]
42	-112.15	-26.80	76.10
43	-141.76	-42.99	69.68
44	-140.27	-43.16	69.23
45	-138.63	-40.44	70.83
46	-35.84	-26.39	26.36
47	-37.73	-27.74	26.47
48	-43.43	-33.39	23.11
50	Wind tower	Wind tower	0.00
51	-126.90	-24.79	80.46
52	-39.22	-29.35	25.16

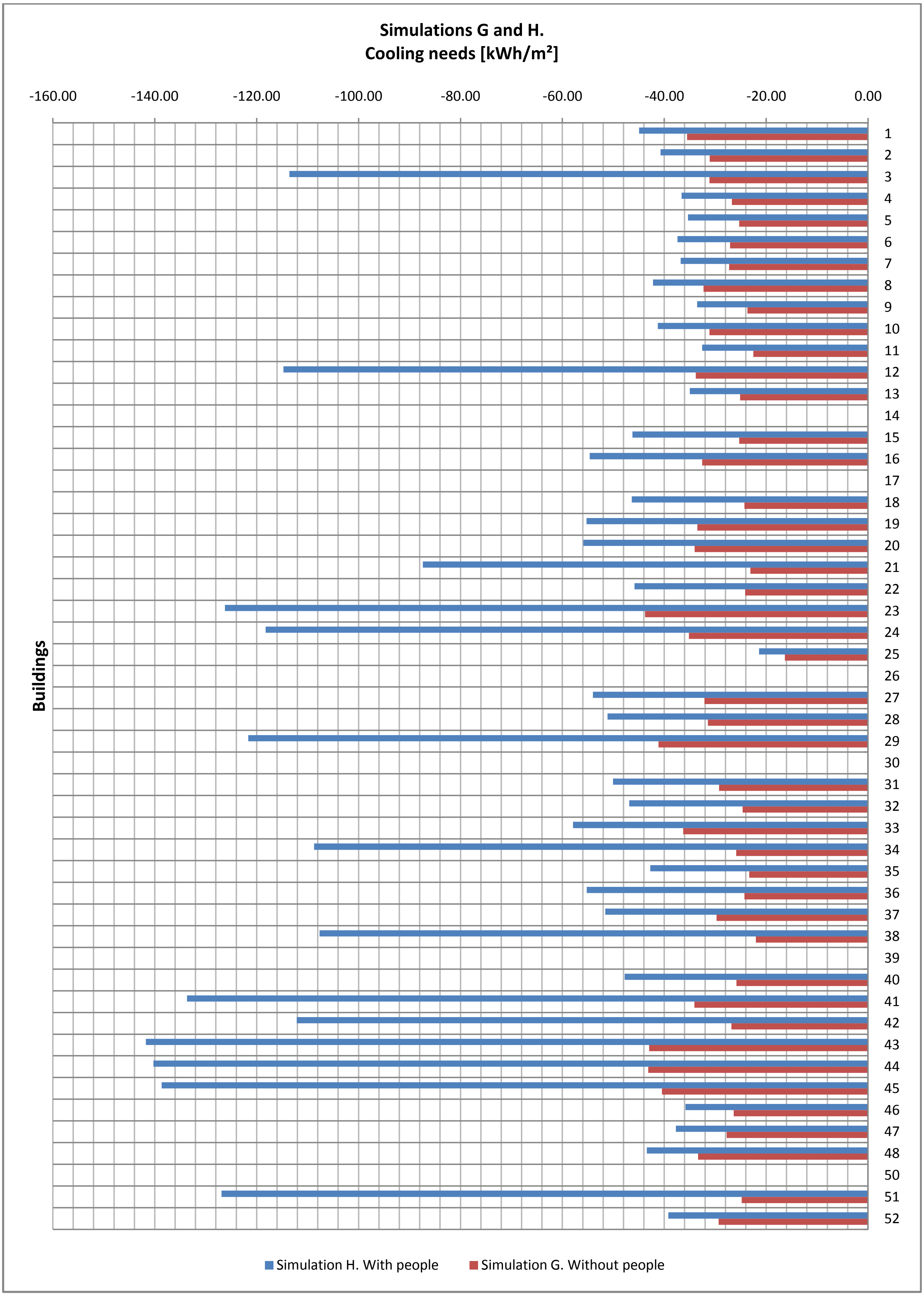


Figure 212 Masterplan simulation with people. Simulation results. Cooling needs per building [kWh/m²y].

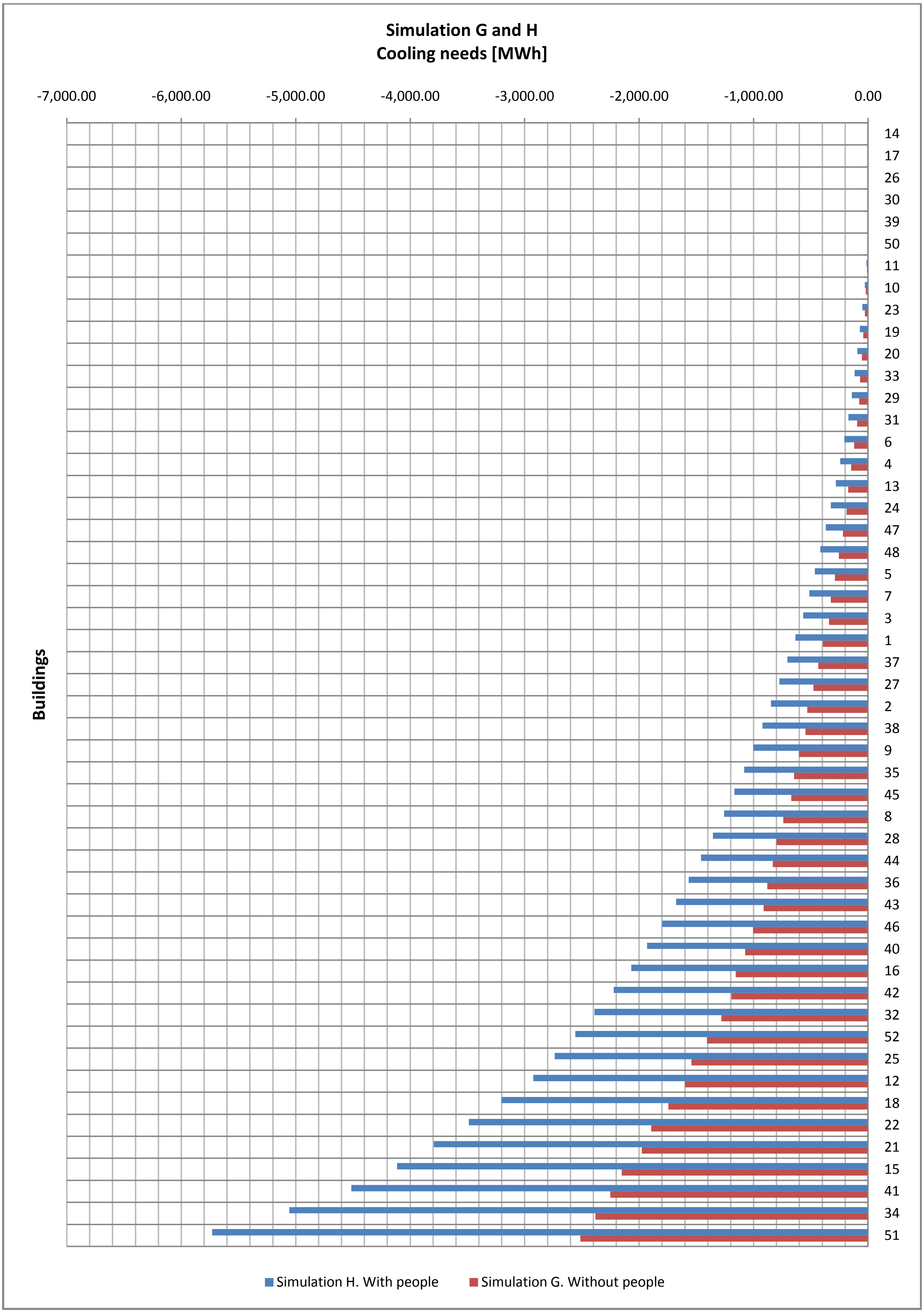


Figure 213 Masterplan simulation with people. Simulation results. Cumulative cooling needs per building [MWh]

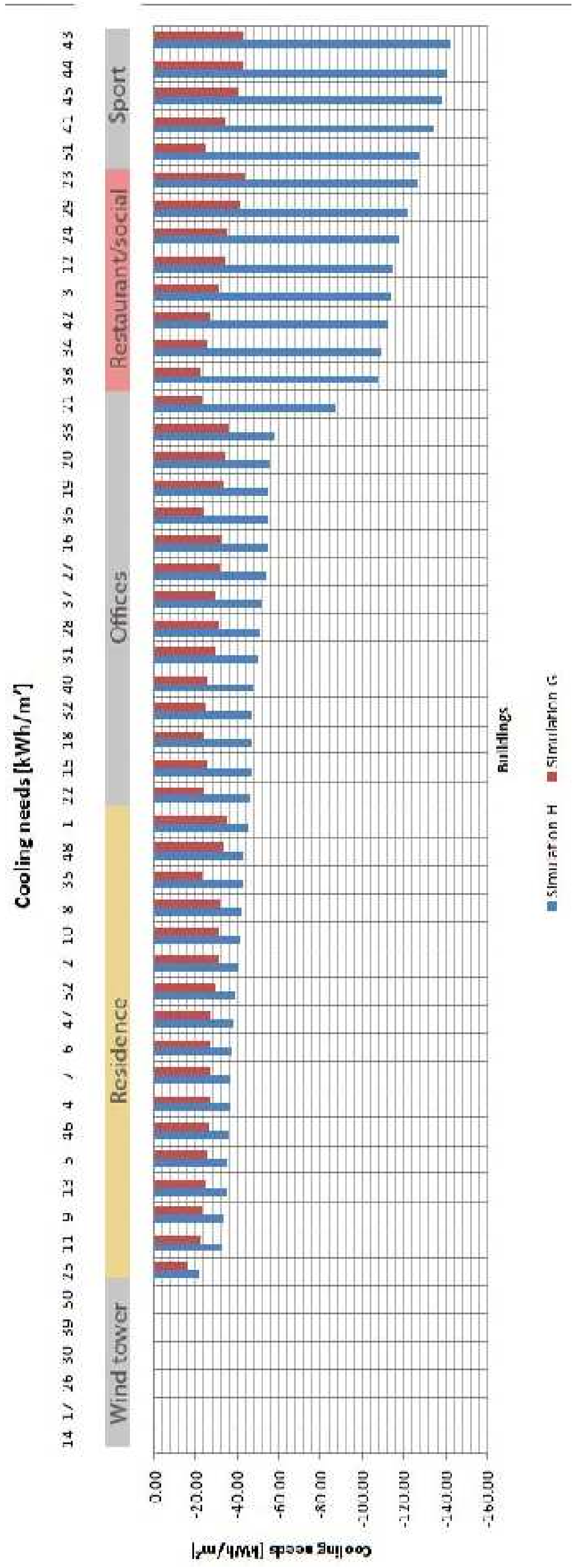


Figure 214 Masterplan simulation with people. Simulation results. Cooling needs per building [kWh/m²y] with function definition.

INFLUENCE OF THE NATURAL VENTILATION

CitySim analyses the value of window's opening, in a percentage of 50 [%] for each surface. The opening are higher in winter months, and null in summer months, as we can see in the figure below, that represent building n. 21. We can notice that the windows are open during the day, except for the hottest hours, in the case of 2nd of January, from 13 to 17 hours. The natural ventilation is important for ameliorate the energy consumption, indeed we've simulated the building with a window's opening of 0 [%], in "Simulation I" and the energy consumption is augmented, with a maximal difference of 18 [%] in building 21.

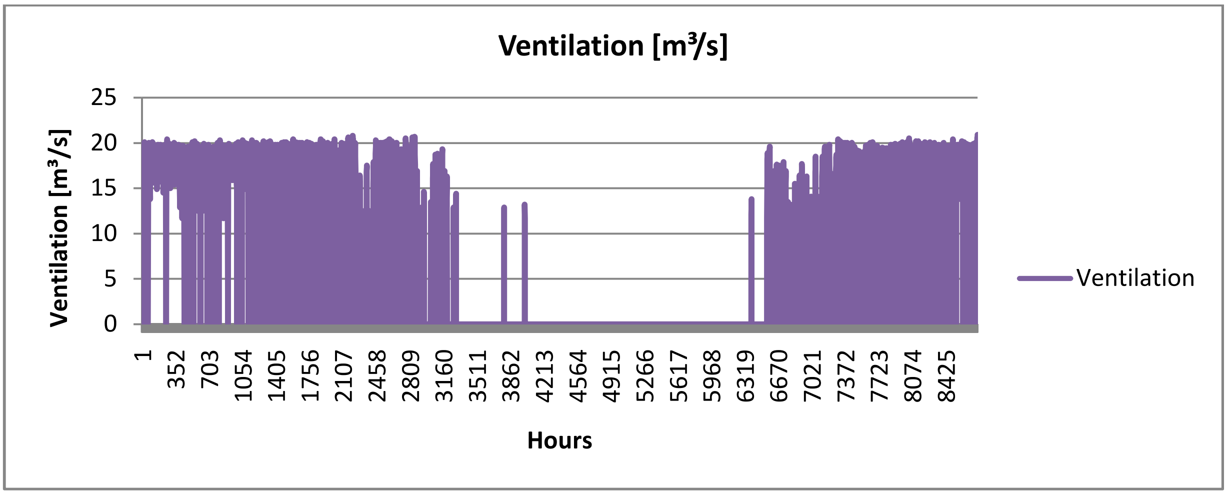


Figure 215 Ventilation [m³/s] during the year

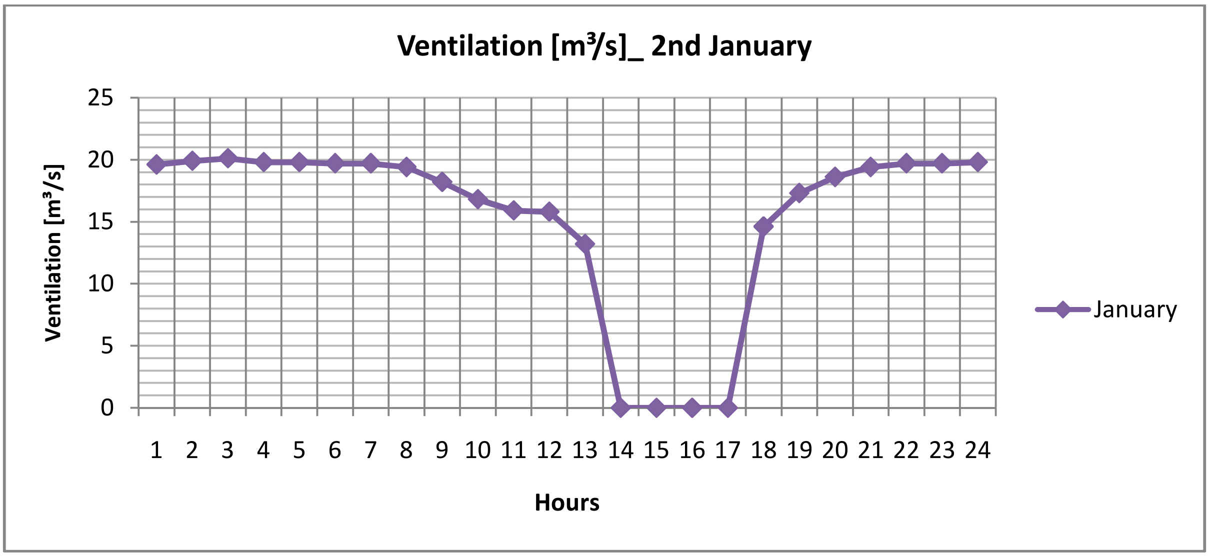


Figure 216 Ventilation [m³/s] hourly value the 2nd January

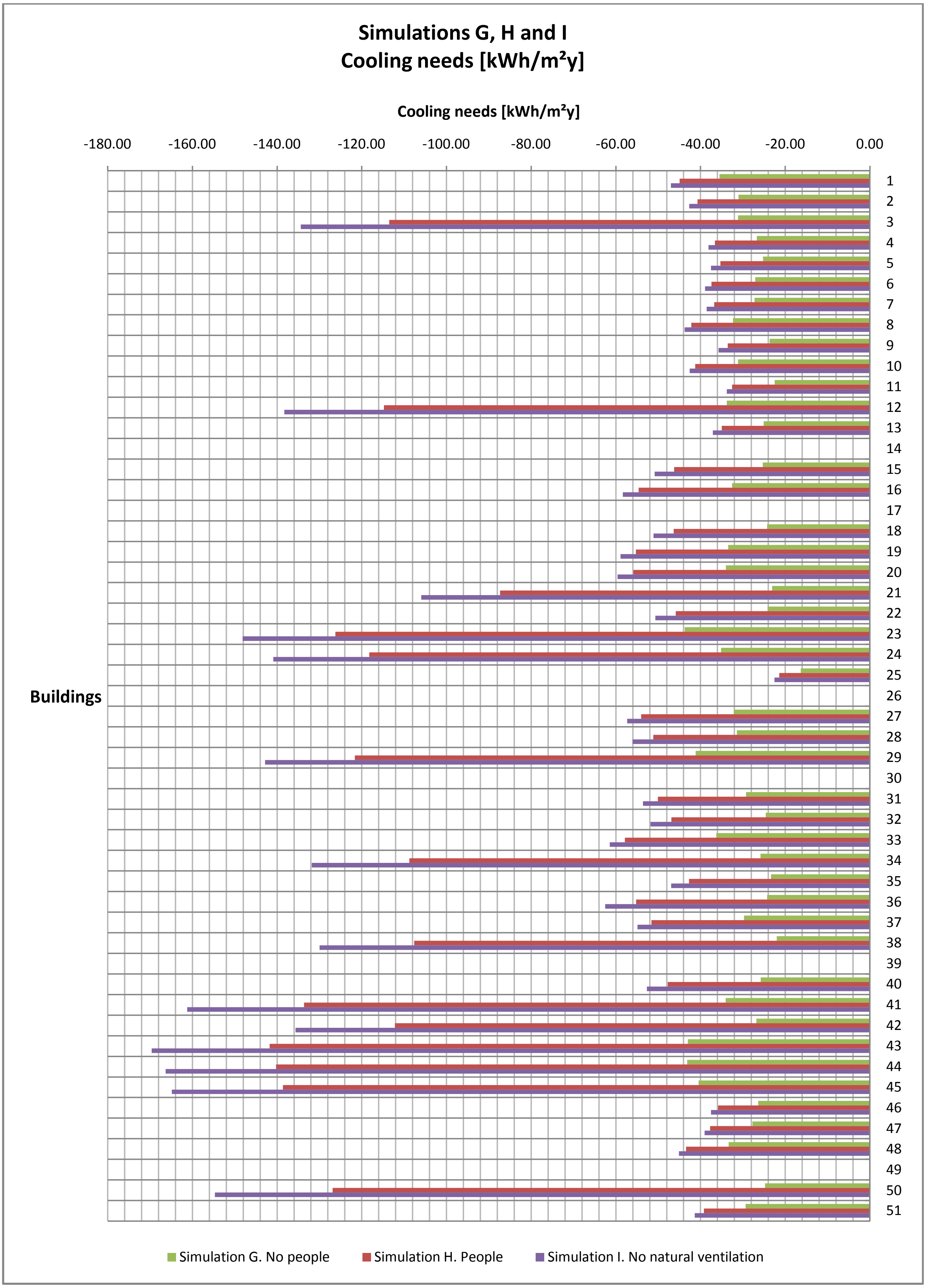


Figure 217 Final graph. Comparison between the simulations

As we can see from the comparison, the optimal energy consumption is “Simulation G”. On the other side buildings with people have higher energy consumption, and if there is no window’s opening, “Simulation I”, they will have incremental energy consumption.

7.0 CONCLUSION

The aim of this master project was to define a correct bioclimatic approach to project the new EPFL Research Centre in Ras Al Khaimah.

In the first chapter we've studied the traditional Arab architecture, starting from the urban scale to the architectural one. We've seen that the Medina is the typical old Arab city, characterized by the closeness of the street, the aggregation of the courtyard house in a continuous urban texture. We've also defined a new approach in the project: the flux of people, the way people move as the way to project.

Then we've studied the UAE, with a economical, social and cultural approach. We've seen the main problem of the area, as the water resource. From this analyse we've defined the main problem and the positive aspects of the area.

Finally we've studied the climate of Ras Al Khaimah, starting from the program Meteonorm. We've seen the high temperature during the summer months, that can reach the 46 [°C] in July, with a meanly amplitude from day and night of 15 [°C]. The precipitation are low, circa 110 [mm/y] and just during the winter months. But the most interesting element is the wind, necessary to guarantee the natural ventilation of the building. The wind in the area of Ras Al Khaimah comes mostly from North- West, during the day, with a maximal speed of 2.5 [m/s]. There is also a strong wind from the South, during the month of August: is the wind of the sand storm.

In the second chapter we've studied two building in Ras Al Khaimah, an office and a house. The buildings were analysed by two students, Maria Papadopoulou and Aabid Fouad, with the software Energyplus. The aim of the simulations was to define the correctness of the software CitySim, compared with Energyplus. Another element was to analyse the research made by Maria Papadopoulou and Aabid Fouad concerning the Minergie standards in UAE, to apply their research in the Masterplan for the EPFL.

In the third chapter we've defined the first two masterplan for the new EPFL research centre in Ras Al Khaimah. They are the first approach to the project, but we can read the first bioclimatic element, as the building's height and orientation.

In the fourth chapter we've defined with CitySim the bioclimatic urban form. We've analysed the number of floors of the building, concluding that is better a compact form, maximising the internal volume, and minimizing the external surface. Then we've studied the best bioclimatic building form, from the rectangle to the courtyard: we've concluded that the courtyard can guarantee a better protection from solar irradiation, and a reduced energy consumption for cooling needs. We've also seen the different solar irradiation upon the surface in the different floor: we can reach the 41 [%] of difference in floor, in the wall facing South- West. We've seen that the windows must be mostly on the South and North side, and reduced in the East and West side. Indeed the solar irradiation on the South side is high during the winter months, and reduced during the summer ones.

As last analyse we decided to study the pedestrian comfort in the urban canyon and courtyard. We've analysed the solar irradiation upon the pedestrian, and we've seen that the maximal solar irradiation on the 21st June at 12.00 is 622 [Wh/m²], and the comfortable solar irradiation for pedestrian is comprise between 200 and 800 [Wh/m²].

In the fifth chapter we've defined the Masterplan, starting from the Cancer constellation, and the main wind direction. The Masterplan looks like an ancient Medina, and it's organized starting from the central- social area, as the fulcrum of the people's fluxes. We've defined the different value of the court, as the private- residential one, the public- social one, and the sports court.

We've tried also to reduce the water needs, using the desert vegetation in the garden, and we've defined some way to collect the rain water, and to create water from humidity. We've estimated the annual water consummation of the campus, and we've defined the water source, as we can see in the figure below.

The last chapter, number six, was dedicated to the simulation made with CitySim of the entire campus. We've analysed the masterplan with and without people, obtaining a total energy consumption for cooling needs respectively of 5,731.06 [MWh] and 2,513.07 [MWh].

LOOKING FOR A 2000 WATT SOCIETY

The vision of the 2000-watt society starts from the city of Zurich. The main topic is to reduce the energy consumption from the actual 6300 watt per person, to 2000 watt in the 2150. The reduction will be achieved by the reduction of the energy consumption, and the use of renewable energy.

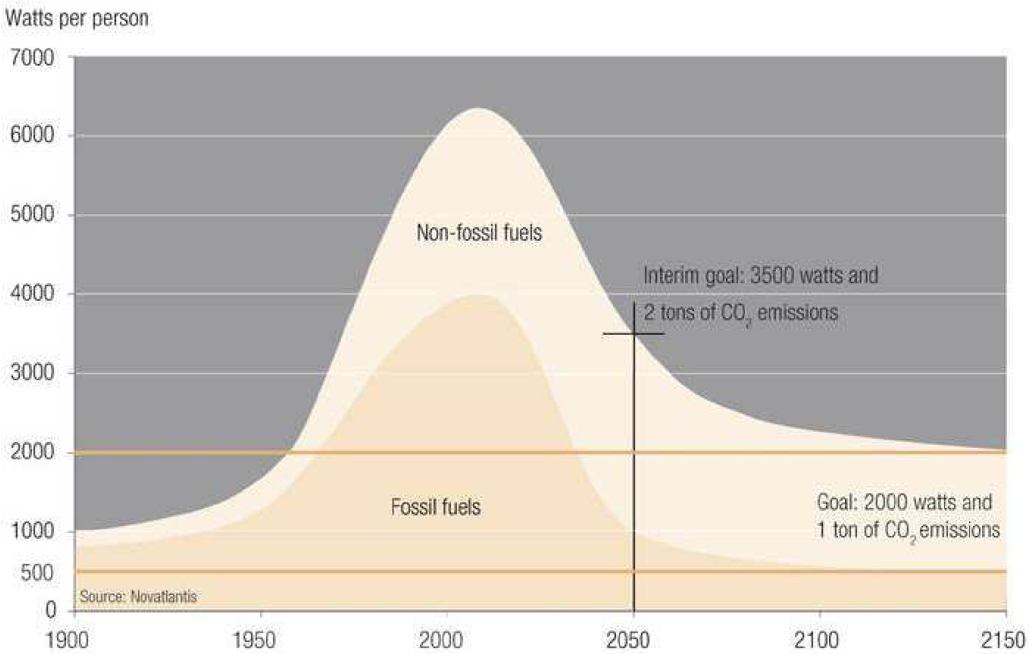


Figure 218 2000 Watt society. Watt per person

Looking for a society of 2000 Watt, the energy consumption for cooling needs in the campus is 1,503 [Watt per person].

The Masterplan has been developed starting from a bioclimatic analysis, achieving the main objective to create a sustainable masterplan, in a difficult climate as UAE.

This Master project can be read as a first approach to the theme of the new EPFL Research Centre in Ras Al Khaimah, as a methodology to reach the sustainable development, thanks to the use of CitySim.

Bibliography

1. Ragette, F., *Traditional Domestic Architecture of the Arab Region*, ed. E.A. Menges. 2006, Sharjah
2. Liébard, A. and A.D. Herde, *Traité d'architecture et d'urbanisme bioclimatiques*, ed. Observ'ER. 2005, Paris.
3. Pearlmutter, D., P. berliner, and E. Shaviv (2006) *Physical modeling of pedestrian energy exchange within the urban canopy*. Building and envirnoment **41**, 783-795.
4. Emirates, U.A. and N.B.o. statistics, *Population in UAE*. 2011.
5. *Climatetemp*. Available from: www.climatetemp.info.
6. Goudie, A.S., et al. (2000) *Desert loess in Ras al Khaimah, United Arab Emirates*. Journal of arid environments **46**, 123- 135.
7. Murad, A.A., H.A. Nuaimi, and M.A. Hammadi (2007) *Comprehensive Assessment of Water Resources in the United Arab Emirates (UAE)*. Water Resour Manage **21**, 1449- 1463.
8. Böer, B. (1997) *An introduction to the climate of the United Arab Emirates*. Journal of arid environments **35**, 3-16.
9. WWF. *Eco- region*. 2012; Available from: http://www.worldwildlife.org/science/wildfinder/.
10. *RAKpedia*. Available from: http://www.rakpedia.com.
11. Alghamdi, A.A.A. and M. Akyurt (2001) *On sandstorms and energy recovery from sandstorms*. Energy Conversion & Management **42**, 1143- 1156.
12. Education, I. *Dunes*. Available from: http://www.indiana.edu/~geol116/Week11/wk11.htm.
13. Rizk, Z.S. and A.S. Alsharhan *Water Resources in the United Arab Emirates*.
14. Sheppard, C., M. Al-Husiani, and Others (2010) *The Gulf: A young sea in decline*. Marine Pollution Bulletin **60**, 13-38.
15. Glasze, G. and A. Alkhayyal (2002) *Gated housing estates in the Arab world: case studies in Lebanon and Riyadh, Saudi Arabia*. Environment and Planning B: Planning and Design **29**, 321-336.
16. Saleh, M.A.E. (1998) *The impact of Islamic and Customary Laws on Urban form Development in Southwestern Saudi Arabia*. Habitat International **22**, 537- 556.
17. Pulselli, R., C. Ratti, and E. Tiezzo (2006) *City out of Chaos: Social Patterns and Organization in Urban Systems*. International journal of Ecodynamics **1**, 125- 134.
18. C.Ratti, et al. (2006) *Mobile Landscapes: using location data from cell phones for urban analysis*. Environment and Planning B: Planning and Design **33**, 727- 748.
19. *Real time*. Available from: http://realtime.waag.org/.
20. Taleghani, M., K.T. Behboud, and S. Heidari (2010) *Energy efficient architectural design strategies in hot dry area of Iran: Kashan*. **2**, 85- 91.
21. *Google maps*. Available from: http://maps.google.ch.
22. Givoni, B., *Man, climate and Architecture*. 1969, Amsterdam- London- New York: Elsevier Publishing Company Limited.
23. Givoni, B., *Climate considerations in Building and Urban Design*, ed. I.T. Publishing. 1998.
24. AboulNaga, M.M. and Y.H. Elsheshtawy (2001) *Environmental sustainability assessment of buildings in hot climates: the case of UAE*. Renewable Energy **24**, pp 553- 563.
25. *Minergie*. Available from: http://www.minergie.ch/minergie_it.html.
26. Papadopoulou, M., *MINERGIE Standard for office buildings in the climate of Ras Al Khaimah. Draft*. 2011.
27. Penwarden, A.D. (1973) *Acceptable wind speeds in towns*. Build. Sci. **8**, 259-267.
28. Ghiaus, C. and F. Allard, *Natural ventilation in the Urban Environment. Assesment and Design*, ed. Earthscan. 2005, Bath
29. Johansson, E. (2006) *Influence of urban geometry on outdoor thermal comfort in a hot dry climate: A study in Fez, Marocco*. Building and envirnoment **41**, 1326-1338.
30. Stathopoulos, T., H. Wu, and J. Zacharias (2004) *Outdoor human comfort in a urban climate*. Building and envirnoment **39**, 297-305.
31. incendie, A.d.é.c.d.a., *Norme de protection incendie*. 2008.
32. FIFA, *Beach soccer. Laws of the game*. 2006.

33. Volleyball.ch, *Beach- Sportanlagen*.
34. Federation, I.T., *Provisional rules of beach tennis*. 2011.
35. Technologies, E., *Earth, Water, Air (EWA)*

in *The rural concept for water supply*. 2008, Israel.
36. Gleick, P.H., *Basic water requirements for human Activities: meeting basic needs*, in *Water International*. 1996. p. 83-92.
37. Sia, *Utilisation rationnelle de l'eau potable dans les bâ τιμεντσ*. 2006: Zuerich.
38. Waggoner, M.C. and S. Baldava (2009) *Structural design of the KAUST Solar Tower*.
39. Awbi, H.B., *Ventilation of buildings*. 1991, Bungay, UK: E&FN SPON.

INDEX OF FIGURES

INDEX OF TABLES