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Analysis of the financial cost, environmental impact and quality of a passive house
Comparison Switzerland - Belgium

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Preface

During this year of thesis writing, it was possible for me to learn much about the subject thanks to outstanding professionals who were willing to share their competences with me. I would like to thank everybody who contributed to this work.

First of all, I want to thank all the people who made it possible for me to undertake my Erasmus exchange to Lausanne. Special thanks goes to the professors of the EPFL who were kind enough to help me with my master thesis. Professor Jean-Louis Scartezzini welcomed me in the LESO-lab and helped me to obtain the necessary software, professor Claude-Alain Roulet for his interesting course about the Indoor Environmental Quality, for showing me the tricks of the Lesosai software and helping me find my way trough the Swiss standards and professors Nicolas Morel and Edgard Gnansounou for their course Energy within Buildings, which gave me an overview of the Swiss energy calculation methods.

I also would like to thank Mrs. Maria Cristina Munari-Probst and her father-in-law Pierre-Alain Probst for allowing me to analyse their dwelling and their help regarding the exact characterisation of the building.

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Ann-Sophie Goudeseune

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Abstract

The objective of this master thesis is the evaluation of different software programs as developed in Switzerland and Belgium for the calculation of the energy consumption and the ecobalance of buildings.
This comparison is not evident because many uncertainties are encountered when calculating the energy consumption of dwellings. However, even though the results do not represent the actual energy consumption, interesting results can be obtained from the software and it is possible to use these in order to optimise the building.
Regarding environmental impacts of dwellings, the Belgian SuFiQuaD project shows that it is useful to include the financial aspects of the building. This will lead to different conclusions regarding the optimal building choices. This allows the building owner to choose the measures that are justified from an integrated point of view, taking into account the economical and ecological aspects.

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AP [kg SO_x-eq]: Acidification Potential. This impact indicator is based on the potential of certain substances to build and release H+ ions. These substances are SO_2, NO_X, HCl, NH_3 and HF. When these gas emissions mix with water molecules in the atmosphere, they create acids. This leads to a decrease of the pH-value of rain and fog. This affects water, vegetation and living species.

CEN: The European Committee for Standardisation.

Characteristic annual primary energy consumption: This is the annual primary energy consumption for space heating, the production of domestic hot water, cooling, auxiliary functions and, in some cases, lighting, calculated according to the method as described in the EPB-decree. The primary energy savings, due to the production of electricity such as photovoltaic panels, are deducted.

End energy consumption: In the Swiss context referred to as 'final energy', this is the end energy necessary to cover the gross heat demand for space heating, including the auxiliary energy for the heat production installation. This way, the production efficiency is taken into account. The energy production of solar thermal collectors is deducted.

Energy related floor surface area: Defined in the Swiss 380/1 standard, Annex F, as the sum of all the floor surfaces of the heated rooms of the building, calculated with the outer measures. In order to take into account the height of the room, a correction factor $f_h = h/h_v$ is applied with h the height of the room and h_v the reference height of 3 m.

EPB: The Energy Performance Regulation for building and renovating in Flanders.

Grey energy [MJ]: The renewable and non-renewable primary energy consumed for the building. It indicates the resources depletion. Often expressed as Cumulative Energy Demand (CED).

Gross heat demand: This represents the energy that is transferred from the heat production installation for space heating to the distribution system for space heating. This introduces the system efficiency in the net energy balance.

GWP [kg CO_2-eq]: Global Warming Potential, an indicator of how much the emission of greenhouse gas contributes to global warming. It sums up the contributions of different gases, converted to the scale of carbon dioxide.

Minergie: A Swiss quality label for new and refurbished low-energy buildings.

Net energy demand: In the Swiss context referred to as 'useful energy'. This is the energy that would be needed to maintain the indoor temperature of a protected volume during a certain period of time, considering a heat installation with a system efficiency and production efficiency of 1.

NRE [MJ]: Non-renewable Energy, indicates the amount of non-renewable primary energy consumed. It is an indication for the depletion of non-renewable sources. Non-renewable energy sources cannot be replaced, or very slowly by natural processes, for example fossil fuels.

POCP [kg C_2H_4-eq]: Photochemical Ozone Creation Potential refers to the potential of VOCs and oxides of nitrogen to generate photochemical ozone production. Ozone has oxidizing properties. This can damage vegetation and can lead to respiratory problems or eye irritation on human beings. It is expressed relative to ethylene equivalents.

SIA: Société Suisse des Ingénieurs et des Architectes. The organisation responsible for the Swiss construction standards.

UBP [Ecopoints]: Umwelt Belastungs Punkte. This is the indicator of the Swiss ecological scarcity method. This factor takes into account emissions to air, to surface waters, to ground water, to soil, resources depletion and wastes. Eco-factors are determined by considering the actual emissions and the maximum allowed flows.

Chapter 1: Introduction

In the Brundtland Report of 1987, sustainable development is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"[1]. The last two decades, there has been an evolution in the building sector towards sustainability. The Flemish Energy Performance Regulation for buildings (EPB) is one of the many results of this evolution. The building sector represents an important share of the environmental impact, because of the great amount of materials used for the construction, the production, transportation and elimination of building materials and of course the energy consumption during the use phase of the building to guarantee a comfortable indoor climate.

Recently, some software programs were developed in order to evaluate these environmental impacts, using a Life Cycle Assessment. These programs often divide the environmental impacts into two categories. On the one hand, the energy consumption of the building is calculated. This allows the analysis of measures to decrease the energy consumption during the use phase of the building. On the other hand, materials have to be produced, transported and the building waste has to be eliminated. The analysis can show the building elements and materials with the biggest impacts.

When approaching the problem from the building owner's viewpoint, another factor will be important, namely the cost of the building. The Belgian SuFiQuaD project takes this supplementary requirement into account and performs a Life Cycle Costing analysis. The initial and life costs of the building will be calculated.

The objective of this master thesis is the analysis and comparison of different software, used to calculate the energy demand and ecobalance of buildings. The steady-state energy calculation with the Swiss program Lesosai and the Belgian EPB-software will be compared. The Swiss ecobalance software Eco+ and Eco-Bat are discussed and some hypotheses are compared with the Belgian SuFiQuaD project. SuFiQuaD however has a different approach as it integrates the environmental impacts and the financial cost of the building.

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[1] Our Common Future, Report of the World Commission on Environment and Development, World Commission on Environment and Development, 1987. Published as Annex to General Assembly document A/42/427, Development and International Co-operation: Environment, August 2nd 1987, p.54

This will be applied for one case study, a Swiss single-family dwelling. Only one dwelling is analysed, so the influence of the design, the surface of the windows etc. will not be taken into account in this master thesis. The installations of the building will not be changed as well, so for the energy calculation, the focus will lie on the net energy demand for heating, which is only influenced by the building parameters.

Chapter 2 discusses the calculation principles of two energy calculation programs and three ecobalance programs. A comparison is made between the Swiss and Belgian approach. Chapter 3 presents the case study and the first output of the different programs. The simplifications and input parameters are described as well. In chapter 4, these different outputs are further discussed and compared. The difference in software results will be explained, based on the principles of the software as described in chapter 2. Some parameters will be changed to analyse their influence. Finally, chapter 5 summarises the conclusions of this master thesis.

Chapter 2: Comparison of the Swiss and Belgian software

Because nowadays, the environmental impact of buildings has gained importance in the international policy, different programs were developed to analyse the energy consumption and the environmental impacts of buildings. The software used at the EPFL in Lausanne, Switzerland, to calculate the energy flows in a building is Lesosai 6.0. Recently, an extra module was added to this software, namely Eco+. With this module, it is possible to retrieve a detailed analysis of the environmental impacts of the building for several impact indicators. At the University Of Applied Sciences of Western Switzerland, Yverdon-les-Bains, another program was developed that only analyses the ecobalance of a building. This software can be used from the early stages of the design process. In Belgium, the EPB-software is currently used to calculate the energy efficiency of a building. At the Catholic University of Leuven, the SuFiQuaD project has been developed, which allows the user to calculate the financial and environmental impacts of dwellings. This chapter contains a description and comparison of these five programs.

2.1 Lesosai 6.0, a Swiss energy balance software

Lesosai 6.0 has been developed by E4tech, in cooperation with the Laboratory of Solar Energy and Building Physics (LESO-PB) of the EPFL in Lausanne. The first version was distributed in 1991. This software calculates the thermal energy of a building, using a method based on the European standards EN ISO 832, EN ISO 13789 [1] and EN ISO 13790 [2].

Lesosai 6.0 allows the calculation of the energy demand according to the European and several national standards (Switzerland, Luxembourg, France and Italy). In this master project, only the Swiss standard is relevant, so the documentation of the software will be limited to the Swiss and European variant. Lesosai is recognised by the Swiss Office Fédéral de l'Energie (OFEN) as certified software for the calculation according to the SIA 380/1: 2009 standard [6].

The weather data for Switzerland used by Lesosai, are in accordance with the official Swiss standards SIA 381/2 or SIA 2028. In order to calculate buildings in other cities or countries than defined in these standards, the weather data generator Meteonorm[2] is integrated in the Lesosai software. Meteonorm is also used when an hourly evaluation of the temperature is necessary.

In order to calculate the thermal conductance coefficient (U-value) of the elements, the Lesosai software uses the database materialsdb.org[3]. This database collects information about the geometry, thermal properties, acoustic properties etc. of different construction elements. The manufacturers of the materials are allowed to manage their own building material database. Lesosai and other building physics software can get access to the decentralised databases via a Dynamic Link Library.

As input for Lesosai, the user has to define the different building zones. Per building zone, the parameters consist of the floor area, volume, air change rate, areas and U-values of the envelope components, orientation, area and type of glazing etc. With this information, Lesosai calculates the energy use for space heating according to monthly simplified models. The calculation of transmission heat loss, ventilation heat loss, internal gains and solar gains will be explained in further detail.

The output is a Sankey diagram[4] and a monthly energy balance. The Sankey diagram shows the annual transmission heat loss for each envelope element, the ventilation heat loss and the internal and solar heat gains. By making the balance of the heat losses and heat gains, the space heating demand is calculated. The monthly energy balance indicates the heat losses for the different components and the internal and solar heat gains. The monthly net energy demand for space heating is estimated.

Besides the energy balance calculation for space heating, it is also possible to execute a life cycle analysis with Lesosai 6.0. With some additional data, the software calculates the environmental impacts of the energy consumption and the materials of the building. This will be explained in detail in the paragraph about the Eco+ module.

The following explanation is based on the manuals of Lesosai 5.0 [3] and 5.5 [4], the syllabus of Energétique du bâtiment [5] and the international standards EN ISO 13370, EN ISO 13789 [1] and EN ISO 13790 [2].

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[2] http://www.meteonorm.com/pages/en/meteonorm.php

[3] http://www.materialsdb.org/

[4] A Sankey diagram is a flow diagram that visualises the different energy transfers. The width of the arrows is proportional to the flow quantity.

Lesosai has different calculation options. The first type of calculation is according to the European standards, CEN[5] (EN 13790). The second type of calculation is in accordance with the Swiss SIA standards. There are different possibilities:

380/1 Verification (used to obtain the building certificate according to the SIA standards),
Minergie[6] (used to obtain the Minergie standards),
Minergie-P (used to obtain the stricter Minergie-P standards),
380/4 Light or Ventilation,
2031 Heat+Lighting,
2031 Heat+Lighting+Ventilation (used to calculate the environmental impacts with Eco+),
2031 Climatisation,
382/1.

Depending on the desired end results, a different option has to be chosen by the user. CEN allows more free parameters, whereas SIA applies certain default values as defined in the SIA standards. In Lesosai, the building is composed of at least one heated zone and possibly several unheated zones. It is necessary to define a different zone for each building part at a different indoor temperature. For each zone, the user has to indicate the function, volume, surfaces, ventilation rates, characteristics of the building envelope and the indoor temperature.
The calculation according to the CEN standards allows the user to define the indoor temperature. The calculation according to the SIA standards uses a fixed value, depending on the type of building, as shown in table 1. The software itself calculates the temperature in the unheated zones.

catégorie d'ouvrages	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	habitat collectif	habitat individuel	administration	écoles	commerce	restauration	lieux de rassemblement	hôpitaux	industrie	dépôts	installations sportives	piscines couvertes
température intérieure °C	20	20	20	20	20	20	20	22	18	18	18	28

Table 1 Indoor temperature for normal conditions, according to SIA 380/1 ([6], p.28)

In order to obtain the net energy demand for heating, Lesosai calculates the heat losses and gains and makes the balance. This balance is calculated for every month. The losses include the transmission heat loss and the

5 Comité Européen de Normalisation

6 Minergie is a Swiss quality label for new and refurbished low-energy buildings, http://www.minergie.ch

ventilation heat loss. The gains consist of the internal and the solar heat gains. The utilisation factor η defines the useful part of the gains.

$$Q_c = Q_T + Q_V - \eta(Q_s + Q_i)$$

Q_c: net energy demand for heating [MJ]

Q_T: transmission loss [MJ]

Q_V: ventilation loss [MJ]

η: utilisation factor [-]

Q_S: solar gains [MJ]

Q_i: internal gains [MJ]

The total heat losses of one zone with constant indoor temperature -these are the first two terms of the previous equation- are defined as:

$$Q_l = H\,(\theta_i - \theta_e)\,t$$

θ_i: indoor temperature [°C]

θ_e: average outdoor temperature [°C]

t: calculation period, usually one month [s]

H: heat loss coefficient [W/K], calculated as

$$H = H_T + H_V$$

H_T: coefficient for transmission losses [W/K]

H_V: coefficient for ventilation losses [W/K]

2.1.1 Transmission heat loss

In order to calculate the total transmission heat loss, Lesosai calculates the heat loss directly to the outdoor environment, the heat loss through the soil and the heat loss through unheated spaces.

$$H_T = H_D + H_S + H_N$$

H_D: coefficient for transmission losses directly to the outdoor environment [W/K]

H_S: coefficient for transmission losses through the soil [W/K]

H_N: coefficient for transmission losses through unheated spaces [W/K]

Transmission losses directly to the outdoor environment

The coefficient for heat loss through the elements of the building envelope to the outdoor environment is calculated with the following formula.

$$H_D = \Sigma_i A_i U_i + \Sigma_k l_k \psi_k + \Sigma_j \chi_j$$

A_i: the surface of the building envelope element [m²]

U_i: thermal conductance coefficient [W/(m².K)]

l_k: length of the linear thermal bridges [m]

Ψ_k: linear coefficient of the thermal bridges [W/(m.K)]

χ_j: point coefficient of the thermal bridges [W/K]

The linear and point coefficients of the thermal bridges can be calculated with external software, but it is also possible to consult the Catalogue of Thermal Bridges as published by the OFEN and added to Lesosai.

Transmission losses through the soil

The heat transmission through the soil is more complex, because of the inertia of the ground and the three-dimensional heat transfer. However, these losses are generally small in comparison to the other heat losses of the building. A simplified method gives results with sufficient accuracy. The calculation method depends on the chosen standard, SIA 380/1 or CEN. The calculation according to the Swiss standards is rather pessimistic.

- **SIA 380/1**: According to the Swiss standards, the calculation method uses a reduction factor b. This correction factor depends on the type of element (floor or wall), the U-value of the element without surface resistances, the depth of the construction in the ground and the relation between the surface and the perimeter of the floor slab. The default values for b can be found according to these parameters in the SIA standards, as shown in table 2.

profondeur dans le terrain*	mur			plancher								
				$A_{FG}/P_{FG} < 5$ m			5 m ≤ A_{FG}/P_{FG} ≤ 10 m			$A_{FG}/P_{FG} > 10$ m		
U_{WG0} resp. U_{FG0}	< 0,4	0,4 ... 0,6	> 0,6	< 0,4	0,4 ... 0,6	> 0,6	< 0,4	0,4 ... 0,6	> 0,6	< 0,4	0,4 ... 0,6	> 0,6
< 0,5 m	0,95	0,93	0,91	0,73	0,65	0,57	0,60	0,51	0,42	0,48	0,39	0,30
0,5 ... < 1,0 m	0,91	0,87	0,83	0,72	0,63	0,54	0,60	0,50	0,40	0,47	0,38	0,29
1,0 ... < 2,0 m	0,86	0,81	0,76	0,70	0,61	0,52	0,59	0,49	0,39	0,45	0,37	0,29
2,0 ... < 3,0 m	0,80	0,72	0,64	0,68	0,58	0,48	0,55	0,46	0,37	0,44	0,36	0,27
≥ 3,0 m	0,74	0,65	0,56	0,66	0,55	0,44	0,53	0,44	0,35	0,42	0,34	0,26

* mesurée «sous plancher contre sol – sur terrain»

Table 2 Reduction factors b for transmission losses through the soil, SIA 380/1 ([6], p.36)

With this correction factor determined for the walls and the floor, the equivalent U-values are calculated with the formulas:

For the walls: $U_{WG} = b_{GW} \cdot U_{WG0}$

For the floor: $U_{FG} = b_{GF} \cdot U_{FG0}$

U_{WG}, U_{FG}: equivalent U-value, taking into account the insulating effect of the ground [W/m²K]

U_{WG0}, U_{FG0}: U-value of the element with $R_{se} = 0$, no insulating effect of the ground [W/m²K]

- **CEN**: The calculation according to the European standards depends on a characteristic value B for the building:

$$B = \frac{2A}{P}$$

A: floor surface [m²]

P: perimeter in contact with the ground [m]

The factor B will be used to calculate the apparent U-value U_0. With U_0, the coefficient of transmission losses through the soil, H_S can be calculated as:

$$H_s = A\ U_0$$

The calculation of U_0 depends on the type of connection with the ground. The most important types will now be specified.

Alternative 1: Floor in contact with the ground

Firstly, the equivalent thickness of the ground d_t has to be calculated.

$$d_t = d_m + \lambda\ R_f$$

d_m: thickness of the surrounding wall [m]

λ: thermal conductivity of the ground, default value 2 W/(m.K)

R_f: thermal resistance of the floor, including the surface resistances of the air [m²K/W]

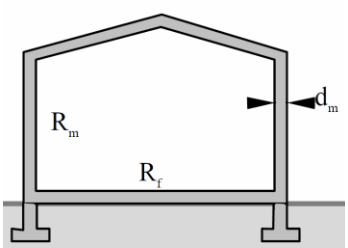


Figure 1 Floor in contact with the ground

Now, U_0 depends on the degree of insulation in the floor.

If the floor is badly insulated ($d_t < B$):

$$U_0 = \frac{2\lambda}{\pi B + d_t} \ln\left(\frac{\pi B}{d_t} + 1\right)$$

If the floor is well insulated ($B < d_t$):

$$U_0 = \frac{\lambda}{0{,}457B + d_t}$$

Alternative 2: Floor above crawl space

In this case, the transmission losses to the ground and the ventilation losses of the crawl space are taken into account. The apparent U-value U_0 is calculated as:

$$\frac{1}{U_0} = \frac{1}{U_f} + \frac{1}{U_g + U_x}$$

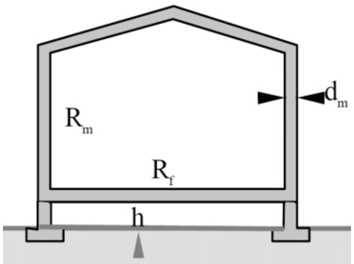


Figure 2 Floor above crawl space

U_f: thermal conductance coefficient of the floor between the heated volume and the crawl space [W/m²K]

U_g: thermal conductance coefficient through the ground [W/m²K], calculated as

$$U_g = \frac{2\lambda}{\pi B + d_t} \ln\left(\frac{\pi B}{d_t} + 1\right)$$

U_x: equivalent thermal conductance coefficient for the heat loss of the crawl space to the outdoor environment via transmission and ventilation [W/m²K], calculated as

$$U_x = \frac{2hU_w + 1450 \varsigma v f_v}{B}$$

- h: average height of crawl space [m]
- U_w: thermal conductance coefficient of the wall of the crawl space [W/m²K]
- ς: total surface of ventilation openings divided by the perimeter of the wall [m²/m]
- v: mean speed of the wind at 10 m height
- f_v: wind-protection factor (0,02 for sheltered places, 0,05 for suburbs, 0,1 for unsheltered places)

Alternative 3: Heated basement

The heat loss coefficient for heated basements is calculated as the sum of the heat losses via the floor and the walls.

$$H_s = A\, U_{ef} + z\, P\, U_{em}$$

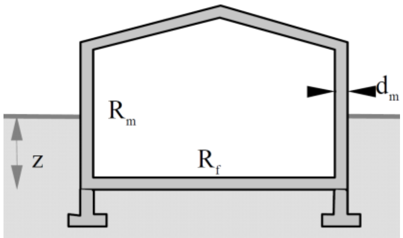


Figure 3 Heated basement

A: floor surface [m²]

P: perimeter in contact with the ground [m]

z: depth of the basement floor under ground level [m]

The equivalent thermal conductance coefficient for the floor U_{ef} is calculated with the equivalent thickness of the floor d_t, calculated as

$$d_t = d_m + \lambda\, R_f$$

d_m: thickness of the surrounding wall [m]

λ: thermal conductivity of the ground, default value 2 W/(m.K)

R_f: thermal resistance of the floor, including surface resistances of the air [m²K/W]

If the floor is badly insulated ($(d_t + z/2) < B$):

$$U_{ef} = \frac{2\lambda}{\pi B + d_t + \frac{z}{2}} \ln\left(\frac{\pi B}{d_t + \frac{z}{2}} + 1\right)$$

If the floor is well insulated ($B < (d_t + z/2)$):

$$U_{ef} = \frac{\lambda}{0{,}457B + d_t + \frac{z}{2}}$$

The equivalent thermal conductance coefficient for the walls under the ground U_{em} is calculated with the equivalent thickness d_{em}:

$$d_{em} = \lambda R_m$$

λ: thermal conductivity of the ground, default value 2 W/(m.K)

R_m: thermal resistance of the wall, including surface resistances of the air

The equivalent U-value for the wall is then calculated as:

$$U_{em} = \frac{\lambda}{\pi z}\left(2 + \frac{d_t}{d_t + z}\right) \ln\left(\frac{z}{d_{em}} + 1\right)$$

Alternative 4: Unheated basement

The equivalent thermal conductance coefficient U_0 is calculated as:

$$\frac{1}{U_0} = \frac{1}{U_f} + \frac{A}{AU_{ef} + zPU_{em} + hPU_m + 0{,}33\dot{V}}$$

A: floor surface [m²]

P: perimeter in contact with the ground [m]

z: depth of the basement floor under ground level [m]

h: average height of the unheated volume above the ground [m]

U_f: U-value of the floor between the heated volume and the basement [W/m²K]

U_{ef}: equivalent U-value of the floor between the basement and the ground [W/m²K]

U_{em}: equivalent U-value of the basement walls under ground level [W/m²K]

U_m: U-value of the basement walls above ground level [W/m²K]

V: volumetric flow rate of the unheated zone [m³/h]

This was a brief overview of the different calculation methods for heat transfer via the soil. More specific cases, such as floor heating, peripheral insulation etc. are specified in the European standard EN 13370.

Transmission losses through unheated spaces

Because an unheated space has a room temperature different than the outdoor temperature, the losses are reduced with a factor b. The transmission heat loss coefficient H_N is calculated as:

$$H_N = H_{in}\, b$$

with

$$b = \frac{H_{ne}}{H_{ne} + H_{in}}$$

b: temperature reduction factor [-]

H_{in}: coefficient for transmission loss from the indoor environment to the unheated space [W/K]

H_{ne}: coefficient for transmission loss from the unheated space to the outdoor environment [W/K]

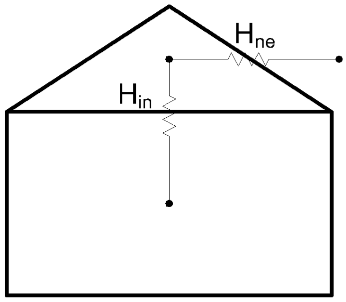


Figure 4 Unheated space

These coefficients include the losses via transmission and ventilation between the two spaces.

$$H_{in} = H_{T,in} + H_{V,in} \qquad H_{ne} = H_{T,ne} + H_{V,ne}$$

The transmission losses are calculated as explained in the previous paragraphs, whereas the ventilation losses are calculated as:

$$H_{V,in} = \rho c\ \dot{V}_{in} \qquad H_{V,ne} = \rho c\ \dot{V}_{ne}$$

ρ: density of air [kg/m³]

c: specific heat capacity [Wh/(kg.K)]

$V_{in/ne}$: volumetric flow rate of air [m³/h]

If the calculation is implemented according to the Swiss standards, default values for the different non-heated zones can be found in the SIA 380/1 standard, as shown in table 3.

espace non chauffé	b_{uR}, b_{uW}, b_{uF}
combles, toit non isolé	0,9
combles, toit isolé: U_e < 0,4 W/(m²·K)	0,7
sous-sol entièrement enterré	0,8
sous-sol partiellement enterré ou entièrement hors terre	0,9
pièce annexe	0,9
jardin d'hiver, véranda	0,9

Table 3 Reduction factors for transmission losses to unheated spaces, SIA 380/1 ([6], p.35)

2.1.2 Ventilation heat loss

The amount of energy that escapes via ventilation depends on the total air flow rate.

$$Q_V = m\, c_p \Delta\theta \left(1-\eta_r\right) = \rho \dot{V}\, t\, c_p \Delta\theta \left(1-\eta_r\right)$$

Q_V: energy consumption during the considered period of time [MJ]

m: the mass of the air that flows through the building [m]

c_p: specific heat of air, default value 1005 J/(kg.K)

Δθ: difference between the indoor and average outdoor temperature [K]

ρ: volumetric mass of air [kg/m³]

V: volumetric flow rate of air [m³/h]

t: considered period of time [h]

η_r: heat recovery efficiency on the evacuated air [-]

At room temperature, $\rho.c_p$ equals 1200 J/(m³.K) or 0,33 Wh/(m³.K).

Recalculating this formula to the coefficient for ventilation losses H_V, gives:

$$H_V = \dot{m} c_p \left(1-\eta_r\right) = \rho \dot{V} c_p \left(1-\eta_r\right)$$

The flow rate of air is the sum of the flow rate by ventilation[7] V_f, and the supplementary flow rate caused by wind and thermal draught V_x. The last factor is present because the building envelope is never completely airtight.

$$\dot{V} = \dot{V}_f + \dot{V}_x$$

V_f: the maximum value of the intake and exhaust flow rate.

V_x: supplementary air flow rate for wind and thermal draught, calculated as in the European standards:

$$\dot{V}_x = \frac{V \cdot n_{50} \cdot e}{1 + \frac{f}{e}\left[\frac{\dot{V}_{sup} - \dot{V}_{ex}}{V \cdot n_{50}}\right]^2}$$

n_{50}: rate of replaced air for a pressure difference of 50 Pa between the indoor and outdoor environment

e, f: coefficients of exposure to the wind

If the ventilation system works intermittent, the air flow rate is calculated as:

$$\dot{V} = (\dot{V}_0 + V_x^{'})(1-\beta) + (\dot{V}_f + \dot{V}_x)\beta$$

[7] This is the average flow rate of the working ventilation system.

V_f: nominal air flow rate of the mechanical ventilation

V_x: supplementary air flow rate by wind and thermal draught, with the ventilation system working

V_0: air flow due to natural ventilation with the ventilation system off, including the air flow in the tubes of the ventilation system

V'_x: supplementary air flow rate by wind and thermal draught, with the ventilation system not working

β: the fraction of time that the mechanical ventilation is working

When the calculation in Lesosai 6.0 is based on the CEN standards, the ventilation rates are user-defined. However, if the calculation is implemented according to SIA 380/1 standards, the coefficient for ventilation losses is calculated with the air flow rates as described in SIA 380/1, as shown in table 4, related to the energy related floor surface area (as defined in the List of Definitions).

catégorie d'ouvrages	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	habitat collectif	habitat individuel	administration	écoles	commerce	restauration	lieux de rassemblement	hôpitaux	industrie	dépôts	installations sportives	piscines couvertes
débit d'air neuf* $m^3/h{\cdot}m^2$	0,7	0,7	0,7	0,7	0,7	1,2	1,0	1,0	0,7	0,3	0,7	0,7

* Ces valeurs tiennent compte du renouvellement d'air occasionné par les installations mécaniques d'extraction d'air, telles celles des cuisines, des salles de bain et des WC.

Table 4 Air flow rates for normal conditions, SIA 380/1 ([6], p.31)

If the calculation is according to the Minergie standards, the values are also fixed.

V_x: 0,15 m³/(h.m²)

V'_x: 0,15 m³/(h.m²)

η_r: maximum 80%

If there is a heat recovery system on the exhausted air, the coefficient for ventilation losses is reduced with a factor $(1-\eta_r)$ and η_r is the global efficiency of the recovery system. This efficiency is not the same as the efficiency of the heat exchanger, as measured in the factory. A part of the volume escapes through the building envelope or is recirculated because of leakage between the intake tube and the exhaust tube. The relation between the efficiency of the global system η_r and the efficiency of the heat exchanger only ε_{HR} is:

$$\eta_r \cong \frac{(1-\gamma_{exf})(1-R_e)}{1-R_e\,\gamma_{exf}}\varepsilon_{HR}$$

γ_{exf}: the part of the fresh air that enters the building and escapes through the building envelope

R_e: recirculation rate, the part of the extracted air that is recirculated

2.1.3 Internal gains

The internal gains are mostly caused by the production of heat by the people occupying the building and the electrical equipment for a certain period of time t.

$$Q_i = t\,(\Phi_h + \Phi_a)$$

Φ_h: thermal power of the inhabitants [W]

Φ_a: thermal power of the electrical equipment [W]

t: certain period of time, mostly a month is considered [s]

The internal gains of the inhabitants depend on the number of people present in the building, the period of time they spend in the building and their activity:

$$\Phi_h = N\frac{P\,h}{24} = A\frac{P\,h}{24D}$$

N: number of inhabitants, present in the heated volume [pers]

P: power exhaled per inhabitant [W/pers]

h: period of presence [hours/day]

A: gross floor surface of the heated volume [m²]

D: available surface per inhabitant [m²/pers]

In this case too, the CEN standard allows the user to define these parameters, whereas according to the SIA standards, default values are used for the calculation, depending on the type of building, as shown in tables 5, 6 and 7. Depending on the surface area of the building, the average number of persons is estimated. This value is used for the calculation of the internal gains.

catégorie d'ouvrages	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	habitat collectif	habitat individuel	administration	écoles	commerce	restauration	lieux de rassemblement	hôpitaux	industrie	dépôts	installations sportives	piscines couvertes
surface par personne m²/P	40	60	20	10	10	5	5	30	20	100	20	20

Table 5 Surface area per person, SIA 380/1 ([6], p.28)

catégorie d'ouvrages	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	habitat collectif	habitat individuel	administration	écoles	commerce	restauration	lieux de rassemblement	hôpitaux	industrie	dépôts	installations sportives	piscines couvertes
durée de présence h	12	12	6	4	4	3	3	16	6	6	6	4

Table 6 Period of presence of the inhabitants, SIA 380/1 ([6], p.29)

catégorie d'ouvrages	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	habitat collectif	habitat individuel	administration	écoles	commerce	restauration	lieux de rassemblement	hôpitaux	industrie	dépôts	installations sportives	piscines couvertes
chaleur dégagée par une personne W/P	70	70	80	70	90	100	80	80	100	100	100	60

Table 7 Power exhaled per inhabitant, SIA 380/1 ([6], p.28)

The internal gains caused by the equipment are calculated as:

$$\Phi_a = P_{el} f_e$$

P_{el}: electrical power, consumed by the equipment [MJ]

f_e: correction factor, because not all the electrical equipment is located inside the heated volume [-]

If the calculation is implemented according to the CEN standards, these values have to be defined by the user. The SIA standards define values for these parameters according to the Swiss situation, as shown in tables 8 and 9.

catégorie d'ouvrages	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	habitat collectif	habitat individuel	administration	écoles	commerce	restauration	lieux de rassemblement	hôpitaux	industrie	dépôts	installations sportives	piscines couvertes
consommation d'éléctricité par année MJ/m²	100	80	80	40	120	120	60	100	60	20	20	200

Table 8 Consumption of electricity, SIA 380/1 ([6], p.30)

catégorie d'ouvrages	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	habitat collectif	habitat individuel	administration	écoles	commerce	restauration	lieux de rassemblement	hôpitaux	industrie	dépôts	installations sportives	piscines couvertes
facteur de réduction des apports de chaleur des installations éléctriques	0,7	0,7	0,9	0,9	0,8	0,7	0,8	0,7	0,9	0,9	0,9	0,7

Table 9 Correction factor for electrical installations, SIA 380/1 ([6], p.30)

2.1.4 Solar gains

The solar gains depend on the incident solar radiation on a particular spot, the orientation of the receiving surfaces, the permanent shade and the characteristic coefficients of transmission and absorption of the different surfaces. The solar gains for space heating include only the passive solar gains[8] and not the gains of solar heat installations (active gains). Generally, the solar gains are calculated with the following formula.

$$Q_S = \sum_j Q_{sj} = \sum_j I_{sj} \sum_n A_{snj}$$

I_{sj}: the solar irradiation, this is the total energy of the solar radiation over a certain period of time, which enters a surface of 1 m² with orientation j [MJ/m²]

A_{snj}: the equivalent area of the receiving surface n with orientation j [m²]

The equivalent area is calculated, depending on the following parameters:

$$A_s = A \; F_S \, F_F \; g$$

A: total area of the receiving surface [m²]

F_S: reduction factor for the permanent shade of the surface [-]

F_F: reduction factor for the frame of the window, equals the area of the transparent part of the window, divided by the total area of the window [-]

g: global solar energy transmittance, this is 90% of the solar energy transmittance of the glazing for perpendicular incidence and further reduced in the case of curtains or sunshades [-]

[8] Passive solar gains use sunlight for useful energy without the use of active mechanical systems. These can be direct or indirect systems. Active solar technology uses electrical or mechanical equipment to maximise the use of the solar energy, for instance thermal solar systems and photovoltaic panels.

The shade factor F_S represents the reduction of the solar radiation because of permanent shade surfaces, such as an overhang, lateral screens and the horizon. The definition of this factor is:

$$F_S = \frac{I_{s,ps}}{I_s}$$

$I_{s,ps}$: the total solar irradiation, received per m² of receiving surface with the permanent shadings, during the heating season [MJ/m²]

I_s: the total solar irradiation, received per m² of surface, without the permanent shadings [MJ/m²]

In order to calculate this factor with the Lesosai 6.0 software, there are different methods available. The three possibilities will be explained.

Fixed shading: it is possible to enter a percentage. This is an average value for the winter, calculated as the part of the window that is shaded on the 21st of November or the 21st of January for a certain position of the sun.

Variable shading: the shaded part of the window changes linearly per month, depending on the meteorological parameter m. For this method, the user has to indicate the minimum and maximum limit in Lesosai. The meteorological parameter m is defined as the relation between the intensity of the global radiation in the plane of the window and the difference between the internal and external temperature ($T_{int} – T_{ext}$).

Calculated shading: by entering the geometrical values for the horizon, the overhang and lateral screens of the windows, Lesosai calculates the shade factor using the method of the EN 832 standard, annex G.

The Swiss standard SIA 380/1 also defines a table with shading coefficients, but since these values are rather pessimistic for the summer situation, they are not used in the Lesosai software.
Generally, only the solar gains trough transparent elements are taken into account. It is possible to calculate the gains through opaque elements with Lesosai, but in that case, the user also has to calculate the radiation balance for radiation with the sky. In order to calculate this, Lesosai 6.0 needs the extra input of the emissivity of the thermal radiation and the absorption coefficient for solar radiation of this element.
It is also possible to calculate the solar gains for sunspaces, double-skin façades, window solar collectors and transparent insulation walls. However, since these aspects are less relevant for this master thesis, there will not be elaborated on this matter.

2.1.5 Utilisation factor

Because of the difference between the static and the dynamic behaviour of a building, the standards define a utilisation factor. This factor is applied because not all of the solar and internal gains can be used for the space heating. A part of the gains is not admitted in the building, for example by the use of sun shades, and another part leads to an undesired rise of the temperature above 26°C. The utilisation factor η is calculated for every month with the following formula.

$$\eta = \frac{1-\gamma^{a}}{1-\gamma^{a+1}} \quad \text{si } \gamma \neq 1$$

$$\eta = \frac{a}{a+1} \quad \text{si } \gamma = 1$$

The factor γ is the relation between the calculated gains and losses per month.

$$\gamma = \frac{Q_g}{Q_l}$$

The numerical parameter a is defined with the following empiric formula, with a_0 and τ_0 depending on the type of building, according to table 10.

$$a = a_0 + \frac{\tau}{\tau_0}$$

	Type de bâtiment	a_0	τ_0 h
I	Bâtiment chauffé en permanence (plus de 12 heures par jour) comme les bâtiments résidentiels, les hôtels, les hôpitaux, etc. Pour une période de calcul mensuelle	1	15
	Pour une période de calcul saisonnière	0,8	30
II	Bâtiments chauffés de jour seulement (moins de 12 heures par jour) tells que les écoles, les bureaux, les salles de réunion, etc.	0,8	70

Table 10 Values for a_0 and τ_0, depending on the type of building ([5], p.101)

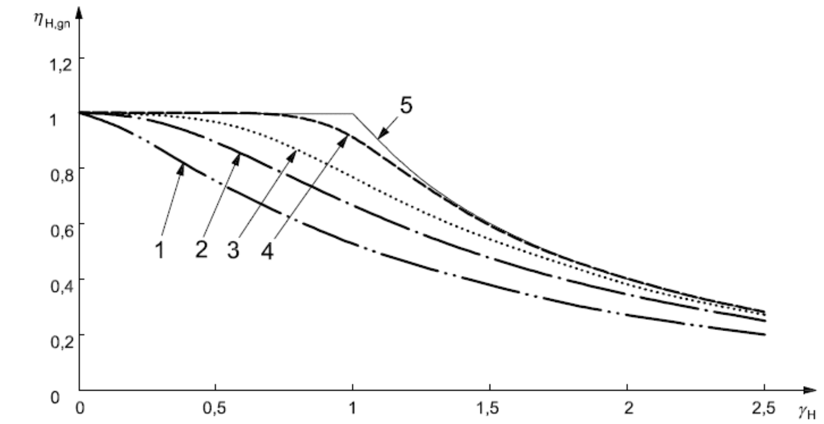
τ is a time constant that represents the inertia of the building.

$$\tau = \frac{C}{H}$$

C: thermal capacity of the building [Wh/K]

H: heat loss coefficient for transmission and ventilation [W/K]

The influence of γ and τ on the gain utilisation factor is illustrated with figure 5.



Key

1 time constant of 8 h (low inertia)
2 time constant of 1 d
3 time constant of 2 d
4 time constant of 7 d
5 time constant infinite (high inertia)

Figure 5 Gain utilisation factor for heating mode, for 8h, 1d, 2d, 7d and infinite time constants, valid for monthly calculation method ([2], p.100)

As long as γ is smaller than 1, there are more losses than gains, so a great part of the gains are useful. If τ decreases, meaning the building has a decreasing inertia, less of the gains can be stored in the buildings capacity, so the utilisation factor will decrease.

In Lesosai, the utilisation factor also depends on the regulation of the heat installation. If the heat installation is well adjusted to the building, the solar and internal gains are more useful. Since the EN ISO 13790 requires a perfect regulation, Lesosai applies a correction factor, depending on the type of temperature regulation system:

Régulation par thermostat dans chaque pièce ou chaque radiateur	1,0
Régulation par thermostat dans une pièce de référence ou dans l'air extrait (installation de ventilation)	0,9
Commande de la température de l'eau de chauffage en fonction de la température extérieure	0,8
Dans le cas d'un chauffage par le sol, on pourra admettre les cas suivants:	
Température de départ ne dépassant pas 30°C le jour le plus froid	1,0
Température de départ supérieure à 30°C:	
Régulation par thermostat sur chaque boucle	1,0
Régulation par thermostat dans une pièce de référence ou dans l'air extrait	0,9
Commande de la température de l'eau de chauffage en fonction de la température extérieure	0,8

Table 11 Correction factors for the utilisation factor, depending on the heat installation ([4], p.14)

2.2 Comparison with the Belgian EPB-software

With the Energy Performance of Buildings Directive (EPBD) of December 16th 2002, the European Parliament encouraged the member states of the European Union to address the problem of the energy performance of buildings, in order to decrease the carbon emission. The key points of the directive are a methodology for calculating the integrated energy performance of buildings and the minimum standards on the energy performance of new and renovated buildings. The Member States are responsible for setting the minimum standards.

In Flanders, this directive led to the Energy Performance Regulation (EPB) for building and renovating, which was implemented on January 1st 2006. New and renovated buildings have to satisfy the regulations regarding thermal insulation, energy performance and indoor environmental quality. The regulations limit the consumption of energy of the buildings and their installations and guarantee a good indoor air quality.

To facilitate the calculation of the energy performance of buildings, the Flemish Energy Agency (VEA) developed the EPB-software. This software is, like Lesosai 6.0, based on the European standards EN ISO 13789 [1] and EN ISO 13790 [2].

The main goal of the software is the calculation of the K-value and the E-value. The detailed calculations of these values can be found in Appendix H. The K-value gives an indication of the overall insulation of the building, whereas the E-value is an indication of the primary energy consumption of the building. The calculation method for the E-value is different for residential buildings (EPW) and for office and school buildings (EPU). The E-value takes into account the installations for space heating, domestic hot water, cooling and the use of sustainable energy. For EPU, the energy use for air conditioning and lighting is also included. It is calculated as the relation of the characteristic annual primary energy consumption for the volume to the reference value for the characteristic annual primary energy consumption for this volume.

$$E = 100\,\frac{E_{char\,ann\,prim\,en\,cons}}{E_{char\,ann\,prim\,en\,cons,ref}}$$

The calculation of the characteristic annual primary energy consumption is implemented in different steps. The first step is the calculation of the monthly net energy demand for space heating and domestic hot water. This corresponds to the output of the Lesosai 6.0 software. This value is translated into the monthly gross energy demand, taking into account the system efficiency. With this value, the software calculates the monthly end energy consumption for space heating and hot water. The energy gains of active solar systems are subtracted and the contributions of cooling and electricity are added. The different energy consumptions are multiplied with a conversion factor, depending on the energy vector, in order to estimate the primary energy consumption. These are added for the whole year. Finally, the software calculates the reference value for the characteristic energy consumption, depending on the surface of the envelope elements, the total volume of the building and the reference air flow rate of the mechanical ventilation. Since January 1st 2010, the E-value of new buildings has to be lower than 80.

In order to calculate the thermal conductance coefficient (U-value) of the envelope elements, EPB uses a database of product data[9]. The database collects information about the thickness and thermal properties of different materials.

This software is only applicable for the Belgian climate and calculates with the same data for the whole country. The weather data are shown in table 12.

Maand	Karak-teristieke dag	Lengte van de maand t_m (Ms)	Maand-gemiddelde buiten-temperatuur $\theta_{e,m}$ (°C)	$I_{s,tot,hor,m}$ (MJ/m²)	$I_{s,dif,hor,m}$ (MJ/m²)
januari	15	2.6784	3.2	71.4	51.3
februari	46	2.4192	3.9	127.0	82.7
maart	74	2.6784	5.9	245.5	155.1
april	105	2.5920	9.2	371.5	219.2
mei	135	2.6784	13.3	510.0	293.5
juni	166	2.5920	16.2	532.4	298.1
juli	196	2.6784	17.6	517.8	305.8
augustus	227	2.6784	17.6	456.4	266.7
september	258	2.5920	15.2	326.2	183.6
oktober	288	2.6784	11.2	194.2	118.3
november	319	2.5920	6.3	89.6	60.5
december	349	2.6784	3.5	54.7	40.2

Table 12 The average outdoor temperature and the average total and diffuse irradiation on an unshaded horizontal plane for the Belgian climate ([7], p.23)

The rest of this chapter focuses on the differences between the Swiss Lesosai 6.0 and the Belgian EPB-software. Therefore, this is not an explanation of the EPB-software in detail, but a comparison of the Belgian and Swiss calculation method to obtain the annual net energy demand for space heating, as this is the output of the Lesosai software. The information about EPB is mostly based on the Annex of the Decision of the Flemish Government of March 11th 2005 [7].

Generally, the calculation method of the Belgian EPB-software is also based on the European standards and thus similar to the Swiss calculation method. The input of the software includes the areas of envelope elements, U-values, orientation, area and type of glazing etc. For each month, the heat losses -transmission and ventilation heat losses- as well as the heat gains -internal and solar gains- are calculated. The utilisation factor determines

9 http://www.epbd.be

the useful part of the gains. The balance of the losses and gains calculates the net energy demand for space heating.

During the calculation procedure in EPB, it is often possible to choose between the simplified or detailed method. The simplified method uses default values, implemented in the EPB-software, whereas the detailed method asks for extra input. The default values are rather pessimistic.

EPB calculates with a fixed value for the indoor temperature of 18°C. This is different than the Swiss SIA value for the indoor temperature, 20°C.

2.2.1 Transmission heat loss

Similar to the Lesosai software, the transmission heat losses are the sum of the losses through the building envelope directly to the outdoor environment, through unheated spaces and through the soil. The heat loss coefficient for transmission H_T is multiplied by the length of the month in Ms and the difference of the indoor temperature (fixed 18°C) and the average outdoor temperature of the month. The calculation of the heat loss coefficient H_T is specified in a supplementary document of the Belgian Government [8].

Transmission losses directly to the outside environment

Officially, the transmission losses are the sum of the direct losses through the building element, the linear thermal bridges and the point thermal bridges, just like the Lesosai software. However, up till now, the calculation of thermal bridges is not mandatory in the EPB-software. During 2010, this will change and it will be required to include the effect of thermal bridges[10].

Transmission losses through the soil

The calculation of the transmission losses through the soil is slightly less detailed with EPB in comparison with the Lesosai method. A summary of the calculation method for the most important cases will be given.

Alternative 1: Floor in contact with underground

The calculation of the heat loss coefficient is simplified with the following formula.

$$H_g = \sum_{i=1}^{n} U_{eq,f,i} . A_i . a_i$$

[10] More information about this can be found on the website http://www.energiesparen.be/epb/bouwknopen

A_i: surface of the floor [m²]

a_i: temperature reduction factor for floor element i, calculated as

$$a_i = \frac{1}{U_{eq,f,i} + 1}$$

$U_{eq,f,i}$: the equivalent U-value of the floor [W/m²K], calculated as

$$U_{eq,f,i} = \frac{1}{R_{si} + R_{f,i}}$$

R_{si}: surface resistance of the air at the indoor environment (0,17 m²K/W)

$R_{f,i}$: thermal resistance of the floor, without surface resistances [m²K/W]

Alternative 2: Floor above crawl space

The heat loss coefficient is defined with a simplified formula, using a temperature reduction factor b.

$$H_g = \sum_{i=1}^{n} U_{eq,f,i} . A_i . b_{U,i}$$

A_i: surface of the floor [m²]

$U_{eq,f,i}$: the equivalent U-value of floor element i [W/m²K], calculated as

$$U_{eq,f,i} = \frac{1}{R_{si} + R_{f,i} + R_{si}}$$

R_{si}: surface resistance of the air at the indoor environment (0,17 m²K/W)

$R_{f,i}$: thermal resistance of the floor, without surface resistances [m²K/W]

$b_{U,i}$: temperature reduction factor of floor element i, as defined in table 13.

Onverwarmde ruimte	b_U (-)
Kelderruimte (minstens 70% van de buitenwanden in contact met de grond)	
• zonder buitenvenster of buitendeur	0,5
• met buitenvenster of buitendeur	0,8
Kruipruimten (*)	
• sterk geventileerd ($n_{ue} \geq 1\ h^{-1}$)	1,0
• niet of zwak geventileerd ($n_{ue} < 1\ h^{-1}$)	0,8
(*) conventionele waarden van het ventilatievoud (n_{ue}) volgens Tabel 6	

Table 13 Default values for the temperature reduction factor b_U ([8], p.48)

Alternatives 3 and 4: Heated and unheated basement

The transmission losses for a heated and unheated basement use the same method as Lesosai 6.0 with one simplification. The thermal resistance of the basement floor R_f is taken as equal to 1 m²K/W.

Transmission losses through unheated spaces

The calculation method for transmission losses through unheated spaces is exactly the same as the Lesosai software, with the use of a reduction factor b.

2.2.2 Ventilation heat loss

Like in the Swiss standards, the ventilation heat losses are the sum of the heat loss caused by mechanical ventilation and by infiltration through the building envelope. However, the implementation of these equations is different. The formula used in the EPB-software is:

$$H_{V,heat,seci} = 0.34\left[\dot{V}_{in/exfilt,heat,seci} + r_{preh,heat,seci}\dot{V}_{dedic,seci} + \dot{V}_{over,seci}\right]$$

H_V: heat loss coefficient for ventilation [W/K]

0,34: the multiplication of the volumetric mass ρ and the specific heat c of air [Wh/m³K]

$V_{in/ex}$: the air flow through the building envelope [m³/h], calculated as

$$\dot{V}_{in/exfilt,heat,seci} = 0.04 \times \dot{v}_{50,heat} \times A_{T,E,seci}$$

- v_{50}: the flow rate of the leakage when applying a pressure of 50 Pa per unit of surface [m³/(h.m²)], default value is 12 m³/(h.m²)
- $A_{T,E}$: the total surface area of all the envelope elements that separate the indoor from the outdoor environment [m²]

r_{preh}: the reduction factor that takes into account the effect of preheating on the net energy demand for space heating

V_{dedic}: air flow, caused by the mechanical ventilation [m³/h], calculated as

$$\dot{V}_{dedic,seci} = \left[0.2 + 0.5\exp(-V_{EPW} / 500)\right].m_{seci}.V_{seci}$$

- m: multiplication factor, depending on the type and quality of the ventilation system, this is a value between 1 and 1,5 (default value is 1,5)
- V_{EPW}: the total volume of the EPW-volume [m³] ([8], p.17)
- V: the volume of the energy sector [m³]

V_{over}: extra air flow, generated when the mechanical exhaust of the air is used for a heat pump, which heats the domestic hot water. Since there is no definitive evaluation of these kind of installations, the effect of too much ventilation in the case of a heat pump is neglected.

In the Belgian formula, the reduction factor for preheating is only applied to the air flow by mechanical ventilation, whereas in the Swiss equation the factor is multiplied with the sum of the air flows. The Swiss formula makes a distinction between a ventilation system that works continuous or intermittent.

In the Swiss formula for the supplementary air flow caused by wind and thermal draught, the coefficients e and f are an indicator for the effects of the wind, whereas the Belgian formula only depends on the flow rate of leakage and the area of the envelope elements.

The recirculation of air in the tubes for mechanical ventilation and the air that escapes through the building envelope is implemented in the Swiss equation in the global efficiency of the heat recovery system η_r, whereas in the Belgian formula this is included in the factor m.

2.2.3 Internal gains

The internal heat gains are the result of the heat emitted by the inhabitants, lighting and electrical equipment in the building. In EPB, the internal gains are calculated with the following formula.

$$Q_{i,seci,m} = (0.67 + 220/V_{EPW}).V_{seci}.t_m$$

V_{EPW}: the total volume of the EPW-volume [m³] ([8], p.17)

V_{sec}: the volume of the energy sector [m³]

t_m: the length of the month [Ms]

Unlike the Swiss formula, the Belgian equation only depends on characteristics typical for the building, such as the volume. The Swiss formula calculates explicitly the thermal power of the inhabitants and the electrical equipment, based on the tables in the SIA standards.

2.2.4 Solar gains

The solar gains are defined as the sum of the solar gains through windows, through unventilated passive solar systems and through adjacent unheated spaces.

$$Q_{s,heat,seci,m} = \sum_{j=1}^{m} Q_{s,heat,w,m,j} + \sum_{k=1}^{n} Q_{s,heat,ps,m,k} + \sum_{l=1}^{p} Q_{s,heat,seci,U,m,l}$$

$Q_{s,heat,w}$: monthly solar gains through the windows [MJ]

$Q_{s,heat,ps}$: monthly solar gains through unventilated passive solar systems [MJ]

$Q_{s,heat,U}$: part of the monthly solar gains in adjacent unheated spaces that contributes to the indoor volume [MJ]

For this project, only the solar gains through windows are relevant, so only this term will be treated in the following explanation. The solar gains are calculated as the sum over all the windows.

$$Q_{s,heat,w,m,j} = 0.95 g_j A_{g,j} I_{s,m,j,shad}$$

0,95: reduction factor for pollution on the windows

$A_{g,j}$: transparent surface of the window [m²]

$I_{s,m,j,shad}$: the solar irradiation, received per 1 m² surface, taking into account the shade of permanent surfaces, such as an overhang and lateral screens [MJ/m²]

g_j: solar energy transmittance of glazing [-], calculated as

$$g = 0.9 \cdot (a_c F_c + (1 - a_c)) \cdot g_{g,\perp}$$

0,9: reduction factor for the angle of incidence

a_c: average factor of utilisation of the sunshades, depending on the control (fixed, manual or automatic)

$g_{g,\perp}$: solar energy transmittance of the glazing for perpendicular incidence of the radiation

F_c: reduction factor for sunshades, calculated depending on the type of sunshade:

Sunshade parallel to the plane of the window:

$$F_C = \frac{g_{g+C,\perp}}{g_{g,\perp}}$$

$g_{g+C,\perp}$: solar energy transmittance for perpendicular incidence for the combination of glazing and sunshades

$g_{g,\perp}$: solar energy transmittance for perpendicular incidence of the glazing only

If $g_{g+C,\perp}$ is not known, default values, as shown in table 14, have to be applied.

Sun shade system	F_C
Exterior sun shades	0,50
Unventilated intermediate sun shades	0,60
Interior sun shades	0,90
Other cases	1,00

Table 14 Default values for the reduction factor F_c for sunshades parallel to the window ([7], p.35)

Sunshade not parallel to the plane of the window:

$$F_C = \frac{I_{s,m,j,shad,wC}}{I_{s,m,j,shad,woC}}$$

$I_{s,shad,wC}$: solar irradiation on the window for one month, taking into account the shade of the permanent screens and sunshades [MJ/m²]

$I_{s,shad,woC}$: solar irradiation on the window for one month, taking into account only the shade of the permanent screens [MJ/m²]

Generally, the Belgian and Swiss software use the same formula. In the Belgian formula, the sunscreens are included in the factor g_j. $A_{g,j}$ already includes the Swiss frame factor F_F and $I_{s,m,j,shad}$ includes the shade factor F_S as used in the Swiss formula. The only difference is the extra reduction factor of 0,95 for pollution in the Belgian formula, which will lead to a small decrease of the solar gains according to the EPB-method.

2.2.5 Utilisation factor

The utilisation factor in EPB is defined as in the Lesosai software, with one supplementary constraint. If γ is bigger or equal to 2,5, meaning the gains are 2,5 times as much as the losses, the utilisation factor η is calculated as

$$\eta_{util,heat,seci,m} = 1/\gamma_{heat,seci,m}$$

There is no extra reduction factor for the regulation of the heat installation in EPB, as there is in the Swiss Lesosai software.

2.3 Eco+ and Eco-Bat , Swiss ecobalance software

2.3.1 Eco+, implemented in the Lesosai 6.0 software

The explanation of the Eco+-module is based on a paper written by Didier Favre and Stéphane Citherlet [9] and communication with the staff of E4tech Software SA and the researchers Didier Favre and Annelore Kleijer of the University Of Applied Sciences of Western Switzerland.

Since a few years, it is possible to extend the Lesosai 6.0 software with the Eco+-module, in order to calculate the ecobalance of buildings as modelled in Lesosai. For the calculation of the environmental impacts of a building, Lesosai has added the mode "SIA 2031 Heat + Lighting + Ventilation". In this mode, it is possible to set the parameters for HVAC systems, thermal solar systems, photovoltaic panels and wind based generators. The software allows the creation of 'rooms' in the 'heated zone', allowing the user to fill in parameters about electric appliances, utilisation time of the room, conditions for lighting, type of lamps, ventilation parameters etc., so the software can make an accurate estimation of the different heat losses and gains for each room of the building[11].

The LCA calculation is in accordance with the ISO 14000 standards. The database implemented in the Eco+-module, is the Swiss KBOB 2006 [24]. KBOB is a publication of the Swiss Federal Office for Construction and Real Estate and can be consulted online. In the KBOB database, LCA data for certain materials, transportation and energy installations can be found. The data for KBOB are extracted from the Ecoinvent database[12]. The environmental impacts are shown per unit, for example 1 kg of material, 1 MJ of useful energy etc. for three impact indicators, namely Global Warming Potential (GWP), Grey Energy and Umwelt Belastungs Punkte (UBP). Definitions of these indicators can be found in the List of Definitions. The Eco+-module calculates the environmental effects of the materials and energy, used in a building, for these impact indicators.

The building life span can be altered. This has an influence on the environmental effects of the energy use and replacement materials. Until now, the software calculates with fixed life spans for the materials, based on an official Swiss document. However, the researchers are investigating ways to make this parameter variable, depending on different circumstances.

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[11] Using these parameters and the information of the envelope elements of a room, the software makes an estimation of the air quality by calculating the emissions of TVOC and formaldehyde. However, because the information for the emissions of the envelope elements is known for few materials, these results are not relevant. In a next version of Lesosai, this evaluation of the indoor air quality will be replaced by a questionnaire.

[12] http://www.ecoinvent.org/database/

2.3.1.1 Materials

Regarding the materials, the Eco+-modules takes into account the effects of production, replacement and end-of-life treatment. The transportation from the factory to the building site is not included because of the European policy in building construction regulation. Because the impacts of maintenance are considered to be small in comparison to the other impacts, these are neglected as well. The environmental effects are calculated as the sum of the effects for each material for each life cycle phase. This sum is made for three different impact indicators, Global Warming Potential, Grey Energy (or Cumulative Energy Demand) and Umwelt Belastungs Punkte.

Production: the total impact for the impact indicator *imp* for element j is the sum over the different materials of the multiplication of the mass for material i and the impact for *imp* for one kg of this material. The mass of material i includes the losses during transportation and assembly.

$$\overline{EI}_{j,imp}^{manuf} = \sum_{i \in j} \left(\overline{M}_i^{manuf} * IF_{i,imp}^{manuf} \right)$$

Replacement: the total impact for the indicator *imp* for element j is the sum of the multiplication of the impact for the production of this element and the number of times this element has to be replaced during the building life span. This depends on the life span of the building and the life span of the different materials. A material will only be replaced if it will be useful for this building at least the half of its possible life span.

$$\overline{EI}_{j,imp}^{replacement} = \sum_{i \in j} \left(Nr_i * \overline{EI}_{i,imp}^{manuf} \right)$$

with Nr_i = Round[13] (LS_{build} / LS_i)

End-of-life treatment: the total impact for the indicator *imp* for element j is the sum of the multiplication of the end-of-life treatment masses for material i and the impact for the end-of-life treatment of one kg of this material. The end-of-life mass includes the final mass of the element and the mass of the replacement materials. The environmental impacts are generated by the transportation to an end-of-life facility and the end-of-life process itself. The possible end-of-life processes are recycling, landfill or incineration.

$$\overline{EI}_{j,imp}^{elim} = \sum_{i \in j} \overline{M_i^{e\lim}} * IF_{i,imp}^{e\lim}$$

[13] The function Round() returns a floating point number to the closest integer value.

2.3.1.2 Energy use

The environmental effects of the energy use are calculated only for the use phase of the building. The consumed energy for heating, domestic hot water, cooling, ventilation, lighting and other electrical equipment is taken into account. The user has to define the technical installations for each of these equipments. Solar thermal systems, photovoltaic panels and wind based generators can be introduced to decrease the energy consumption by non-renewable energy. So far, the Eco+ software has implemented only the Swiss electricity mix.

The consumed energy is calculated according to the Swiss standards. Unlike the Lesosai software which implements the SIA 380/1 standards and a monthly calculation method for the energy demand of space heating, the calculation method according to the Eco+-module is performed more accurately according to the SIA 2024 standards with an hourly calculation method.

In order to calculate the energy demand for ventilation and lighting, the software needs extra input. For lighting, parameters such as the type and amount of lamps, the power of specific electrical devices, the type of regulation of the lighting etc. can be specified per room. For the ventilation, the regulation type, specific fan power, the working hours etc. can be defined. It is possible for the user to define these parameters, but if they are unknown, the software calculates with default values.

2.3.1.3 Output

The extracted results are the same as the three impact indicators that are used in the KBOB database [24], Global Warming Potential (GWP), Grey Energy (or Cumulative Energy Demand CED) and Umwelt Belastungs Punkte[14] (UBP). The GWP and CED will be used to determine the class of the building, once the Swiss standards introduce an energy certificate. The UBP is a Swiss endpoint indicator.

Grey energy [MJ] is defined as the renewable and non-renewable primary energy consumed for the building. It indicates the resources depletion.

GWP [kg CO_2-eq] is an indicator of how much the emission of greenhouse gas contributes to global warming. It sums up the contributions of different gases, converted to the scale of carbon dioxide.

UBP [Ecopoints] is the indicator of the Swiss ecological scarcity method, first published in 1990 and recognised by the Swiss Federal Office for the Environment (OFEN). This factor takes into account emissions to air, to surface waters, to ground water, to soil, resources depletion and wastes. Eco-factors are determined by the actual

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[14] More information on UBP can be found in the publication FRISCHKNECHT, R. et al, *The Ecological Scarcity Method – Eco-Factors 2006. A method for impact assessment in LCA.* Environmental studies no. 0906. Federal Office for the Environment, Bern, 2009.

to be consulted at http://www.bafu.admin.ch/publikationen/publikation/01031/index.html?lang=en

emissions and the maximum allowed flows. These critical values are set by Switzerland. Eco-factors are expressed as Ecopoints per unit of pollutant emission or resource extraction.
There are different ways to extract the results of the Eco+-module. It is possible to compare the results for energy and material impacts on building level for the whole life span of the building. It is also possible to compare the environmental effects of the different elements. Finally, the last tab gives an overview of the environmental impacts per material used in the building. This way, the user can quickly understand which elements or which materials have the biggest impacts and which should be changed to improve the environmental performance of the building.

2.3.2 Eco-Bat

This explanation is based on a paper written by Didier Favre and Stéphane Citherlet [10] and communication with the staff of E4tech Software SA and the researchers Didier Favre and Annelore Kleijer of the University Of Applied Sciences of Western Switzerland.
Eco-Bat was first released for external use in September 2006. It is developed at the Laboratory of Solar Energetics and Building Physics of the University Of Applied Sciences of Western Switzerland. The Eco-Bat software allows the impact assessment of buildings, taking into account the energy consumption and the materials. The life cycle assessment approach is in accordance with the ISO 14040 standards [14]. The data are extracted from the Swiss Ecoinvent database and the KBOB 2009 database [24]. Besides these data, Eco-Bat has an own database, based on practitioners' information, with data such as life spans of the materials, transport distances, end-of-life treatment rates, etc. The Eco-Bat software can be used starting from the early stages of the design process, in order to evaluate and replace the materials with the greatest environmental effects.

2.3.2.1 Materials

The environmental impacts of the materials are the result of the life cycle phases of fabrication, replacement and end-of-life treatment. Contrary to the Eco+-module, in Eco-Bat the user can choose to include the transportation from the factory to the construction site. There is a possibility to choose the Swiss default values or to fill in user-defined transportation parameters. Concerning the replacements, the impacts are calculated for the production of the replacement material, the transportation and the end-of-life treatment of the material. The possibilities for the end-of-life treatment are recycling, incineration or landfill. Once again, the impacts for maintenance are neglected.

2.3.2.2 Energy use

Regarding the energy use during the use phase, Eco-Bat defines six different energy consumers: heating, domestic hot water, cooling, ventilation, lighting and electrical equipment. For each consumer, it is possible to indicate which energy vector is used. Eco-Bat has the electricity data for all European countries and the UCTE-mix[15]. Other energy production systems are fossil fuels, heat pumps, wood, solar thermal systems and photovoltaic panels.

In order to calculate the environmental effects, the user has to indicate the annual consumption of useful energy per consumer. However, for buildings in the design stage, it is possible to apply the pre-sizing module. Depending on the location, the function of the building, the heated floor area, the different spaces and the energy standards the building wants to meet, the software estimates the different energy consumptions.

2.3.2.3 Output

It is possible to evaluate the environmental impacts of the materials and energy use for six impact indicators. Three of them are the same as the Eco+-software: Global Warming Potential, Cumulative Energy Demand and Umwelt Belastungs Punkte. An additional three impact parameters can be extracted: Non-Renewable Energy (NRE), Acidification Potential (AP) and Photochemical Ozone Creation Potential (POCP).

NRE [MJ] indicates the amount of non-renewable primary energy consumed. It is an indication for the depletion of non-renewable sources. Non-renewable energy sources cannot be replaced, or very slowly by natural processes, for example fossil fuels.

AP [kg SO_x-eq] is based on the potential of certain substances to build and release H+ ions. These substances are SO_2, NO_X, HCl, NH_3 and HF. When these gas emissions mix with water molecules in the atmosphere, they create acids. This leads to a decrease in the pH-value of rain and fog. This affects water, vegetation and living species.

POCP [kg C_2H_4-eq] refers to the potential of VOCs and oxides of nitrogen to generate photochemical ozone production. Ozone has oxidizing properties. This can damage vegetation and can lead to respiratory problems or eye irritation on human beings. It is expressed relative to ethylene equivalents.

Again, there are different possibilities to extract these results: on building level, element level and material level. Eco-Bat allows the comparison of different variants of a building, an element or materials. The results can be extracted numerical or in charts. It is also possible to calculate the yearly evolution of the environmental impacts, thus analysing the effects of replacements and the increasing energy use.

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[15] Union for the Coordination of Transmission of Electricity, further explained in 2.4.2, paragraph i

2.4 Comparison with the Belgian SuFiQuaD software

SuFiQuaD is the abbreviation of Sustainability, Financial and Quality evaluation of Dwelling types[16]. It is a project elaborated by three partners, the Catholic University of Leuven (KULeuven), the Belgian Building Research Institute (BBRI) and the Flemish Institute for Technological Research (VITO). It was started out of necessity of an integrated evaluation of the sustainability of dwellings.

The SuFiQuaD project uses a quite different approach in comparison with the Swiss ecobalance software. In the first paragraph, the general principles will be explained. The second paragraph will elaborate on the methodology of the SuFiQuaD project and compare several hypotheses with the Swiss Eco+ and Eco-Bat software. This explanation is based on several documents ([11],[12] and[13]) about the development of the software, written by researchers at KULeuven, BBRI and VITO.

2.4.1 General methodology of SuFiQuaD

The aim of the research is "to develop and apply a methodology to evaluate both the initial and future 'costs' (financial and environmental costs) and 'benefits' (building qualities) of different housing types" ([11], p.11). This will lead to an optimisation of the dwelling and the Belgian housing stock from a sustainability point of view.

In order to calculate the financial costs, a LCC analysis will be executed. The environmental impacts will be evaluated using a LCA method, but in order to integrate these impacts with the financial costs, the environmental impacts will be translated into monetary terms. A detailed explanation on monetising environmental impacts can be found in the Note on monetary valuation of environmental impacts [12].

The evaluation structure that is used for the SuFiQuaD project is based on the element method for cost control. This method uses a hierarchical structure to arrange the different elements of a building, as shown in figure 6. The building is divided in building elements, such as external walls, floors, technical solutions, etc. which can be subdivided in work sections, such as brickwork and in situ concrete.

The environmental impacts and financial costs can be determined for these work sections, and added together to calculate the impacts and costs on building level. The functional unit in the SuFiQuaD project is chosen as one m² of the total floor area per year.

[16] More information can be found on http://www.belspo.be/belspo/fedra/proj.asp?l=nl&COD=SD/TA/12A

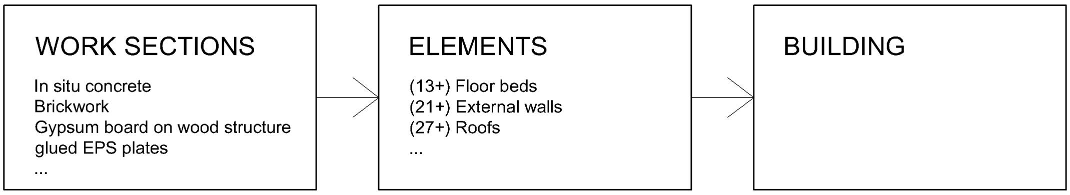

Figure 6 Hierarchical structure of the element method ([13], p.11)

The following paragraphs are a description of the general approach how the environmental and financial costs are determined, how this is linked to the quality evaluation of the dwelling and how the dwelling is optimised.

2.4.1.1 Environmental costs

In order to determine and evaluate the environmental impacts of the dwelling, a Life Cycle Assessment (LCA) study will be executed. SuFiQuaD considers a cradle-to-grave approach. The goal of the LCA study within SuFiQuaD is defined in accordance with the ISO 14040/44 standards and the calculation of the environmental impacts follows the four phases of a LCA as described in these standards ([14], p.18). These phases are goal and scope definition, life-cycle inventory (LCI), life-cycle impact assessment (LCIA) and interpretation.
As defined by the ISO 14040 standards [14], a Life Cycle Assessment consists of different stages. Based on this subdivision, the SuFiQuaD project defines three stages, as shown in figure 7, in order to determine the monetary valuation of the environmental costs. Firstly, emissions and other environmental burdens must be identified and quantified. In a next step, these will be associated with different impacts. Finally, these impacts must be evaluated on a monetary scale. Regarding the monetary valuation of the impacts, two methods are possible. The first option is to list the emissions and burdens and translate them into monetary terms, while the second option includes the assessment of the impact of these emissions before translating it into monetary terms.
However, because the ISO requirements for comparative assertions do not allow a weighting procedure for the environmental impacts, the last part of the method, where the environmental impacts are monetised, is not in line with the ISO 14040/44 standards.

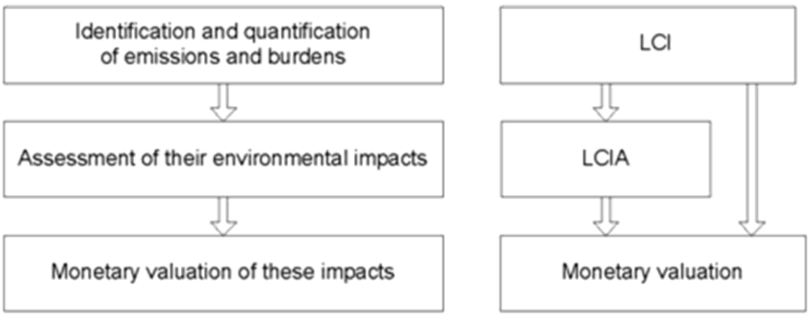

Figure 7 Methodological framework of a LCA ([11], p.14)

The Life Cycle Inventory analysis (LCI) consists of the collection of data that are necessary to quantify the environmentally related inputs and outputs, associated with the dwelling. The input data are the energy inputs, raw material, ancillary inputs and other physical inputs. The output data consist of products, co-products, waste, emissions to air, discharges to water and soil, and other environmental aspects, such as losses of heat. The input-output balance has to be made for all life cycle phases.

The Life Cycle Impact Assessment (LCIA) provides additional information in order to translate the LCI results of a product into its consequences. This way, a better understanding of the environmental significance is possible. LCIA links the emissions as determined in the LCI phase to specific environmental impact or damage categories. The advantage is that at the end of the LCIA phase less categories remain. For example CO_2, methane and other greenhouse gases are aggregated into one impact category, namely global warming or climate change. Other impact categories are acidification, eutrophication, stratospheric ozone depletion, aquatic toxicity, human toxicity, fossil fuel depletion, water depletion and land use.

The impact assessment is still in accordance with the ISO 14040/44 and consists of five steps [14]:

1. The identification and selection of impact categories
2. Classification of LCI results to the different impact categories
3. Characterisation, expressing the damages in terms of a numerical indicator
4. Normalisation, relating the results to outside concerns
5. Valuation, weighting of the contributions of the impact categories

ISO 14040 states that “in the case of comparative assertions disclosed to the public, the evaluation shall be conducted in accordance with the critical review process and presented category indicator by category indicator” ([15], p.23). This is not the case for the SuFiQuaD project, but as SuFiQuaD aims for a single environmental indicator, weighting will be necessary. There is no scientific agreement for reducing the LCA results to a single score, so the application of subjective choices will be unavoidable. The last step of the LCA analysis as performed in the SuFiQuaD project is not in line with the ISO standards.

As stated in the Note on monetary valuation of environmental impacts, the environmental cost is considered as the “damage that the environmental impacts impose on human health, ecosystems and resources. (…) These costs are mostly passed on to society as a whole or to future generations” ([12], p.13).

2.4.1.2 Financial costs

The financial costs are calculated for the whole life cycle of the building, using a Life Cycle Costing Analysis (LCC). The included life phases are described in the Note on optimising economic, environmental and quality aspects ([11], p.65).

- Building investment costs
    - cost of the building materials, including transportation to the construction site
    - cost of the building installations, including transportation to the construction site

- Building operational costs
    - occupation: heating and domestic hot water
    - transportation of the inhabitants and goods during the use phase[17]
    - services of cleaning of the building
    - maintenance of the building
    - replacement of the building materials
    - replacement of the building installations
- Building end-of-life costs
    - labour cost to demolish the building and separate the building waste or reuse or recycling
    - disposal (landfill) of the building materials, including transportation cost or burning (with or without heat recovery)
    - recycling of the building materials, including the transportation cost

The building investment costs are seen as the initial financial cost (IF) of the building. This includes the designing and engineering costs. The building operational costs and end-of-life costs are the periodic financial costs (PF). The end-of-life costs are considered to be a 'once-only' periodic cost, even though they are spread out over different years because some elements have a shorter life expectancy than the structure. But this distinction is made because it will be necessary to calculate the present value of the periodic costs, in order to add this to the investment costs. Future financial costs have to be reduced, because of the varying time value of money. The sum of the IF and present value of the PF represents the total financial cost (TF).
The parameters for calculating the present value of future financial costs within the SuFiQuaD project are ([13], p.51):

Discount rate		2% or 4%
Growth rate	material prices	0%
	labour prices	1%
	energy prices	2% or 4%

The most important database to calculate the financial cost of the different elements is the Aspen database. For missing data, the database of the Bouwunie will be used. The prices for energy are based on statistical data for the Belgian context. The prices for fossil fuels (gas and fuel) and electricity will be determined.

[17] In this phase of the SuFiQuaD project, this is not yet included.

2.4.1.3 Quality of the building

Even with a thorough analysis of the environmental and financial costs, there are still some building parameters not taken into account. These parameters are related to the performance of the dwelling. Qualities that cannot be monetised will be included in the quality evaluation. The quality evaluation is executed according to an existing method [16], used for housing in Belgium. The method is a multi-criteria analysis (MCA) of the parameters and includes the selection of qualities, the determination of scores and the assignment of weighting factors. The different criterions for the dwelling are ([11], p.105):

Dimensional characteristics:	Size of the rooms
	Room width
	Windows size and orientation
	Efficient use of floor area
Functional characteristics:	Available length for furniture
	Relation between the different rooms
	Flexibility/adaptability
Technical characteristics:	Ventilation and safety
	Hygro-thermal characteristics
	Acoustical performance
	Technical installations
	Surface of materials: maintenance
Surroundings of the dwelling:	Direct surroundings
	Broader surroundings

Each of these aspects is subdivided in different sub-aspects for which a score needs to be determined. The importance of the different qualities is defined by assigning weighting factors.

2.4.1.4 Optimisation

In order to optimise the dwellings, a cost/benefit analysis (CBA) will be executed. A cost/benefit analysis is a type of decision-making tool that involves weighting the total costs against the total benefits. Applied for the SuFiQuaD project, the costs are the sum of the environmental and financial costs, expressed in €, and the benefits are the qualities of the dwelling. This way, all the parameters are analysed and optimised at once. The best options can be selected by using the Pareto front.

The solutions on the diagram that are located under and to the right of another solution are excluded because, for a higher cost, the quality will be lower. For an additional life cycle cost, the highest quality improvement will be preferred.

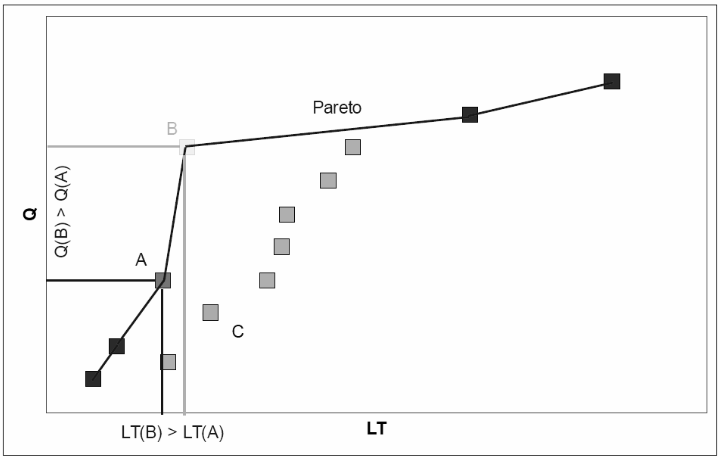

Figure 8 Pareto front within a CBA ([11], p.123)

The cost/benefit analysis can also be executed for the initial and periodical costs. In that case, solutions with a higher initial cost and a higher total cost will be excluded. The highest marginal return will be preferred, meaning the periodical costs per additional investment cost must be reduced as much as possible.

2.4.2 Comparison with the Swiss ecobalance software

In this chapter, the most important elements of the Belgian and Swiss ecobalance software will be compared. The focus lies on the hypotheses used for the calculation of the environmental impacts with SuFiQuaD and Eco+/Eco-Bat, so the calculation of the financial cost and quality as performed with the SuFiQuaD project will not be elaborated.

a. General methodology

Within the SuFiQuaD research, the four steps of a LCA are applied. However, when calculating the Life Cycle Impact Assessment, the final step -this is the monetising of the environmental impacts- is not in accordance with the ISO 14040/44 standards. The only results that can be published according to the standards are at the level of the different impact categories. The researchers decided to weight the impacts anyway, because weighting facilitates the further monetising process and because it is only possible to rank buildings when using a single indicator.

The output of the Eco+ and Eco-Bat software are five impact indicators (NRE, GWP, AP, POCP and CED). This way, it is very difficult to compare the buildings amongst each other, based only on these parameters. However, it is also possible to extract the value for the Swiss endpoint indicator Umwelt Belastungs Punkte.

b. Included life cycle phases

According to the SuFiQuaD documentation ([11], p.18 and p.38), the life cycle of a dwelling consists of the following phases:

Life cycle stage	Eco+	Eco-Bat	SuFiQuaD
PRODUCTION PHASE			
Raw material supply	X	X	X
Transport	X	X	X
Manufacturing	X	X	X
CONSTRUCTION PHASE			
Transport to building site		X	X
Construction/installation process			X
USE PHASE			
Maintenance (incl. cleaning)			X
Replacement	X	X	X
Refurbishment			X
Operational energy flows	X	X	X
User's transportation			(X)[18]
END OF LIFE PHASE			
Deconstruction	X	X	X
Transport of building waste	X	X	X
Recycling/re-use/burning	X	X	X
Disposal	X	X	X

Table 15 Included life cycle phases in the Swiss and Belgian software

Not all the life cycle phases that are included in SuFiQuaD are present in the Swiss software. Especially for the construction and use phase, data are missing in the Eco+ and Eco-Bat software. In the analysis of the case study, the effect of these omissions will be analysed.

c. Databases for environmental impacts (LCI data)

The databases for the environmental impact of the building materials and energy are the Swiss Ecoinvent database and KBOB 2009 for Eco-Bat and KBOB 2006 for Eco+. KBOB [24] is an adaptation of the Ecoinvent database, with less data but applied for building constructions. The impact indicators are Umwelt Belastungs

[18] The user's transportation cost is not yet included.

Punkte, Grey Energy and Global Warming Potential. KBOB data include only the environmental impacts of the construction phase and the end-of-life phase. The data do not include maintenance, construction of the building and transportation to the construction site. Unfortunately, it is not published which data exactly are used for the different materials. As stated in the paper by Stéphane Citherlet and Didier Favre: “Some materials come directly from Ecoinvent, while some others are the results of calculations based on Ecoinvent data. The details of these calculations is not available to the general public”([9], p.2).

For the SuFiQuaD project, the environmental impact data for transportation, end-of-life treatment and energy are also gathered from the Swiss Ecoinvent database. If data are missing, the sources that were consulted are ETH, BUWAL, IDEMAT and IVAM. Because the Ecoinvent database sometimes uses data specifically for the Swiss conditions, SuFiQuaD will translate the records to the Belgian or European situation. This is executed in a harmonisation process. The harmonisation is mainly related to the energy carrier electricity. Within the LCI Ecoinvent data records, the Swiss electricity mix is used. In order to change this to the Belgian situation, knowing that building materials can be produced all over Europe, the Swiss mix will be replaced by the European electricity mix on the first level. Only the electricity input, needed directly to produce the materials, is modified. The other input and output flows, such as water, emissions, waste etc. remain the same.

Because in the software the emissions are directly translated into impact categories, and these impact categories are different for the Swiss and Belgian programs, it is only possible to compare data for the Global Warming Potential. The Global Warming Potential for three different materials is compared in table 16.

	Eco+	Eco-Bat	SuFiQuaD
1 m³ concrete in situ	278,1 kg CO_2-eq	313,4 kg CO_2-eq	332,6 kg CO_2-eq
1 m³ sawn timber, softwood, air dried	61,6 kg CO_2-eq	68,0 kg CO_2-eq	86,3 kg CO_2-eq
1 kg glasswool	1,47 kg CO_2-eq	1,60 kg CO_2-eq	2,39 kg CO_2-eq

Table 16 Comparison of GWP for three materials in Eco+, Eco-Bat and SuFiQuaD

The values in Eco+ are lower than in Eco-Bat because the transportation of the building material is not included in Eco+ and because of the use of the different databases of Ecoinvent and KBOB. The values of the SuFiQuaD software are higher. This might be explained by the modification of the Ecoinvent records to the European electricity mix.

d. Life span of the building

The life span of a building depends on many parameters, such as the function of the building, the quality of the building and its materials, economical aspects, changes in the neighborhood etc. This is the reason why there is a wide range for the life span of buildings.

The reference service life of buildings as described in the SuFiQuaD documentation, based on SETAC information, is different for each country, as shown in table 17. SuFiQuaD accepts 60 years as a good average value for the life span of residential buildings in Belgium.

Country	Reference service life
The Netherlands	75 years
United Kingdom	60 years
Finland	100 years
Switzerland	80 years[19]

Table 17 Reference service life of buildings ([11], p.41)

According to the information by Dr. M. Kornmann on the life span of buildings, presented on the symposium ER'09[20] [17], the average life span of Swiss traditional constructions is over 136 years. However, in the SIA standards, lower values are assumed, as shown in table 18.

SIA standard	Life span
SIA 480	100 years
SIA 2032	60 years
SIA D0200	30 years

Table 18 Building life spans according to SIA standards [17]

In the Belgian and Swiss software, it is possible to change the life span of the building. Since the building lifetime is an uncertain value, a sensitivity analysis for this parameter is recommended.

e. Life span of the materials

Because the life span of the materials is often shorter than the life span of the building, replacements during the use phase have to be taken into account. The relation between the two life spans determines the number of replacements. The number of replacements with Eco+ depends on the life span of the building and the life span of the different materials with the following formula:

$$Nr_i = \text{Round}\,(LS_{build} / LS_i)$$

[19] This is indeed the default value in the Eco-Bat software.

[20] Symposium sur les Energies Renouvelables et l'Environnement dans le bâtiment, 19-20 November 2009, Yverdon-les-bains, Switzerland

The function Round() returns a floating point number to the closest integer value. A material will only be replaced if it will be useful for this building at least the half of its possible life span. In SuFiQuaD, the number of replacements is calculated as:

$$Nr_i = (LS_{build} / LS_i) – 1$$

If the result of this equation is an integer, this represents the number of replacements. If the result is not an integer, the software rounds off to the higher integer (e.g. 2 instead of 1,4).

Furthermore, SuFiQuaD makes the distinction between esthetic and necessary replacements. The necessary replacements will be carried out until the end of the building life span, whereas the execution of the esthetic replacements depends on the life span of the material that is to be replaced. The replacement will only be carried out if the remaining life span is more than half of the life span of the subpart.

Regarding the life span of the building materials, there are some significant differences between the Swiss[21] and Belgian software. The Eco+ and Eco-Bat use the same values, which are between 30 and 50 years for finishing materials and about the double for the structural elements. Because of the fixed life spans, some replacements are taken into account, while in reality they are impossible. For example, the expanded polystyrene under the floor beds are replaced, which is practically impossible. The SuFiQuaD does make this distinction. For example, the life span of extruded polystyrene for cavity walls is 120 years -this equals the life span of the structure- while the life span of XPS that will be plastered is only 40 years. Most of the time, this assumption leads to higher material life spans and thus less replacements in the SuFiQuaD project.

f. Transportation data for building materials

The transportation is not included in Eco+, so transportation data are only available for the Eco-Bat and SuFiQuaD software.

In Eco-Bat, it is possible to use default values for transportation or introduce user-defined transportation. The default values are determined for a construction site in Switzerland. These are the results of an internal research amongst building material manufacturers. Average distances are used for inland and imported materials. A distinction is made for transportation directly to the construction site or via a specialised facility where prefabricated elements are assembled. The Eco-Bat researchers found these assumptions to be sufficient since the transport impacts represent only a small amount of the total environmental impacts.

The Belgian transportation data are the results of an unpublished survey by the Belgian Building Research Institute. Different scenarios were analysed for eight material categories. A distinction is made between the materials which are transported from the factory directly to the construction site and the materials which are

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[21] The life spans of the materials, used in the Swiss software, were communicated via e-mail but are not allowed to be published in this master project.

transported via a reseller. In contrary to the data in the Eco-Bat database (one distance and one vehicle per material), the database of SuFiQuaD is more complex. Different scenarios define the percentage of direct transportation and transportation via a reseller. This is subdivided in different possible transportation vehicles, as illustrated in figure 9.

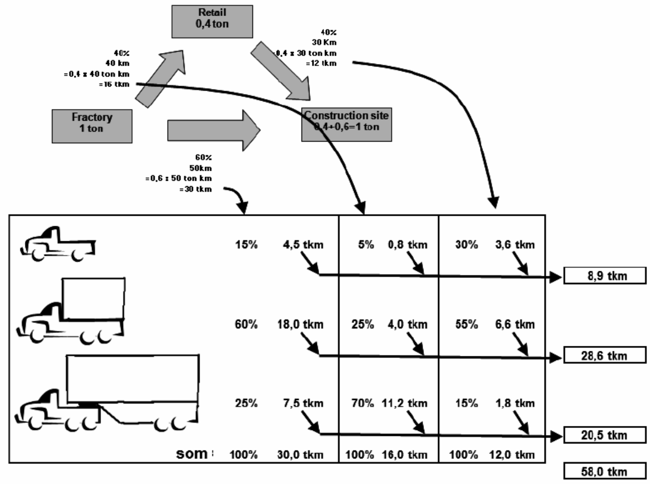

Figure 9 Calculation of environmental cost per transport mode ([13], p.20)

Table 19 shows the comparison of transportation distances and vehicles in Eco-Bat and SuFiQuaD. In order to facilitate the comparison, only the most important vehicle of the SuFiQuaD software is shown. The distance is calculated as the weighted distance for the fraction that is transported directly to the construction site and the fraction that is first transported to the reseller.

	Eco-Bat		SuFiQuaD	
Materials	Distance	Vehicle	Distance	Vehicle
Reinforced concrete	30 km	Lorry 16t	56 km	Lorry 16t
Poor concrete C8/10	30 km	Lorry 16t	56 km	Lorry 16t
Sandstone	60 km	Lorry 16t	100 km	Lorry 16t
Gypsum plasterboard	100 km	Delivery vehicle < 3.5t	111 km	Lorry 16t
Cement cast plaster floor	60 km	Delivery vehicle < 3.5t	95 km	Lorry 16t
Cement mortar	40 km	Delivery vehicle < 3.5t	56 km	Lorry 16t
Gypsum (external)	40 km	Delivery vehicle < 3.5t	111 km	Lorry 16t
Glazing 2-IV-IR (Argon)	40 km	Delivery vehicle < 3.5t	105 km	Lorry 16t
Wooden window frames	40 km	Delivery vehicle < 3.5t	105 km	Lorry 16t
External wooden door, aluminium	40 km	Delivery vehicle < 3.5t	105 km	Lorry 16t
Internal wooden door	40 km	Delivery vehicle < 3.5t	105 km	Lorry 16t
Zinc titanium sheet	500 km	Lorry 16t	100 km	Lorry 16t

Particle board, soft	100 km	Lorry 16t	105 km	Lorry 16t
OSB board	80 km	Lorry 16t	105 km	Lorry 16t
Softwood, kiln dried	40 km	Lorry 16t	105 km	Lorry 16t
Softwood, air dried	40 km	Lorry 16t	105 km	Lorry 16t
Expanded polystyrene EPS	60 km	Lorry 16t	100 km	Lorry 16t
Extruded polystyrene XPS	80 km	Lorry 16t	100 km	Lorry 16t
Glass wool	80 km	Lorry 16t	100 km	Lorry 16t
Rock wool	100 km	Lorry 16t	100 km	Lorry 16t
PVC pipe	60 km	Lorry 16t	117 km	Lorry 16t
Acryl dispersion	80 km	Lorry 16t	108 km	Van < 3,5t
Steel profile, uncoated	500 km	Lorry 16t	66 km	Lorry 16t
Hardwood, air/kiln dried	40 km	Lorry 16t	105 km	Lorry 16t

Table 19 Comparison of transportation distances and vehicles with Eco-Bat and SuFiQuaD, data extracted from the SuFiQuaD and Eco-Bat software

For the transportation according to SuFiQuaD, the lorry of 16 tonne is dominating, because most of the time, the transportation from the factory to the reseller represents the largest distance (variation between 66 and 109 km) and this is mostly transported with a lorry of 16 tonne. According to the scenarios, the most important fraction is transported via a reseller. This leads to higher transportation distances in comparison with the Eco-Bat transportation data.

g. Energy calculation on element level

In order to evaluate and compare the building envelope elements, it will be necessary to estimate the transmission losses and resulting energy costs also on the element level. Without this addition, the optimal solution on element level would be the variant without insulation, because the addition of insulation increases the environmental impacts.

The Eco+ and Eco-Bat software do not take this parameter into account when calculating the environmental impacts of the envelope elements. This leads to the evaluation of uninsulated walls as having lower environmental impacts than insulated walls. In the paper by Stéphane Citherlet and Didier Favre on Eco-Bat [10], the authors analyse three different variants of a light weight building façade and one heavy weight building façade. The comparison is based on the different environmental impacts for four indicators, NRE, GWP, AP and POCP. However, the influence of the thermal conductivity (λ-value) of the different insulation materials is not taken into account, which can lead to a higher energy demand on building level and thus higher environmental impacts in the use phase.

In order to include the transmission losses through the building envelope on element level, SuFiQuaD uses the ‘equivalent Kelvin days method’. The number of Kelvin days is an indicator for the heating season and calculated as the sum of the product of the days where heating is required with the temperature difference between inside and outside. In a colder climate, the number of Kelvin days will be bigger. Equivalent Kelvin days include some corrections for the positive effect of internal and solar gains. The heating demand is calculated as proportional to the number of equivalent heating days.

$Q_T = 0,024 . k_s . S . eq°d$

Q_T: heating demand, caused by the transmission losses [kWh/a]

k_s: surface-averaged heat transmission coefficient [W/m²K]

S: heat transmission surface [m²]

eq°d: number of equivalent Kelvin days [Kd]

In the SuFiQuaD project, two values will be assumed for the equivalent Kelvin days parameter. For a standard dwelling in Belgium, the estimation will be 1400 Kelvin days, whereas for a Belgian dwelling with higher solar and internal gains, the software will calculate with 1200 Kelvin days. This supplementary factor is omitted on building level, because then the actual transmission losses are included.

h. Energy calculation on building level

Because buildings have a long life cycle, an important part of the environmental impact will be the result of the use phase of the building. The energy consumption depends on many parameters, such as the design, the location and the orientation of a building, but also on the efficiency of the installation and the behaviour of the inhabitants. In the tempered climate of Belgium and the continental climate of Switzerland, the most important part of the energy use is caused by heating.

Energy vector	Eco+	Eco-Bat	SuFiQuaD
Heating	included	included	included
Domestic Hot Water	included	included	included
Cooling	included	included	not included
Ventilation	included	included	included
Electrical Equipment	included	included	possible to include
Lighting	included	included	possible to include

Table 20 Included energy consumptions in Eco+, Eco-Bat and SuFiQuaD

It has to be noted that the energy consumption for electrical equipment and lighting cannot be calculated in the SuFiQuaD project. The reason for this decision is that the design of the building has almost no influence on this consumption. However, it is possible to fill in an estimated or actual electricity consumption value in order to add this to the financial and environmental costs. The Eco+ and Eco-Bat software also include this energy consumption.

In the Eco-Bat software, there is no energy calculation procedure implemented. The impacts of the use phase are calculated with the energy consumption for the different energy vectors as estimated by the user or calculated with the pre-dimensioning module of the software. The energy consumption in the Eco+ module is calculated with the procedures as described for the Lesosai software, with the hypotheses as defined in the SIA standards.

In order to make a good assumption of the net energy demand for space heating in the SuFiQuaD project, the EPB methodology is implemented on the building level. This procedure is in accordance with the standards NBN EN 12831:2003 [18], NBN B 62-003 [19] and the method of the Flemish EPB-software as described in the previous paragraph. The heat losses for transmission and ventilation and the internal and solar gains through the windows are calculated. The detailed method is described in appendix A.

The calculation of the energy use for domestic hot water in SuFiQuaD is not the same as the EPB-methodology. The EPB calculation method is based on the volume of the building. SuFiQuaD uses the more accurate calculation method of PHPP[22], based on the number of inhabitants. It is considered that one person uses 25 litre of domestic hot water per day.

i. Electricity mixes

Electricity mixes differ from country to country, because of the shares of the different production possibilities. The electricity mixes, used in the Swiss and Belgian software are not the same. Eco+ only calculates with the Swiss electricity mix. Eco-Bat allows the choice of the European UCTE mix[23] and the mix for different European countries, such as Belgium and Switzerland. For SuFiQuaD, the electricity mix used for the production of materials is the European mix. For the electricity consumption during use phase, the Belgian electricity mix is considered. For the end of life treatment of construction waste, the European electricity mix will be used as well ([22], p.17-18).

Data for the different mixes can be found in the Ecoinvent documentation. The European Network of Transmission System Operators for Electricity (ENTSO-E)[24] defines the average European electricity mix. The electricity mix of UCTE consists of the countries as defined in table 22. The data for the Belgian, Swiss and UCTE electricity mix are compared in table 21.

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[22] Passive House Planning Package, http://www.passiv.de/07_eng/index_e.html

[23] Union for the Coordination of Transmission of Electricity

[24] http://www.entsoe.eu/

	BE	CH	UCTE
Fossil	40,7%	1,9%	51,1%
Nuclear	55,0%	42,7%	31,6%
Hydro	0,4%	50,5%	11,4%
Pumped storage	1,6%	1,5%	1,3%
New renewable	1,0%	0,1%	3,1%
Waste	1,4%	3,3%	1,4%

Table 21 Domestic production mixes for Belgium, Switzerland and the UCTE mix ([20], p.54)

The most important shares in the Belgian mix are the nuclear and fossil power. The Swiss electricity mix is dominated by hydropower and nuclear power. More than half of the UCTE mix is produced with fossil energy. The CO_2 emissions are more important for countries with a bigger fossil part.

	Anteil Kernkraft	Anteil Wasserkraft	Anteil Pumpspeicherung	Anteil Fossil-thermisch	Anteil neue erneuerbare Energien	Anteil Abfälle	Produktionsmenge	**Anteil an UCTE-Produktion**
	%	%	%	%	%	%	GWh	%
Österreich (AT)	0.0	58.7	3.4	32.6	2.7	2.6	62'751	**2.47%**
Bosnien-Herzegowina (BA)	0.0	48.4	0.0	51.6	0.0	0.0	12'071	**0.48%**
Belgien (BE)	55.0	0.4	1.6	40.7	1.0	1.4	81'706	**3.22%**
Bulgarien (BG)	40.5	8.5	0.0	51.0	0.0	0.0	39'086	**1.54%**
Schweiz (CH)	42.7	50.5	1.5	1.9	0.1	3.3	63'719	**2.51%**
Serbien & Montenegro (CS)	0.0	31.5	0.9	67.7	0.0	0.0	36'510	**1.44%**
Tschechische Republik (CZ)	32.1	2.6	0.7	63.7	0.9	0.0	77'186	**3.04%**
Deutschland (DE)	27.4	3.6	1.2	60.7	5.7	1.4	577'754	**22.79%**
Spanien (ES)	22.8	11.6	1.1	56.4	7.9	0.3	268'863	**10.60%**
Frankreich (FR)	78.1	10.8	0.9	9.1	0.6	0.6	547'967	**21.61%**
Griechenland (GR)	0.0	8.5	0.9	88.1	2.2	0.2	54'884	**2.16%**
Kroatien (HR)	17.2	46.3	0.9	35.6	0.0	0.0	15'132	**0.60%**
Ungarn (HU)	35.2	0.7	0.0	61.9	2.1	0.2	31'208	**1.23%**
Italien (IT)	0.0	13.5	3.5	74.7	2.9	5.3	289'525	**11.42%**
Luxemburg (LU)	0.0	2.5	20.1	73.9	1.7	1.8	3'949	**0.16%**
Mazedonien (MK)	0.0	23.8	0.0	76.2	0.0	0.0	6'208	**0.24%**
Niederlande (NI)	3.7	0.1	0.0	89.5	4.1	2.5	96'351	**3.80%**
Polen (PL)	0.0	1.5	1.1	96.6	0.6	0.2	140'687	**5.55%**
Portugal (PT)	0.0	22.4	0.6	70.9	4.9	1.2	43'625	**1.72%**
Rumänien (RO)	9.7	30.5	0.0	59.7	0.0	0.0	43'625	**1.72%**
Slowenien (SI)	36.4	28.1	0.0	34.7	0.7	0.1	14'348	**0.57%**
Slowakische Republik (SK)	55.2	14.3	0.4	30.0	0.0	0.1	28'253	**1.11%**
UCTE	**31.6%**	**11.4%**	**1.3%**	**51.1%**	**3.1%**	**1.4%**	**2'535'405**	

Table 22 Net production mix for UCTE, based on the production data of 2004 ([20], p.54)

In table 23, data are resumed for the LCI and LCIA results of the Swiss and UCTE mix.

LCI and LCIA results		unit	CH (per kWh)	UCTE (per kWh)
CED	non renewable energy resources, fossil	MJ-eq	1,42	5,78
CED	non renewable energy resources, nuclear	MJ-eq	5,88	4,69

CED	renewable energy resources, water	MJ-eq	1,92	0,69
CED	renewable energy resources, wind, solar	MJ-eq	0,03	0,12
CED	renewable energy resources, biomass	MJ-eq	0,03	0,07
resource	land occupation	m²a	6,40E-03	9,50E-03
air	carbon dioxide, fossil	kg	1,10E-01	4,50E-01
air	NMVOC	kg	3,20E-05	1,00E-04
air	nitrogen oxides	kg	1,80E-04	8,30E-04
air	sulphur dioxide	kg	1,90E-04	1,80E-03
air	particulates < 2,5 μm	kg	2,40E-05	1,20E-04
water	BOD	kg	5,10E-05	2,80E-04
soil	cadmium	kg	4,80E-11	1,10E-10
air	sulphur hexafluoride	kg	3,10E-10	7,80E-10
air	radoon-222	kg	3,40E+02	2,70E+02

Table 23 Selected LCI results and cumulative energy demand for the Swiss and UCTE supply mixes ([21], p.171-172)

Since the UCTE mix has a greater share of fossil energy for the production of electricity, this mix causes more carbon dioxide emissions to the air. The Swiss electricity mix, with half of the electricity produced with hydropower causes remarkably less emissions in comparison with the UCTE mix.

j. Discounting

When performing a LCA study, it is not common to discount; the emissions and impacts are simply added up over time. This is the case for Eco+ and Eco-Bat. However, because the SuFiQuaD project monetises the environmental impacts, it seems logic to apply discounting. In economics, discounting means that future benefits and costs have a lower value. As can be concluded from table 24, the emissions of the building occur in different life phases and with different impacts in the time.

Time path of the emissions	Impacts on current generation		Impact on future generations
	Immediate	Delayed	
Current emissions (construction phase)	Crops, acute health, ecosystems	Chronic health, ecosystems	Global warming, resource depletion, ecosystems
Future emissions (use & renovation)	None	Immediate impacts (depending on the time path of emissions)	Global warming, resource depletion, ecosystems

Table 24 Different time paths of impacts ([12], p.20)

The monetising of the environmental impacts is based on the willingness to pay by the people. More information about this can be found in the Note on monetary valuation of environmental impacts [12]. Since it is assumed that the willingness to pay is bigger for immediate impacts, future impacts will be discounted to include this effect.
It is difficult to determine the discount rate. Different discount rates are used, depending on the context and the problem. In the SuFiQuaD project, it is assumed that the willingness to pay will not evolve importantly over the years. The discount and growth rates for environmental costs that will be applied in the SuFiQuaD project are:

Discount rate		1 or 3%
Growth rate	materials	0 or 0,5%
	energy	1%

2.5 Conclusion

This chapter discusses the different principles behind the software used in Switzerland en Belgium in order to calculate the net energy demand for space heating and the environmental impacts of a building.

Regarding the comparison of the EPB and Lesosai software, we can conclude that the general calculation method is very similar. The Belgian EPB-software uses a different formula for the ventilation heat losses and more simplified formulas for the heat transmission losses through the soil and for the internal heat gains, depending on only the volume of the building.
However, the biggest influence on the heat demand is the different indoor temperature. The design indoor temperature for a residential building is 20°C according to the SIA standards, whereas this is only 18°C in EPB. This will lead to a lower net energy demand according to the Belgian software. The SuFiQuaD project solves this issue by making the indoor temperature variable. The default value is also 18°C, but it is possible for the user to define the indoor temperature himself, or include the rebound effect, which will have an influence on the temperature as well.

The Swiss ecobalance software does not include the environmental impacts for maintenance and Eco+ even doesn’t include the transportation effects. When analysing the case study, the importance of neglecting these impacts will be estimated. As more and more construction materials are produced in other countries, the environmental impacts as calculated with Eco+ might be seriously underestimated by not including the transportation data.

Because the results of SuFiQuaD are monetary values and because of the different time paths of the emissions, discounting is applied. This is not the case for Eco+ and Eco-Bat. However, as the discount and growth rates are rather small, this will not have a great influence.
The most important difference is that the output of the Swiss ecobalance software consists of several impact categories, whereas SuFiQuaD is a single-indicator method. The advantage of the Swiss method is the possibility to see on which impact indicators a particular building element or material score best or worst. The results are free to be interpreted by the user himself. The Belgian method uses a weighting method in order to obtain the single indicator. This way, the results are already interpreted by the software. The importance of the different impacts is attributed by the researchers and contains some uncertainties. However, this way it is much easier to understand the output and necessary for the comparison of different buildings.

Generally, it can be noticed that the output of the Swiss and Belgian software is different. For Lesosai, Eco+ and Eco-Bat, the output is simply the net energy demand or the total environmental impacts for several impact indicators. The Belgian software takes this output to the next step by giving an interpretation to it. This makes the results easier to understand for the general public.
In the EPB-software, this is done by relating the annual primary energy consumption to the reference value for the annual primary energy consumption, which is the E-value. Because the concept of the K- and E-value is already well-known in Belgium, this output is quickly understandable.

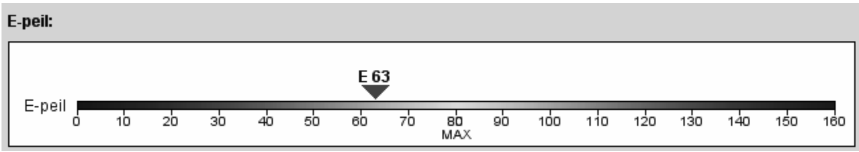

Figure 10 The E-value as output of the EPB-software

Lesosai 6.0 also gives an indication of the limit value for the calculation according to the SIA 380/1 standard, but this is less understandable for the public and is only an indication for the net energy demand for space heating.

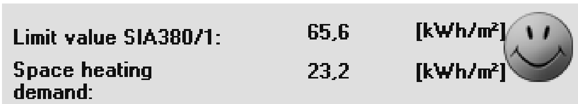

Figure 11 Output of the Lesosai software

The same argument can be applied for the ecobalance software. Whereas Eco+ and Eco-Bat give an elaborated overview of the different impacts for several impact indicators on building, element and material level, the SuFiQuaD project combines the impacts on building level. By monetising the environmental impacts, the results are immediately interpreted, which is easier for the user to understand and compare with other dwellings.
This different approach of the Swiss software in comparison with the SuFiQuaD project makes it difficult to compare the results of the two programs. In the further analysis of the case study, the Swiss and Belgian output will not be compared.

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Chapter 3: Analysis of ‘Maison Probst’

The analysis with the Belgian and Swiss software will be illustrated using one case study. This is a dwelling located in Saint Sulpice, a suburban area just next to Lausanne, Switzerland. This chapter gives an explanation of the construction and installations of the building. The different simplifications, necessary to define the building in the software, will be indicated. In a second part the first analyses with the different programs will be discussed. The plans, façades, cross sections and wall constructions of the dwelling are added in Appendix B and C.

3.1 Introduction to the dwelling

The case study that will be analysed with the Swiss and Belgian software, is a single-family house, located in Saint Sulpice, just outside of Lausanne. The dwelling is inhabited by two persons. A part of the building is designed as an office space, this is the practice of Mr. Probst. The architect of the building was Mrs. Maria Cristina Munari-Probst. The house was built in 2001 and was one of the first in the canton of Vaud to obtain the Minergie label. This is a Swiss quality label for low energy buildings.

Figure 12 Location and facades of Maison Probst

The architect paid attention to the energetic aspects by designing a very compact volume. The house consists of a ground floor with kitchen, living room, two small bathrooms and an office. There is a cellar under the whole building. The first floor contains two bedrooms, a larger bathroom, another office space and a mezzanine. The two floors are connected by an

open space. It is possible to extend the floor and close this open space, thus increasing the living area of the dwelling. This way, it is also possible to divide the dwelling into two separate apartments. Because of this flexibility in the building design, the life span should be increased.
The construction site allowed an optimal orientation of the building, with large windows facing south in the direction of the garden and a rather closed façade facing north. The 80 m² of windows facing south maximise the passive solar gains in winter, thus reducing the space heating demand.

3.1.1 Materials

The materials used for the building are mostly concrete, glass and wood. In the walls and roof construction, there is fifteen to twenty centimetres of insulation, mostly mineral wool, to minimise the transmission losses. The use of concrete for the structural walls gives a large thermal inertia to the building. This limits the risk of overheating.
The engineering office Sorane SA, specialised in energy efficient design, paid special attention to the construction details, in order to avoid thermal bridges. The peripheral insulation goes one meter into the ground against the cellar wall, thus minimising the linear thermal bridge to the soil.
By making the whole south wall and parts of the east and west wall glazed surfaces, the house is designed to maximise the solar gains. In order to limit the risk of overheating in summer, the dwelling is also equipped with exterior sunshades for most of the windows. The windows facing north have aluminium Venetian blinds and the windows in the direction of east, south and west have roller blinds as sun shades. Because of the large glazed surface in the south direction, a screen of green plants in summer and the horizontal overhang of the photovoltaic panels form an extra filter for solar radiation.

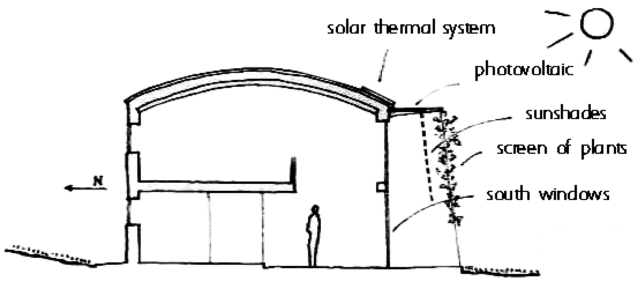

Figure 13 Cross section of the dwelling by Maria Cristina Munari-Probst

3.1.2 Installation list

This is a short description of the technical installations of the dwelling. The monthly energy consumptions for the building services are registered by the inhabitants. The data for 2006 are shown in detail in Appendix D.

Heating

Condensing boiler on natural gas, efficiency of 107%, 12 – 25 kW

On ground level: floor heating, on first floor: four radiators

Annual consumption of gas: 6359 kWh/year or 22892 MJ/year (for 2006)

Domestic hot water

40%: condensing boiler on natural gas

60%: thermal solar collector, 3 systems of 2,18 m², orientation south, inclination 22°, glazed captors

Annual production of thermal solar collector: 1700 kWh/year (for 2006)

Annual consumption of gas: 1133 kWh/year or 4079 MJ/year (for 2006)

Cooling

Not present in the dwelling

Ventilation

System D, meaning mechanical intake of the fresh air and mechanical exhaust of the used air

Heat recovery is applied

Intake in living room and bedrooms, exhaust in bathrooms and kitchen

Two possibilities: low speed (150 – 180 m³/h, 100W) and high speed (250 m³/h, 157W)

Specific fan power: 0,314 W/(m³/h) for inlet and outlet ventilator

Heat exchanger with theoretical efficiency of 92%

Electricity

60%: Swiss electricity mix

40%: photovoltaic panels, 12 systems of 1,266m² cells, monocrystalline silicon, freestanding with central converter, orientation south, inclination 0°

Annual photovoltaic production: 1697 kWh/year or 6109 MJ/year (for 2006)

Annual consumption current night/weekend: 1374 kWh/year or 4946 MJ/year (for 2006)

Annual consumption current day/week: 1181 kWh/year 4252 MJ/year (for 2006)

3.1.3 Simplifications

In order to make sure that the same assumptions for the materials can be introduced in the Lesosai/Eco+, Eco-Bat, EPB and SuFiQuaD software, some materials and thicknesses had to be adapted. The resulting constructions for the envelope elements can be found in Appendix C.

The non-loadbearing interior walls of the dwelling are in reality constructed with massive plaster elements. Since this is not a common practice in Belgium, it is not possible to select this in the SuFiQuaD project. This has been modified to sand-lime brick, keeping the same thickness of 9 cm.
The roof is slightly curved. This has been simplified to an inclined roof, one part facing north and one part facing south, with an average inclination angle of 12°.
The simplification with the biggest influence on the impact of the materials is the omission of the cellar. The implementation of a cellar in SuFiQuaD is not yet finalised, so in order to simplify the input of the building, the cellar is neglected. The perimeter insulation around the cellar is neglected as well.
The choice of window frames and glazing is often limited in the different programs. This leads to a different input. An overview of the choices in the different software is shown in table 25. The U- and g-values are only important in the Eco+ and SuFiQuaD software, because of the calculation of the transmission losses.

	Lesosai/Eco+	Eco-Bat	SuFiQuaD
Window frame	Wooden frame, 70mm	Wooden frame	Meranti frame, standard
	U_f = 1,65 W/m²K		U_f = 1,8 W/m²K
Window glazing	Triple glazing with Krypton	3-IV-IR glazing	Triple glazing with Krypton
	U_g = 0,6 W/m²K, g = 0,6		U_g = 0,6 W/m²K, g = 0,6
	Ψ_g = 0,03W/mK		Ψ_g = 0,03W/mK

Table 25 Window frames and glazing as defined in the ecobalance software

The stairs are neglected because it is not yet possible to define these elements in SuFiQuaD and it is rather difficult to do this in the Swiss ecobalance software. Because stairs are responsible for a small part of the environmental impacts, this assumption is sufficient.
An office, specialised in energy efficient buildings, paid special attention to the construction details, regarding thermal bridges. As the influence of the thermal bridges is assumed to be very small, they are neglected as well.

3.2 Results with the different software

3.2.1 Lesosai

This paragraph shows the first analysis of the building with the Swiss Lesosai software, according to the European CEN standards and for the Swiss climate of Lausanne. The climate data are extracted from the SIA 381/2 standard. In chapter 4, the standards and the climate will be altered in order to analyse the influence of these parameters. A summary of the specific hypotheses in Lesosai:

General data:	
Indoor temperature:	18°C
Thermal capacity:	500 kJ/m²K
Number of persons:	2 persons
Mean heat release per person:	70 W/person
Annual electricity consumption:	58,0 MJ/m² (actual consumption of the inhabitants for 2006)
Supply air flow rate, ventilation:	250 m³/h
Exhaust air flow rate, ventilation:	250 m³/h
Heat recovery efficiency:	80%
Fresh air flow rate:	fixed, 0,87 m³/(h.m²)
Wind exposure for infiltration:	'mean' (e = 0,07; f = 15)
Air tightness:	'high' (V_x = 141,5 m³/h; n_{50} = 3 (1/h))
Gross floor surface area:	263,6 m²
Energy related floor surface area:	286,3 m² (as defined in the List of Definitions)

Envelope elements:	
Roof facing North/South:	U = 0,159 W/m²K
Wall North:	U = 0,262 W/m²K
Wall East:	U = 0,209 W/m²K
Wall South:	U = 0,158 W/m²K
Wall West:	U = 0,209 W/m²K
Floor in contact with ground:	U = 0,388 W/m²K without reduction factor
	U = 0,241 W/m²K with reduction factor

With these parameters is the net energy demand for the building 14,0 kWh/m².year or 50,5 MJ/m².year. The Sankey diagram as illustrated in figure 14 shows the flows of the heat losses and gains.

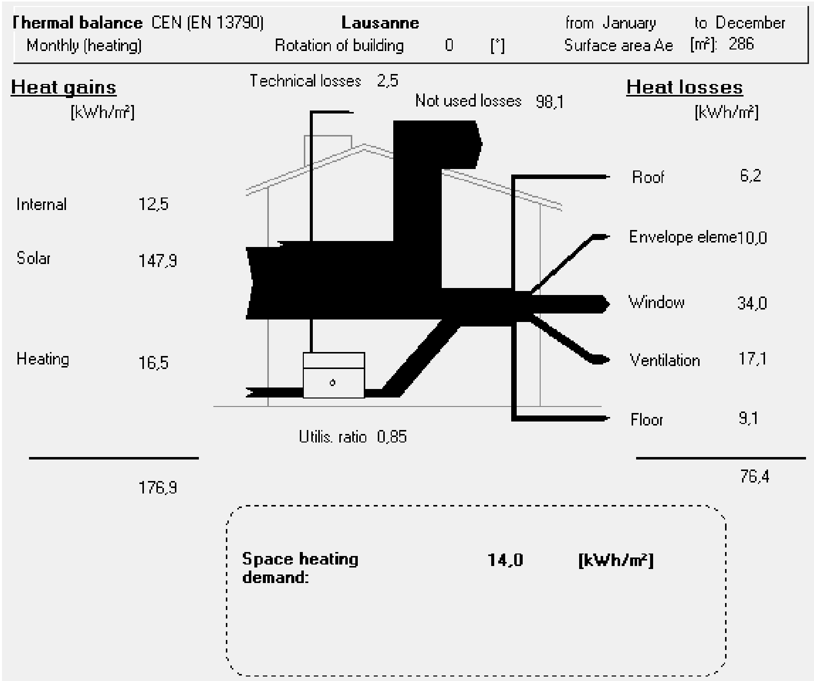

Figure 14 Result of the analysis with Lesosai: Sankey diagram [kWh/m²]

As can be seen on the diagram, the biggest heat losses for transmission occur through the windows. The solar gains are very high, but an important part is not useful and will be kept out of the building by the use of sun shades.

3.2.2 Eco+

Lesosai with the Eco+-module generates a different output. This analysis is executed for the dwelling in the Swiss climate of Lausanne and according to the Swiss SIA 2031 standards. Most of the hypotheses are equal to the calculation with Lesosai. However, in some cases the default values from the SIA standards will be implemented by the software. Some extra input is asked for as well. This is a summary of the values that are different or supplementary in comparison with the Lesosai software.

General data:

Building lifetime:	120 years
Excavation volume:	172 m³
Indoor temperature:	20°C (SIA default value)
Number of persons:	4,39 (SIA default value)
Annual electricity consumption:	80 MJ/m² (SIA default value)

Construction elements:

Floor in contact with ground: U = 0,394 W/m²K without reduction factor

U = 0,243 W/m²K with reduction factor

In order to calculate the environmental impacts of the building elements which are not in contact with the outdoor environment, the internal floor, the internal walls of 15 and 18 cm concrete, the internal walls of 9 cm sand brick, the interior doors, the steel columns, the concrete beam and the foundations were added.

HVAC:

Heating: natural gas, efficiency 95% (default value)

Domestic hot water: natural gas, efficiency 92% (default value)

Specific fan power inlet ventilator: 0,314 W/(m³/h)

Specific fan power outlet ventilator: 0,314 W/(m³/h)

Wind exposure for infiltration: 'mean' (e = 0,02)

Air tightness: 'high' (n_{50} = 2 (1/h))

For these parameters is the net energy demand for space heating 14,8 kWh/m².year or 53,4 MJ/m².year. This is slightly higher than the Lesosai value, because a different Swiss standard was used. The result of the life cycle analysis on building level for a life span of 120 years is shown in figure 15.

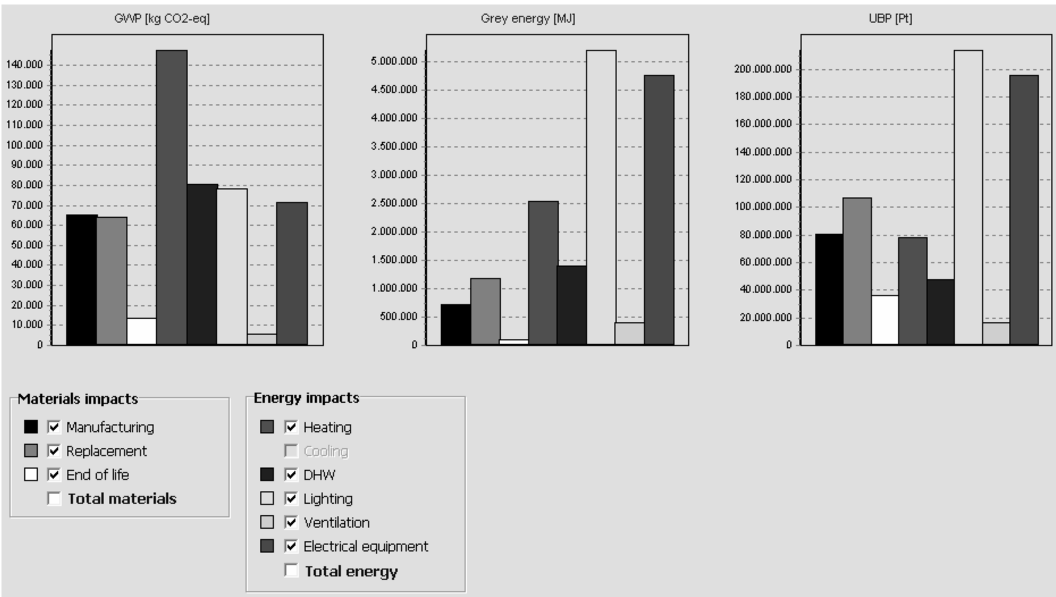

Figure 15 Life cycle analysis with Eco+, impacts for a life span of 120 years

The impacts are shown for three impact indicators GWP, Grey Energy and UBP, as defined in the List of Definitions. The most important factor for the GWP is the consumption of natural gas for heating, whereas for Grey Energy and UBP the impacts of the electricity consumption for lighting and electrical equipment are bigger.

For the three indicators, the values are much more important for the energy consumption during the use phase than the production and end-of-life treatment of the building materials.

3.2.3 Eco-Bat

The Eco-Bat software does not perform an energy calculation, but calculates the environmental impacts using the energy consumptions as defined by the user. For this analysis, the consumptions are introduced as registered by the inhabitants. The data of the year 2006 are used (see Appendix D). The electricity consumption includes the total of the electricity for lighting, ventilation and electrical equipment. This total amount was divided over the three categories in accordance with the percentages as calculated in Lesosai.

Heating:	6359 kWh/year (22892 MJ/year)	(gas)
Domestic hot water:	2833 kWh/year (10199 MJ/year)	(gas + thermal solar collector)
Lighting:	2134 kWh/year (7682 MJ/year)	(low voltage UCTE + photovoltaic)
Ventilation:	166 kWh/year (598 MJ/year)	(low voltage UCTE + photovoltaic)
Electrical equipment:	1952 kWh/year (7027 MJ/year)	(low voltage UCTE + photovoltaic)

The different envelope elements are defined in the software with their construction and area. The results of the environmental impacts for the life cycle of the building are shown in figure 16.

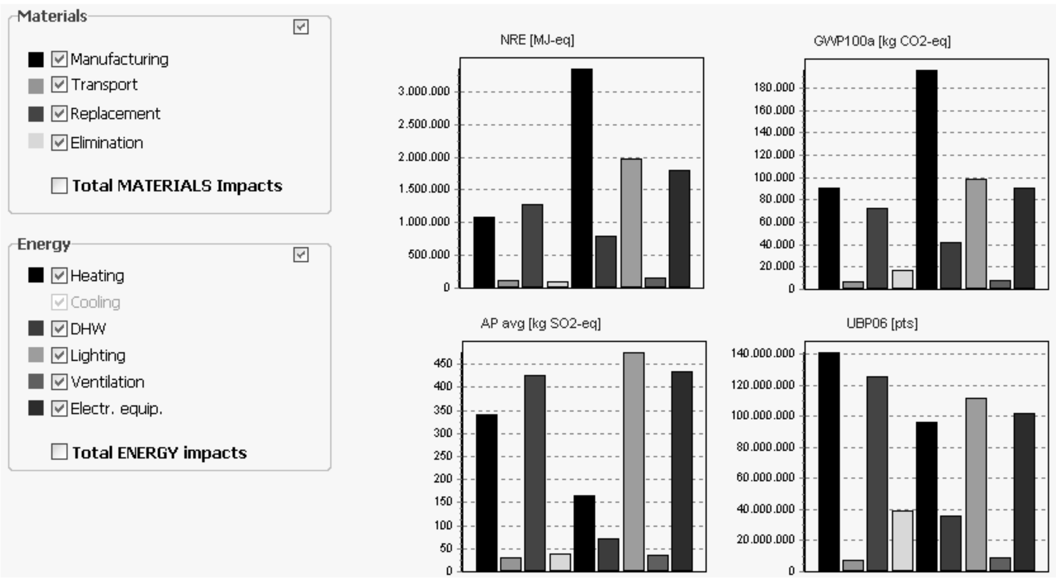

Figure 16 Life cycle analysis with Eco-Bat, impacts for a life span of 120 years

For Non Renewable Energy and Global Warming Potential, heating is the dominating factor, whereas for Acidification Potential the lighting and electrical equipment represent the biggest share. Regarding the endpoint indicator UBP (Umwelt Belastungs Punkte), the production and replacement of the building materials are the most important part. The impacts of the energy consumption during use phase are bigger than the impacts of the building materials, but for UBP, the difference is small, as illustrated in figure 17.

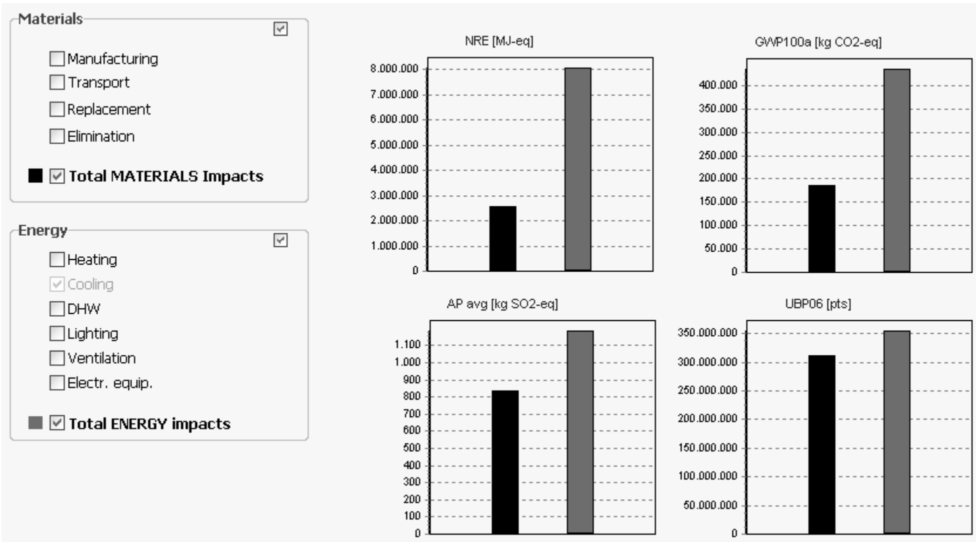

Figure 17 Life cycle analysis for materials and energy with Eco-Bat for a life span of 120 years

3.2.4 EPB

The Belgian EPB-software calculates the primary energy consumption for heating, cooling, auxiliary energy and domestic hot water. The K- and E-value are determined. The calculation parameters for the case study are summarised below.

General data:

Indoor temperature:	18°C
Type of construction:	middle heavy
Gross floor surface area:	260,4 m²
Volume:	841,8 m³
Efficiency of condensing boiler:	107%
Efficiency of the heating system:	0,85
Efficiency of the system for DHW:	0,45
Supply air flow rate, ventilation:	425,8 m³/h
Exhaust air flow rate, ventilation:	350 m³/h
Flow rate of the leakage:	0,6 m³/(h.m²)

Reduction factor heat recovery: 0,35

Multiplication factor m: 1,24

Power of the ventilators: 157 W

Envelope elements:

Roof facing North/South: U = 0,19 W/m²K

Wall North: U = 0,28 W/m²K

Wall East: U = 0,24 W/m²K

Wall South: U = 0,17 W/m²K

Wall West: U = 0,24 W/m²K

Floor in contact with ground: U = 0,356 W/m²K without reduction factor

U = 0,26 W/m²K with reduction factor

The solar gains are calculated with the detailed method. First of all, the vertical, left and right overhang angles were defined. For the windows in the North façade, external solar shading with a manual operation type, parallel to the window surface were defined. The East, South and West façade are equipped with automatic external solar shadings. The south wall also has a fixed solar shading, not parallel to the window surface.

The results of the analysis of the case study with EPB are an E-value of 62 while the Flemish standard is E80 since January 1st 2010. The K-value is 35, relative to the standard of 45. The detailed calculation method for the K- and E-value are described in Appendix H.

De eerste 12 kolommen in de tabel geven per maand het primair energieverbruik voor elk van de verbruiksposten. De twee volgende kolommen tonen het jaarlijks primair energieverbruik voor elke verbruikspost en het aandeel van elke post t.o.v. het totaal jaarlijks primair energieverbruik.

	jan [MJ]	feb [MJ]	mar [MJ]	apr [MJ]	mei [MJ]	jun [MJ]	jul [MJ]	aug [MJ]	sep [MJ]	okt [MJ]	nov [MJ]	dec [MJ]	totaal [MJ]	aandeel [-]
Ep,verwarming	3986	791	66	0	0	0	0	0	0	0	778	4973	10595	0,09
Ep,koeling	10	127	1137	4936	10929	13055	14310	14877	10396	3180	87	4	73048	0,64
Ep,hulpenergie	2476	1233	1075	1017	1051	1017	1051	1051	1017	1051	1295	2829	16166	0,14
Ep,tapwater	1901	1482	1302	858	537	434	539	674	951	1439	1750	1967	13834	0,12
Ep,PV	247	440	851	1287	1767	1845	1794	1581	1130	673	310	190	12116	-0,11
Ep,WKK														

Karakteristiek jaarlijks primair energieverbruik volgens de conventionele methode:	**101527**	**[MJ]**
Referentiewaarde voor het karakteristiek jaarlijks primair energieverbruik:	**164174**	**[MJ]**
E-peil:	**62**	**[-]**
Maximaal E-peil:	**80**	**[-]**

Figure 18 Result of analysis with EPB

The primary energy consumption for cooling represents the biggest share of the total primary energy consumption. According to the EPB-software, the dwelling will suffer from overheating in summer and a cooling installation will be necessary in order to control the temperatures in summer. This doesn't correspond with the reality as there is no cooling installation present in the building. Because the building is equipped with sun shades for almost all windows and has a high inertia due to the concrete construction, the building can control the temperatures in summer.

3.2.5 SuFiQuaD

Finally, the case study is analysed with the Belgian SuFiQuaD software. The parameters applied for the dwelling are listed below.

General data:

Life span building:	120 years
Equivalent degree days:	1200 Kd (necessary for the energy calculation on element level)
Protected volume:	817,12 m²
Indoor temperature:	18 °C
Air tightness:	0,6 number of air change volumes/hour
Ventilation installation:	mechanical intake and exhaust with heat recovery, direct current
Power of the ventilators:	157 W
Furnace type:	condensing boiler on natural gas
n30% (T30%):	107% (30°C)
Emission system specific:	radiator/convector
Emission system:	low temperature system
Electricity consumption:	15307 MJ/year (actual consumption as registered by the inhabitants)

Envelope elements:

Roof facing North/South:	U = 0,19 W/m²K
Wall North:	U = 0,24 W/m²K
Wall East:	U = 0,21 W/m²K
Wall South:	U = 0,16 W/m²K
Wall West:	U = 0,21 W/m²K
Floor in contact with ground:	U = 0,35 W/m²K without reduction factor
	U = 0,26 W/m²K with reduction factor

In order to calculate the environmental impacts of the building elements which are not in contact with the outdoor environment, the internal floor, the internal walls of 15 and 18 cm concrete, the internal walls of 9 cm sand brick, the interior doors and the foundations were added.

The solar gains are calculated with the detailed method, as described in Appendix A. First of all, the vertical, left and right overhang angles were defined. For the windows in the North façade, external solar shading with a manual operation type, parallel to the window surface were defined. The East, South and West façade are equipped with automatic external solar shadings. The south wall also has a fixed solar shading, not parallel to the window surface.

The output of SuFiQuaD is rather elaborated. The K-value and E-value according to SuFiQuaD are respectively K29 and E57, so slightly lower than the EPB values. The output related to environmental impacts is monetised and added to the financial costs. The unit is euro/m²floor net. The explanation for the different values is enlisted here.

IF	initial financial costs for materials and labour
IE	initial environmental costs for production, transportation to the building site and the construction phase
IT	total initial costs (financial + environmental)
PF	periodical financial costs for cleaning, small and big maintenance and replacement
PE	periodical environmental costs for cleaning, small and big maintenance and replacement
PT	total periodical costs (financial + environmental)
LF(excl.heating)	sum of the initial + periodical + EOL financial costs
LE(excl.heating)	sum of the initial + periodical + EOL environmental costs
LT(excl.heating)	total life cycle costs (financial + environmental)
LF(incl.heating)	sum of LF (excl.heating) and the financial costs for space heating, hot water, electricity heating and electricity ventilation
LE(incl.heating)	sum of LE (excl.heating) and the environmental costs for space heating, hot water and electricity ventilation
LT(incl.heating)	total life cycle costs (financial + environmental), including space heating, hot water, electricity heating and electricity ventilation
LF(incl.heating+elec)	the sum of the LF (incl.heating) and the electricity demand of the dwelling, minus the production of electricity of the photovoltaic panels
LE(incl.heating+elec)	the sum of the LE (incl.heating) and the electricity demand of the dwelling, minus the production of electricity of the photovoltaic panels
LT(incl.heating+elec)	total life cycle costs (financial + environmental), including the electricity demand, minus the production of electricity of the photovoltaic panels

As can be seen in figure 19, the monetary value of the environmental impacts is much lower than the financial costs of the building. The environmental costs represent less than 10% of the total costs. For the financial and the total costs, the initial value represents a rather small share: respectively 25,3% and 27% when compared to the life cycle costs without heating and 22,6% and 23,7% when the costs are compared to the life cycle costs including heating and electricity.

The financial and total costs of the materials are much bigger compared to the financial and total costs for the space heating demand, domestic hot water and electricity. However, for the environmental costs, the materials are only responsible for 55% of the life cycle cost including heating and electricity. This is comparable with the Eco-Bat software, who shows for the indicator Umwelt Belastungs Punkte a division of approximately 47% for the materials and 53% for the energy impacts (see paragraph 3.2.3).

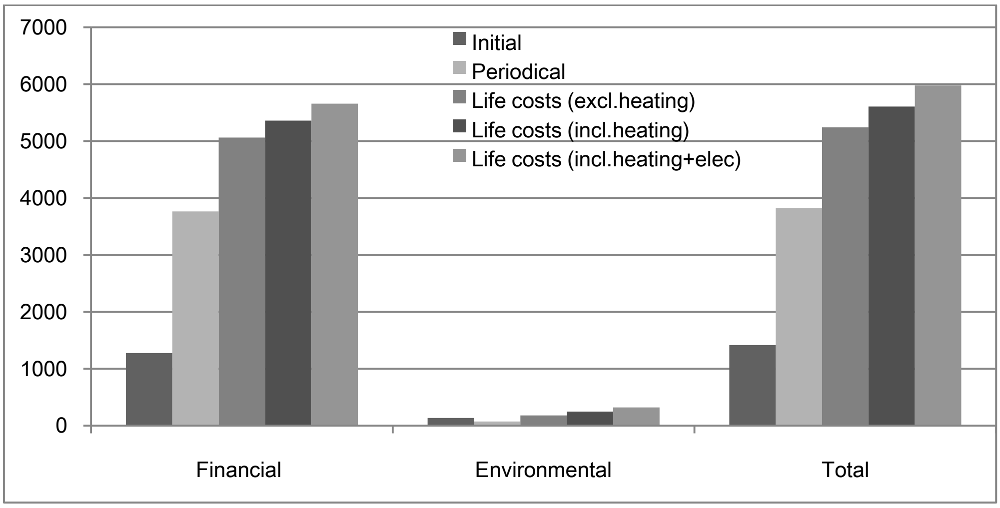

Figure 19 The financial, environmental and total costs in SuFiQuaD [€/m²fl net]

3.3 Conclusion

The Sankey diagram of the Lesosai software indicates that the most important heat losses occur through the windows, even though the U-value of the glazing and the frame are low. The only solution would be to decrease the window surface in the south wall, but this would also lead to a decrease of the solar heat gains and would not be in line with the architectural concept of the dwelling.

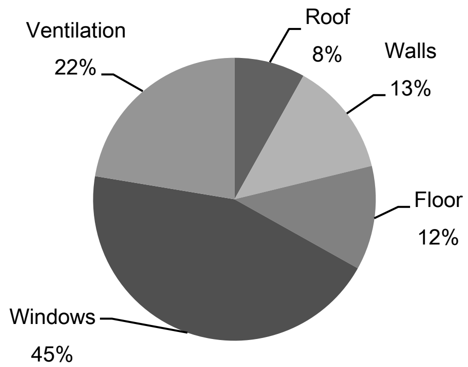

Table 26 Percentages of the different heat losses, according to Lesosai

Table 27 compares the U-values of the envelope elements as calculated with the different programs (the three first columns) to the limit values of the Swiss and Belgian standards (the last four columns). The U-values as calculated with the different programs vary slightly because they sometimes use different values for the thermal conductivity. For example, for the rock wool insulation in the Wall E/W, Lesosai and SuFiQuaD calculate with λ = 0,036 W/m.K and EPB with 0,041 W/m.K.

U [W/m²K]	Lesosai	EPB	SuFiQuaD	EPB[25]	PHP[26]	SIA[27]	Minergie[28]
Roof	0,16	0,19	0,19	0,30	0,15	0,20	0,15
Wall N	0,26	0,28	0,24	0,40	0,15	0,20	0,15
Wall E/W	0,21	0,24	0,21	0,40	0,15	0,20	0,15
Wall S	0,16	0,17	0,16	0,40	0,15	0,20	0,15
Floor	0,24	0,26	0,26	0,40	0,15	0,20	0,15

Table 27 Comparison of the U-values of the case study and the Swiss and Belgian standards

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[25] http://energiesparen.be/epb/tabeluwaarden

[26] http://www.passiefhuisplatform.be/index.php?col=-welkom&doc=passiefhuis&lng=nl

[27] SIA 380/1: 2009, L'énergie dans le bâtiment, SIA, Zürich

[28] Minergie, Le standard de construction Minergie -info pour les professionnels du bâtiment, publication to be consulted at http://www.minergie.ch/publications_minergie.html

First of all, it can be noticed that the U-values of this dwelling, who were in accordance with the Minergie standards when it was built in 2001, are too high for the updated Minergie standards. This is an indication of the fast evolution of the standards between 2001 and 2010. All the values correspond to the EPB-standards. The roof and the south wall are rather well insulated, the values satisfy the new SIA standards, but are still too high for the PHP and Minergie standard. The values for the north, east and west wall and the floor are even too high for the SIA standards.

A passive house as defined by the Belgian Passive House Platform (PHP) is “a specific construction standard for residential buildings with good comfort conditions during winter and summer, without traditional heating systems and without active cooling. Typically this includes very good insulation levels, very good air tightness of the building, whilst a good indoor air quality is guaranteed by a mechanical ventilation system with highly efficient heat recovery.”[29] This is realised by applying the six following steps.

- Reducing the heat losses by a high insulation level and reducing the effects of thermal bridges.
  As illustrated in table 27, the U-values of the roof, walls and floor are too high, so more insulation is needed to meet the PHP standards. Special attention was paid to minimise the effect of thermal bridges.
- Reducing the heat losses by extreme air tightness of the building.
  There has been no Blowerdoor measurement of the air tightness of the building. The inner part of the exterior walls is 15 cm of concrete, which has a good air tightness. However, there are no data about the leakage air flow at the connection with the windows. In the software is assumed that the building satisfies the n_{50} < 0,6 (1/h) requirement.
- Optimising the use of passive heat gains (solar and internal).
  The building is definitely designed to maximise the solar gains. Big window surfaces in the south-east, south and south-west direction make sure the building benefits of the passive solar energy. The solar energy transmittance (g-value) of the windows is 0,6, sufficient to allow a great part of the solar radiation to enter the dwelling. In order to limit the risk of overheating in summer, the windows have sun shades.
- A guaranteed air quality by a mechanical ventilation system with efficient heat recovery.
  The dwelling is equipped with a mechanical ventilation installation with heat recovery. The ventilation system D is applied, with mechanical intake and exhaust of the air.
- Low energy use by using efficient equipment.
  Energy efficient appliances are used to decrease the energy use as well.
- The use of renewable sources for the remaining energy demand.
  A thermal solar collector is responsible for 60% of the energy demand for domestic hot water. Photovoltaic panels provide 40% of the electricity consumption of the dwelling.

[29] http://www.passiefhuisplatform.be/index.php?col=-welkom&lng=en&doc=passiefhuis

The requirements a passive house has to satisfy according to the PHP are, since July 1st 2009:

- The air tightness n_{50} has to be lower than 0,6 (1/h).
  As mentioned before, there are no data to confirm this requirement.
- The frequency of an indoor temperature higher than 25°C has to be less than 5% of the time.
  Despite the big window surfaces facing south, the inertia of the building and the sun shades are sufficient to minimise the risk of overheating in summer
- The net energy demand for space heating and cooling is limited to 15 kWh/m².year or 54 MJ/m².
  The actual consumption of gas for space heating as registered by the inhabitants is 6359 kWh/year (22892 MJ/year). This is the end energy consumption for the space heating system of the entire dwelling. So in order to obtain the net energy demand, the efficiency of the heating system is estimated as 0,85, this is the efficiency as calculated in EPB. This leads to a net energy demand for space heating of 5405 kWh/year or 20,7 kWh/year.m² (74,5 MJ/year.m²). This is too high to meet the passive house standards.

Chapter 4: Comparison of the results with the different software

This chapter will use the case study, presented in chapter 3, to analyse the influence of different parameters and compare the output of the different software. Only one parameter at a time will be changed to be able to understand the results. Firstly, two parameters of the Lesosai software will be analysed. The difference between the Swiss SIA and the European CEN standard will be investigated and the climate data for Belgium and Switzerland will be compared. Then the output for the net energy demand with Lesosai and EPB will be evaluated. After this, the analysis switches to the ecobalance software. The difference between the results of the Eco+ and Eco-Bat software will be analysed. The effect of the building life span on the environmental impacts will be illustrated. Finally, some variants for the building envelope will be compared with Eco-Bat and SuFiQuaD.

4.1 Analysis in Lesosai

In the previous chapter, the analysis of the dwelling with Lesosai is described according to the European CEN standards and for the climate of Lausanne, Switzerland. Since there are some differences between the European CEN and the Swiss SIA standards and between the Swiss and Belgian climate, the influence of these parameters will be examined. The significant difference between the values for the net energy demand is illustrated in table 28. The energy demand is lower when calculated according to the CEN standard and for the Swiss climate.

	CEN	SIA
Swiss climate	14,0 kWh/m² (50,5 MJ/m²)	16,2 kWh/m² (58,4 MJ/m²)
Belgian climate	16,4 kWh/m² (59,2 MJ/m²)	20,2 kWh/m² (72,8 MJ/m²)

Table 28 Net energy demand, calculated with Lesosai

4.1.1 Comparison of the SIA and CEN standards

Figure 20 shows the output of the Sankey diagram for the CEN and SIA standards in the Swiss climate. The heat losses and the internal heat gains are higher for the calculation with the SIA standards. The solar heat gains are equal. Overall, this leads to a higher net energy demand for space heating for the calculation according to the SIA standards.

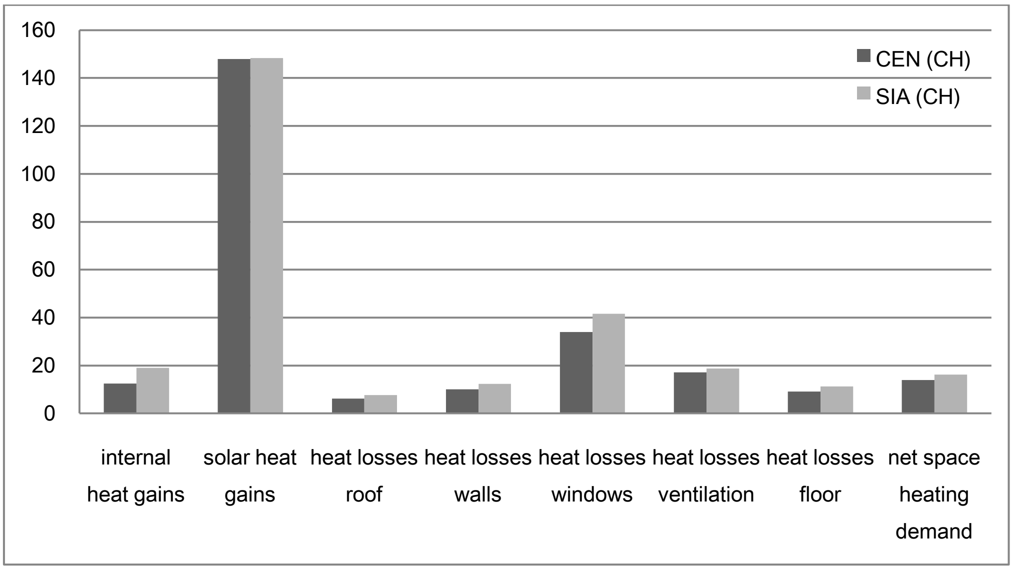

Figure 20 Analysis of the dwelling with Lesosai, according to SIA and CEN [kWh/m²]

The difference for the heat losses through the roof, walls and windows can be explained with the indoor temperature. SIA uses a fixed indoor temperature for single-family dwellings of 20°C. In the CEN standards was chosen for the value like in Belgium of 18°C for the indoor temperature. Since the heat losses through the roof, walls and windows only depend on the U-value and the indoor temperature, the difference for these values is explained with this difference in temperature.

The transmission losses through the floor are more complex. As explained in chapter 2, the SIA standards calculate with a correction factor b. For this specific situation, the correction factor b equals 0,67. This leads to an equivalent U-value of 0,264 W/m²K. The calculation according to the CEN standards is more complex. The result of this equation is an equivalent U-value of 0,237 W/m²K. Combined with the difference in indoor temperature, this leads to relatively higher heat losses according to the SIA standards.

The heat losses for ventilation are lower for the CEN calculation with an indoor temperature of 18°C, but slightly higher than SIA for an indoor temperature of 20°C. SIA calculates with a fixed value for the fresh air rate flow of 0,7 m³/(h.m²) whereas these values can be filled in more detailed for the CEN standard. For the analysed dwelling, this value is 0,87 m³/(h.m²). A higher fresh air flow rate will lead to higher ventilation losses as more fresh air has to be heated before it can be supplied to the building.

The internal gains are bigger for the SIA calculation because of two reasons. Firstly, when using the SIA standard, the number of persons is determined depending on the surface area. For the surface of the dwelling, SIA estimates 4,39 inhabitants. Since in reality there are only two inhabitants, the internal gains of the inhabitants are lower in CEN. For the internal gains of the electrical equipment, SIA also uses a fixed value for the electrical consumption of 80 MJ/m² for single-family dwellings. However, the actual consumption of the inhabitants is only 58 MJ/m², again leading to a lower value for internal heating according to the European standard.
The solar gains are equal for the CEN and SIA calculation. The SIA standards for the calculation of shading are not used in the Lesosai software because they are too pessimistic for the summer situation.
Overall, the supplementary internal gains of the SIA calculation do not compensate the higher transmission losses. This leads to a calculation of the net energy demand that is 15,7% higher than the calculation according to the CEN standards. Generally, it is assumed for the Central Swiss plateau that an indoor temperature difference of 1°C will cause a variation on the net energy demand of about 6%. In this case, the different indoor temperatures of 18°C and 20°C will be responsible for a variation on the results of 12%. The remaining 3,7% is only due to the difference in the standards. This is a very small difference.

4.1.2 Comparison of the Swiss and Belgian climate data

Figure 21 shows the difference for the heat gains and losses in the Swiss and Belgian climate, both calculated according to the CEN standards. The climate data used for the Swiss climate are obtained from the SIA 381/2 standard ([1], p.12). The Belgian climate data were found in the EPB documentation ([2], p.23).

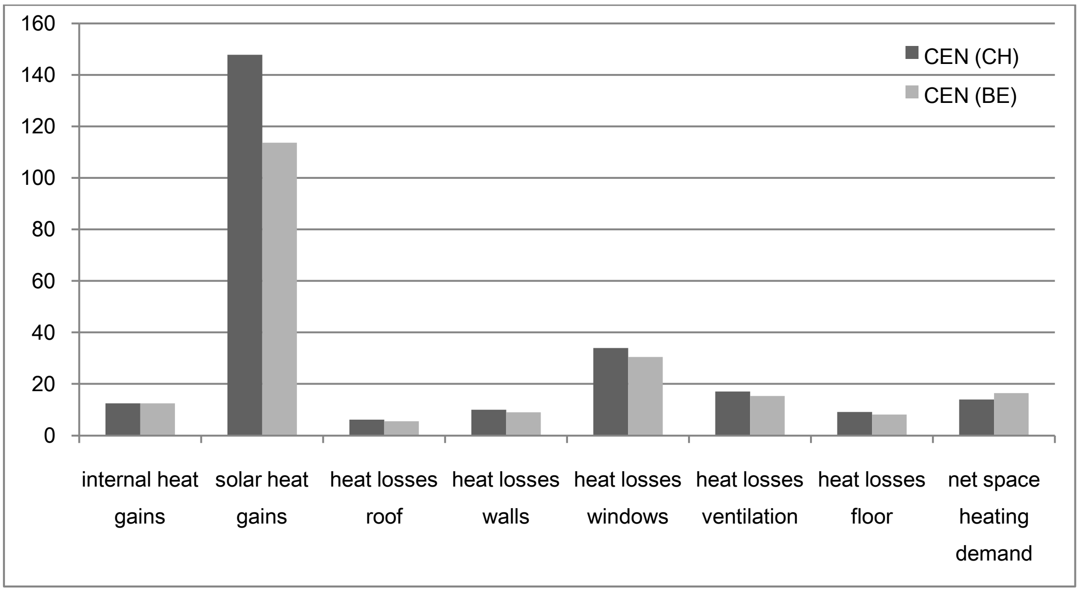

Figure 21 Analysis of the dwelling with Lesosai for the Swiss and Belgian climate [kWh/m²]

In Switzerland, the heat losses for transmission and ventilation are higher than in Belgium, but the solar gains are much more important as well. The internal heat gains are not influenced by the climate. This results in a net energy demand slightly higher for the Belgian climate.

The figures 22 and 23 give an indication of the climate difference for the monthly temperature and the monthly solar irradiation in Lausanne (CH) and Ukkel (BE). The Belgian climate is more tempered than the Swiss, leading to higher temperatures in winter and slightly lower temperatures in summer. The higher temperatures in winter are the reason for the lower transmission losses in Belgium.

The diagram of the monthly solar irradiation shows significant higher values for the Swiss climate. Even though a great part of the supplementary solar gains in the Swiss climate occur in summer and have no influence on the heating demand, the higher solar gains in the winter compensate the higher transmission losses. The result is a net energy demand of 14 kWh/m² in the Swiss climate and 16,4 kWh/m² in Belgium, an increase of 17%. On the other hand, because of the much higher solar gains in summer in Switzerland, the risk of overheating is much bigger.

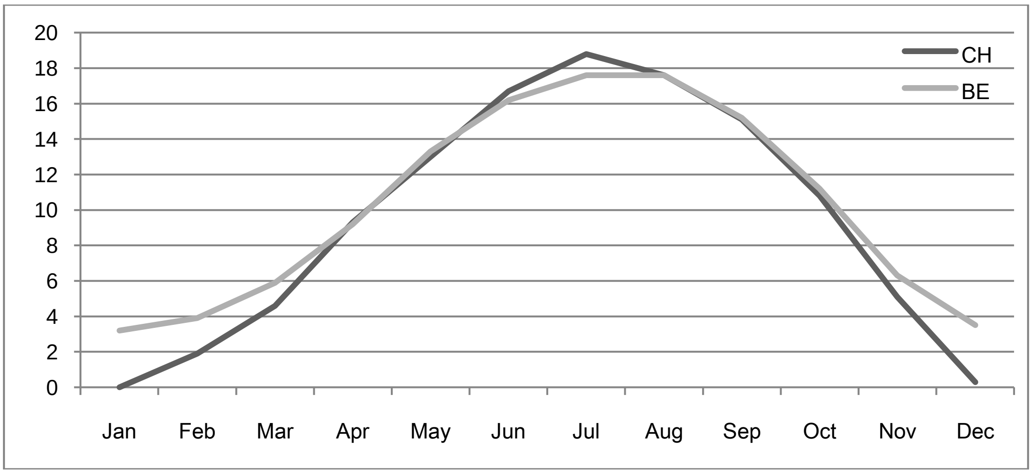

Figure 22 Belgian and Swiss climate: temperature [°C]

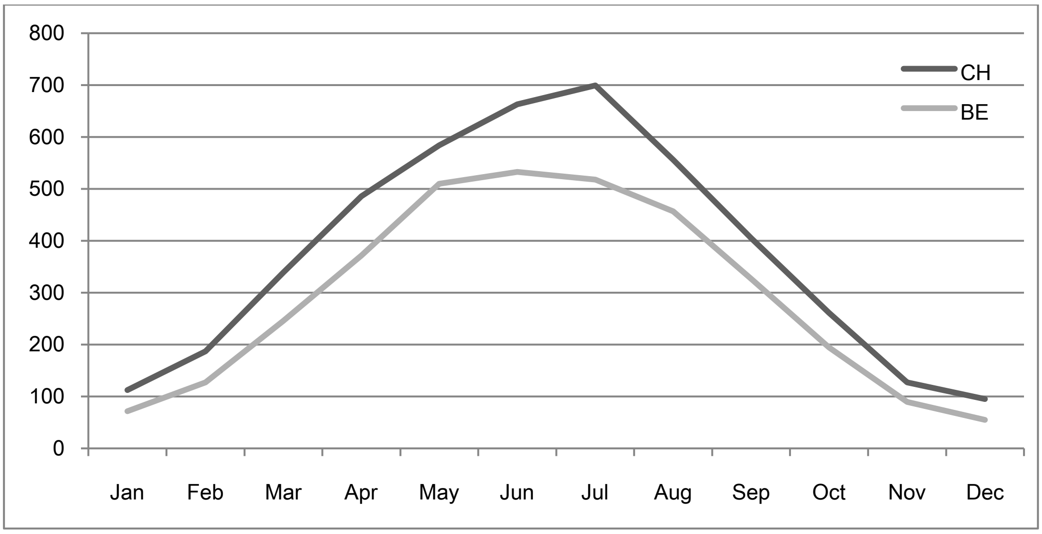

Figure 23 Belgian and Swiss climate: solar irradiation, received per 1 m² surface [MJ/m²]

4.2 Comparison of the results in Lesosai and EPB

As discussed in chapter 2, the Belgian EPB-software and the Swiss Lesosai program are based on the same European standards EN ISO 13790 and EN ISO 13789. The biggest differences of the calculation method are the formulas for the transmission losses through the soil, the ventilation heat losses and the internal heat gains.
This chapter compares the values for the heat losses and heat gains for the case study as calculated with Lesosai and EPB. The Lesosai calculation was performed according to the CEN standards for the Belgian climate of Ukkel. The same weather data are used, so this will have no influence on the results. Because the floor surface area as calculated in Lesosai differs from the surface as defined in EPB, the results are shown in kWh for the whole building instead of kWh/m².

Firstly, the transmission losses through the roof, walls, floor and windows are considered. The results are shown in figure 24. The transmission losses are slightly higher for the calculation according to EPB. This is probably the result of the different U-values as illustrated in the conclusion of chapter 3 in table 27. The U-values are a little higher for EPB in comparison with the Lesosai software. However, the difference is small.

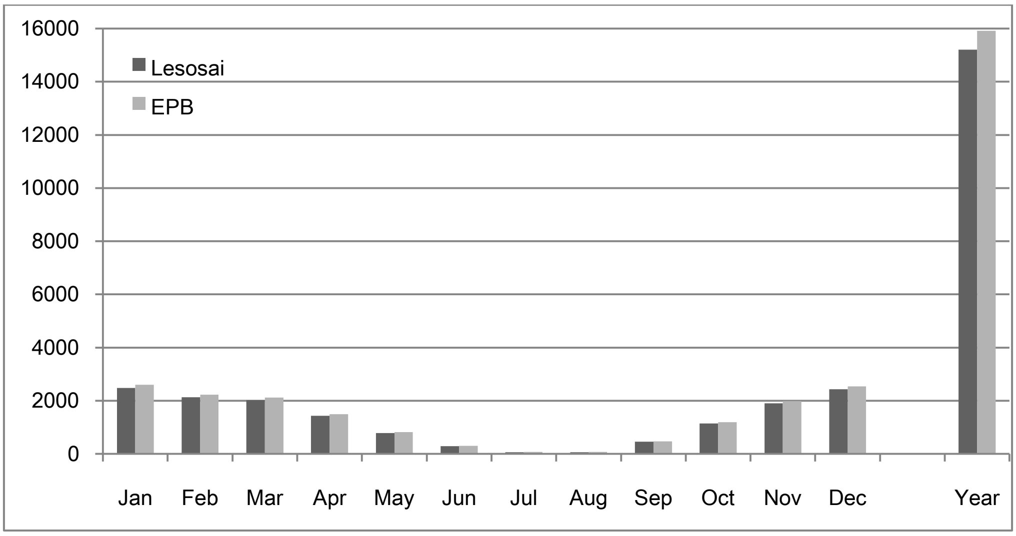

Figure 24 Monthly transmission losses as calculated with Lesosai and EPB [kWh]

In figure 25, the ventilation losses as calculated with the Swiss and Belgian software are shown. The different formulas lead to a significant difference. The heat loss caused by ventilation is much bigger when calculated with Lesosai. In EPB the number of air change volumes per hour is defined as 0,6 (1/h). In Lesosai, the most airtight option was chosen (Tightness: ‘High’), but this represents a number of air change volumes of 3 (1/h) for a pressure difference of 50 Pa. Indeed, if this parameter is changed in EPB to 3 (1/h), the ventilation losses are comparable.

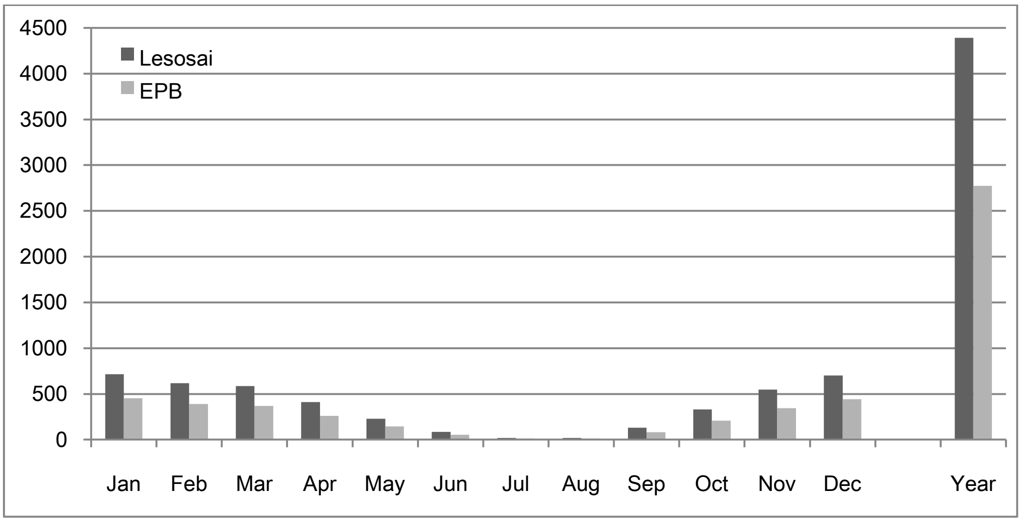

Figure 25 Monthly ventilation losses as calculated with Lesosai and EPB [kWh]

The internal heat gains also show a significant difference between the two programs. Figure 26 shows the internal gains multiplied with the utilisation factor.

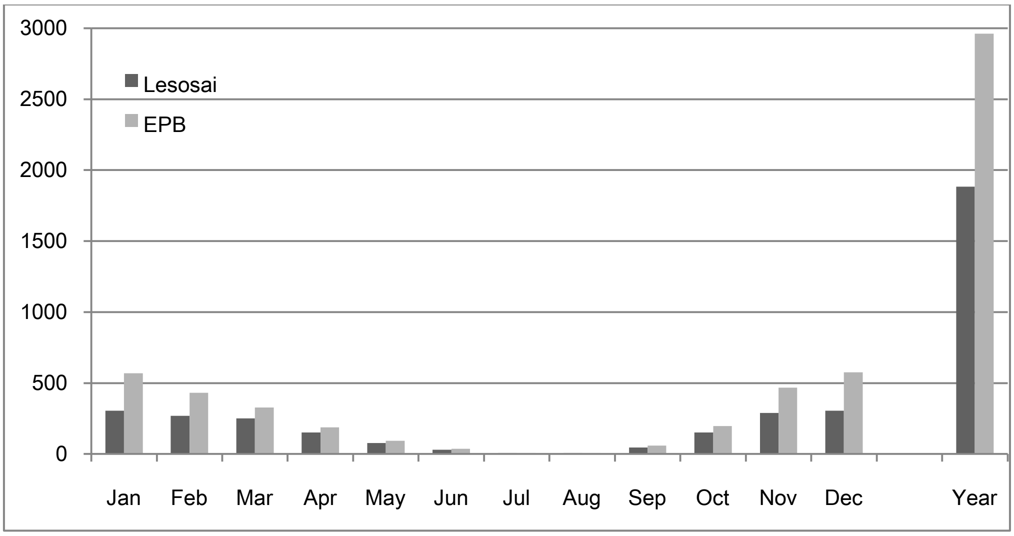

Figure 26 Monthly internal gains as calculated with Lesosai and EPB [kWh]

As explained in chapter 2, the Belgian software calculates the internal gains based on the volume of the building, whereas the Swiss software makes more detailed assumptions. In paragraph 4.1.1, the difference between the SIA and CEN calculation method for internal gains is illustrated. In this case, CEN was applied for two persons and an annual electricity consumption of 58 MJ/m². These values are rather low. Because the floor surface of the dwelling is big, EPB probably assumes more inhabitants and a higher electricity consumption, leading to higher internal gains.

Finally, the results for the solar heat gains are shown in figure 27. Only the useful part of the solar gains as determined with the utilisation factor is presented. The only difference in formulas is the supplementary reduction factor for pollution of 0,95 in the Belgian formula. This should lead to slightly lower solar gains for the EPB-software. For the months March to October, this is approximately right. However, for the months of the heating season, November to February, the solar gains are higher in EPB. The yearly solar gains are also bigger with the EPB calculation method. This might be explained by the implementation of the calculation in the EPB-software. When the researchers of the SuFiQuaD project analysed the solar gains as calculated with EPB and SuFiQuaD, a remarkable difference was noticed ([6], p.66-67). However, the difference with Lesosai is small, so this will not have a great influence on the space heating demand.

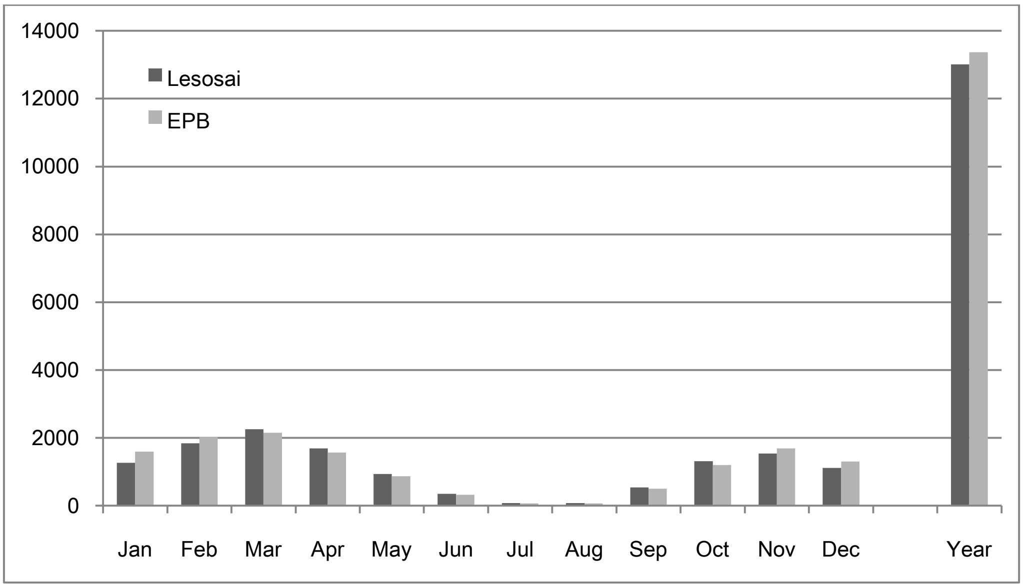

Figure 27 Monthly solar gains as calculated with Lesosai and EPB [kWh]

Based on the transmission and ventilation heat losses and internal and solar heat gains, the net energy demand for heating is determined. The monthly resulting heat demands are shown in figure 28. The net energy demand for space heating is 4708 kWh/year (16949 MJ/year) according to Lesosai and 2356 kWh/year (8482 MJ/year) for EPB, this only half of the Lesosai output. The higher ventilation losses and lower internal gains as calculated with Lesosai lead to this big difference.

When comparing with the actual situation, the ventilation losses are probably better estimated by the EPB software. As much attention was paid to the construction details, a high air tightness is assumed. This will lead to a lower net energy demand for the Lesosai calculation. On the other hand, the internal gains are overestimated in the EPB software. The more detailed calculation of the CEN standards in Lesosai is probably more realistic. Lower internal gains in EPB would lead to a higher space heating demand. In conclusion, the right estimate would be in between the Lesosai and EPB value.

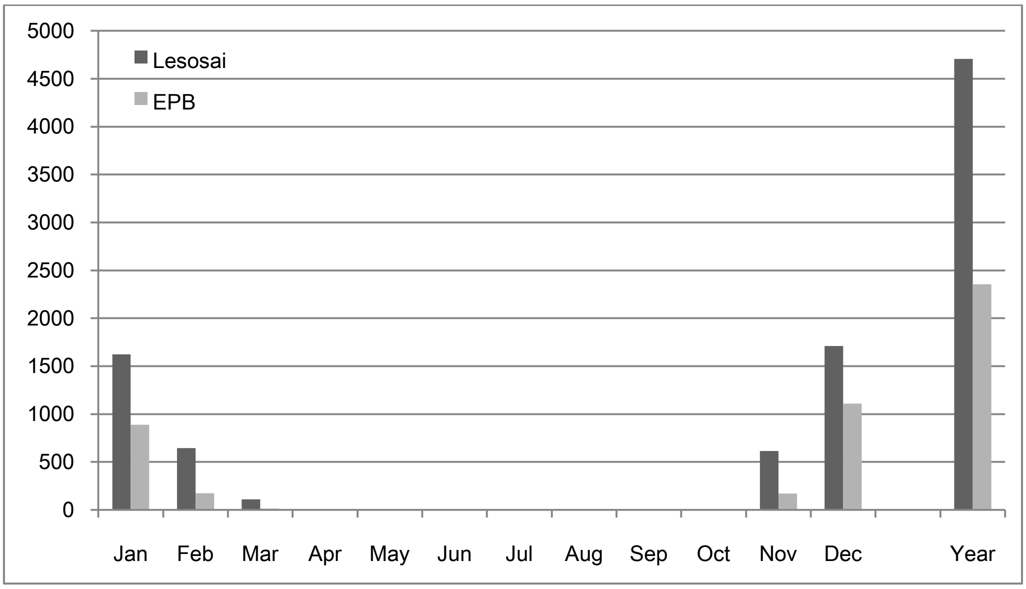

Figure 28 Monthly net energy demand as calculated with Lesosai and EPB [kWh]

4.3 Comparison of the results in Eco+ and Eco-Bat

In chapter 3, the dwelling has been analysed with the two Swiss ecobalance programs, Eco+ and Eco-Bat. This software has two impact indicators in common: Global Warming Potential and Umwelt Belastungs Punkte. Even though the Eco+ and Eco-Bat use similar databases and are in accordance with the same standards, we will encounter some differences in the results for the dwelling between Eco+ and Eco-Bat.

4.3.1 Comparison of the results for the materials

Firstly, the differences between the Eco+ and Eco-Bat software will be analysed for the materials. The life cycle phases that are considered are manufacturing, transportation, replacement and end-of-life treatment. A building life span of 120 years was applied. As can be seen in figure 29, the environmental impacts for manufacturing and replacement are lower in Eco+. Transportation is only considered in Eco-Bat, but represents a small part of the total impacts. The GWP and UBP for end-of-life treatment are similar in Eco+ and Eco-Bat. The total environmental impacts of the materials in Eco-Bat is about 31% higher for the GWP and 40% for the UBP.

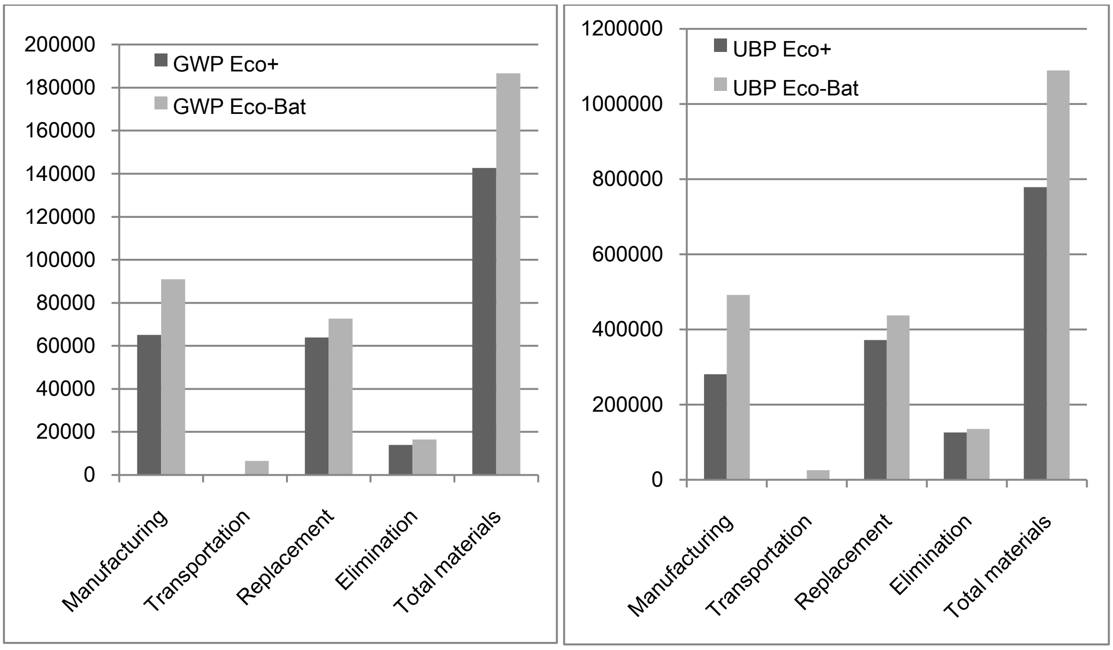

Figure 29 GWP [kg CO2-eq] and UBP [Ecopts/m²] of the materials with Eco+ and Eco-Bat

When looking at the detailed overview of the GWP and UBP of the materials in Appendix E, three materials show an important difference. The impact of reinforced concrete is bigger for Eco-Bat, the zinc-titanium sheet of the roof is not included in Eco+ and finally, even though the GWP of glazing is similar, the UBP is bigger in Eco+.

The reason for the bigger impact of **concrete** in Eco-Bat is illustrated with tables 29 and 30.

	KBOB 09 ([5], p.7)	Eco+	Eco-Bat
	concrete C30/37	reinforced concrete 1% steel	reinforced concrete (100kg/m³ steel)
manufacturing	0,110	0,110	0,169
transportation	0,000	0,000	0,009
replacement	0,000	0,000	0,000
end-of-life treatment	0,011	0,011	0,010
total	**0,120**	**0,121**	**0,188**

Table 29 GWP [kg CO2-eq] of 1 kg of concrete

	KBOB 09 ([5], p.7)	Eco+	Eco-Bat
	concrete C30/37	reinforced concrete, 1%steel	reinforced concrete (100kg/m³ steel)
manufacturing	90,8	91,8	199,5
transportation	0,0	0,0	9,7
replacement	0,0	0,0	0,0
end-of-life treatment	25,7	27,5	26,2
total	**116,0**	**119,3**	**235,4**

Table 30 UBP [Ecopoints] of 1 kg of concrete

The values of reinforced concrete in the Eco+ software are similar to the KBOB database record for concrete C30/37.[30] It is possible to select reinforced concrete in the Eco+ software, but since there is no record for it in the KBOB database, the data for concrete C30/37 are used for its environmental impacts. The Eco-Bat software does include the amount of steel, leading to almost double Ecopoints in comparison to Eco+. Because the whole loadbearing structure of the analysed dwelling is built with concrete, this difference has a large influence on the manufacturing impacts. This has no influence on the replacement, because the life span of concrete is 100 years, so no replacement will be needed. The values for end-of-life treatment are similar for regular and reinforced concrete so this will have no influence on the EOL impacts.

The **zinc-titanium sheet** is another reason why the impact for manufacturing is bigger in Eco-Bat. The LCA values for zinc-titanium are not available in the Eco+ software. This leads to a rather big underestimation, as illustrated in table 31.

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[30] There is a slight difference because the Eco+ uses the KBOB version of 2006, whereas in this table the values of KBOB 2009 are shown.

	GWP [kg CO2-eq]	UBP [Ecopoints]
manufacturing	5,3	32353,8
transportation	0,143	162,6
replacement	5,3	32353,8
end-of-life treatment	0,0	0,0
total	**10,74**	**64870,2**

Table 31 GWP and UBP of 1 kg of zinc-titanium sheet, calculated with Eco-Bat

In Eco-Bat, the zinc-titanium roof covering is responsible for 6,1% of the GWP and 22,1% of the UBP of the total material impacts, so this will have an important influence on both the manufacturing and replacement impacts. The life span of zinc-titanium is only 50 years, so one replacement of the roof covering will be executed for a building life span of 120 years. The impact of end-of-life treatment is zero because the zinc-titanium sheet is re-used or recycled.

Finally, the **glazing** of the windows shows a significant difference, but only for the UBP, as illustrated with the following table.

	KBOB 09 ([5], p.7)	Eco+	Eco-Bat
GWP [kg CO_2-eq]			
manufacturing	56,8	69,4	62,9
transportation	0,00	0	2,1
replacement	56,8	69,4	62,9
end-of-life treatment	2,49	0,101	5,4
total	**116,1**	**138,9**	**133,3**
UBP [Ecopoints]			
manufacturing	58300	123024	76238
transportation	0	0	2339
replacement	58300	123024	76238
end-of-life treatment	5400	1000	11893
total	**122000**	**247048**	**166708**

Table 32 Values for GWP and UBP of 1 m² of glazing

The windows as extracted from the KBOB database are 3-IV glazing. In Eco-Bat, a limited number of choices can be made for the windows. In this case was chosen for 3-IV-IR glazing. In Eco+, it is possible for the user to define the glazing type. The type of glazing as defined in the software corresponds with the data for 3-IV-IR glazing with Krypton. As can be deduced from table 32, the addition of the IR-coating and Krypton for the glazing leads to a small increase of the Global Warming Potential, but a big increase of the Umwelt Belastungs Punkte.
The impact of the replacement will be bigger than is suggested in table 32. Because the life span of the windows is only 30 years, for a building life span of 120 years, the windows will be replaced three times.

In general, for the manufacturing phase, the greater impacts of reinforced concrete and the additional zinc-titanium sheet in Eco-Bat lead to higher environmental impacts when compared to Eco+. For the replacement phase, only the windows and the zinc-titanium sheet matter. The supplementary impacts of the replacement of the zinc sheet in Eco-Bat will be partially compensated by the extra impacts of the three replacements of the windows. The transportation represents a small extra impact for the Eco-Bat software.

4.3.2 Comparison of the results for the energy consumption

In this paragraph, the differences between Eco+ and Eco-Bat for the energy use of the dwelling will be described. The energy consumptions are calculated in Eco+, whereas the values for the actual consumption were filled in in the Eco-Bat software. The Global Warming Potential and Umwelt Belastungs Punkte for energy consumption are shown in figure 30. The different categories are heating (with natural gas), domestic hot water (produced with a thermal solar collector and natural gas), lighting, ventilation and electrical equipment (electricity and photovoltaic panels). Heating is responsible for the highest GWP value, but for the single-point indicator UBP, the electricity shows the highest values.

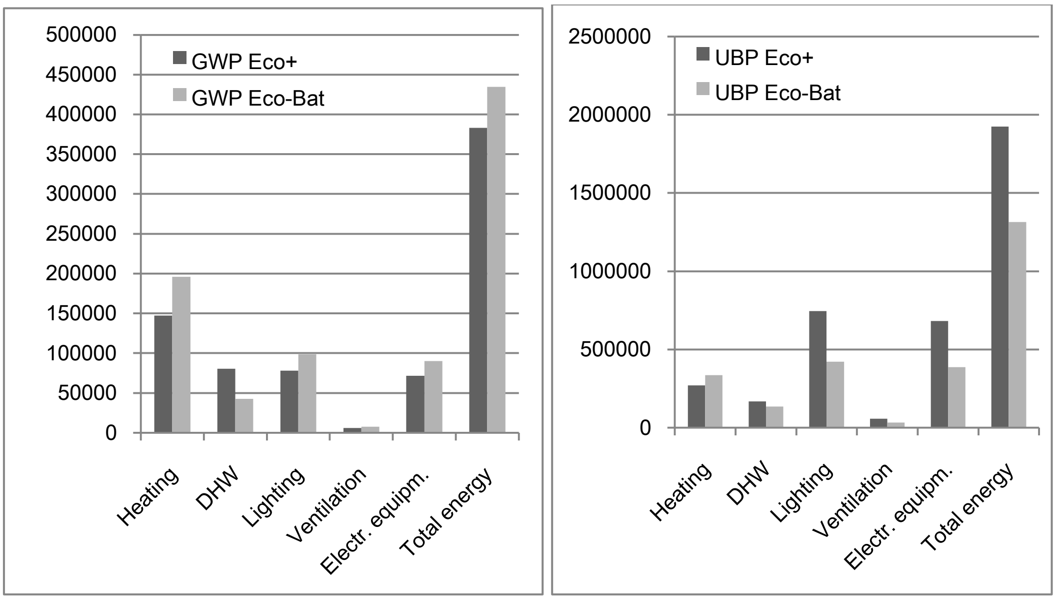

Figure 30 GWP [kg CO2-eq] and UBP [Ecopts/m²] of the energy with Eco+ and Eco-Bat

The values for **heating** are higher for Eco-Bat than for Eco+. The consumption of natural gas for heating as registered by the inhabitants is 6359 kWh/year (22892 MJ/year). The end energy consumption as calculated with Eco+, including the efficiency of the heating system, is 17 kWh/m².year or 4867 kWh/year (17521 MJ/year). The actual consumption is 30% higher than the calculated value, leading to bigger environmental impacts.

The production of **domestic hot water** (DWH) shows a significant difference for the GWP. The environmental impacts are bigger when calculated with Eco+. This is because Eco+ calculates with the values as defined in the SIA standards. The number of inhabitants is determined by the software, depending on the surface area of the dwelling. For a surface of about 260 m², Eco+ assumes there are 4,39 inhabitants, while in reality only two persons live in the dwelling. The production of DHW is calculated with the following formula ([3], p.118):

$$Q_{ec} = \rho \cdot c \cdot V_{ec} \cdot \left(\theta_{ec} - \theta_{ef}\right)$$

ρ: volumetric mass of water (1000 kg/m³)

c: thermal capacity of water (4180 J/(kg.K))

V_{ec}: consumed volume of water [m³]

θ_{ec}: temperature of warm water [K]

θ_{ef}: temperature of cold water [K]

The temperature difference between warm and cold water is considered as 50 K. The consumed volume of water is calculated as the number of inhabitants, multiplied by the annual consumption of water per person. In Switzerland, it is considered that an average person consumes 50 l/day for DHW ([3], p.124).

The consumption of DHW as calculated with Eco+ for 4,39 persons is 4552 kWh/year. The actual consumption as measured in the building is only 2822 kWh/year. On the other hand, if we apply the formula for two persons and 50 l/pers.day, the consumption would be 2119 kWh/year. The inhabitants consume 33% more DHW compared to the Swiss average.

An important part of the production of domestic hot water is realised with thermal solar collectors, as illustrated in table 33. According to the actual measurements and as introduced in Eco-Bat, the solar energy is responsible for 60% of the production of DHW. However, because the production of DHW is overestimated in Eco+, the solar energy represents a significant smaller part (41%).

	Eco+	Eco-Bat
Thermal solar collector	1884 kWh/year (6782 MJ/year)	1700 kWh/year (6120 MJ/year)
Natural gas	2668 kWh/year (9605 MJ/year)	1133 kWh/year (4079 MJ/year)

Table 33 Production of DHW with thermal solar collector and natural gas

Finally, the **electricity** consumption for lighting, ventilation and electrical equipment will be compared. As shown in figure 30, the GWP is bigger but the UBP is significantly lower in Eco-Bat. There are two reasons for this difference. Firstly, the Eco+ software only calculates with the Swiss electricity mix, whereas in the Eco-Bat software the UCTE mix was selected. Since these two mixes have different main production modes, the environmental impacts are different. The Swiss electricity mix mainly depends on hydropower and also on nuclear power, whereas the biggest share of the UCTE mix is produced with fossil power and also a smaller share with nuclear power. The values of the GWP and the UBP of the Swiss and UCTE mix are shown in table 34. The source is KBOB 2009 ([5], p.12).

	UCTE	Swiss consumption mix
GWP [kg CO2-eq]	0,165	0,0428
UBP [Ecopoints]	180	123

Table 34 GWP and UBP for UCTE and Swiss electricity mix

When the electricity mix in Eco-Bat is changed to the Swiss mix, the result is shown in the following figure. When comparing the environmental impacts for the dwelling with the Swiss mix, the values are significantly lower in Eco-Bat.

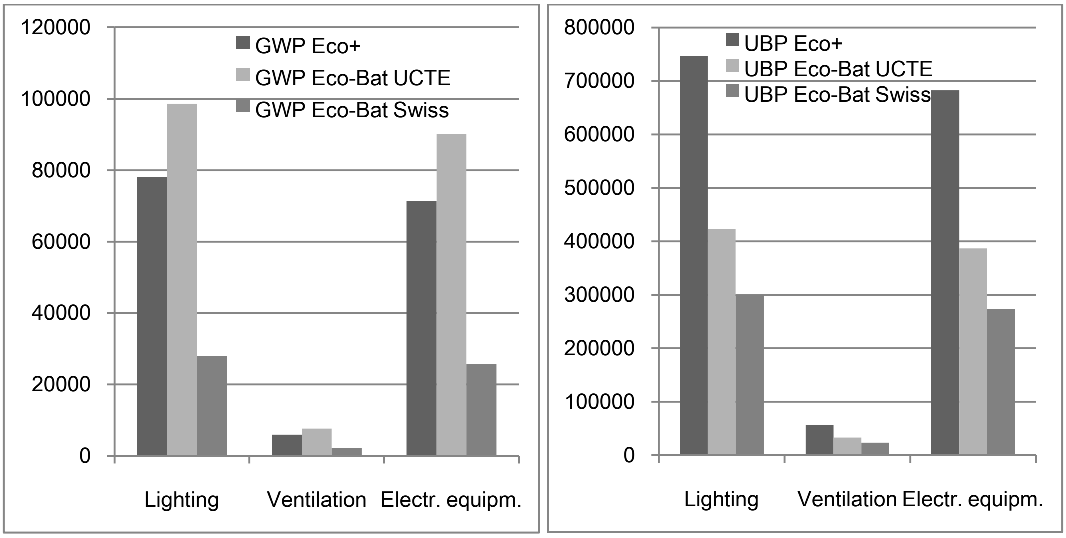

Figure 31 GWP and UBP for electricity in Eco+, Eco-Bat (UCTE mix) and Eco-Bat (Swiss mix)

To explain this difference, we must have a look at the actual electricity consumption and the electricity consumption as calculated with Eco+. Table 35 shows the share of the electricity consumption of the dwelling, produced with the photovoltaic panels and the share of the electricity consumption that depends on the supply of electricity from the energy provider.

	Eco+	Eco-Bat
Photovoltaic	1777 kWh/year (6397 MJ/year)	1697 kWh/year (6109 MJ/year)
Electricity mix	7871 kWh/year (28336 MJ/year)	2555 kWh/year (9198 MJ/year)
Total consumption	9648 kWh/year (34733 MJ/year)	4252 kWh/year (15307 MJ/year)

Table 35 Electricity consumption in Eco+ and Eco-Bat

The use of the electricity mix is three times lower for the actual consumption (Eco-Bat) in comparison with the consumption as calculated in Eco+. This is approximately the ratio as found in the graph. Apparently the electricity consumption is significantly overestimated in Eco+.

The SIA standards define the annual consumption of electricity for a single-family house as 80 MJ/m².year ([4], p.30). For this dwelling, that would mean 6362 kWh/year. If we compare this with the actual consumption (Eco-Bat), we see that the inhabitants succeed to decrease this value with 33% to only 4252 kWh/year. On the other hand, the more detailed calculation method in Eco+ overestimates the SIA value with 52%.

Overall, Eco+ calculates with a significant bigger electricity consumption, but this is partially compensated by the use of the Swiss electricity mix. The Eco-Bat software calculates with a much lower electricity consumption, but when the UCTE mix is used, the environmental impacts increase. This leads to the figures with a bigger impact for GWP and lower values for UBP in Eco-Bat.

4.4 Sensitivity analysis on the life span of the building

This paragraph illustrates the importance of the estimation of the building life span. This is very difficult, since many factors influence the building life span, making this a very uncertain value. Figure 32 shows the total environmental impacts for the building as calculated with Eco-Bat. The values are per m² of floor surface and per year.

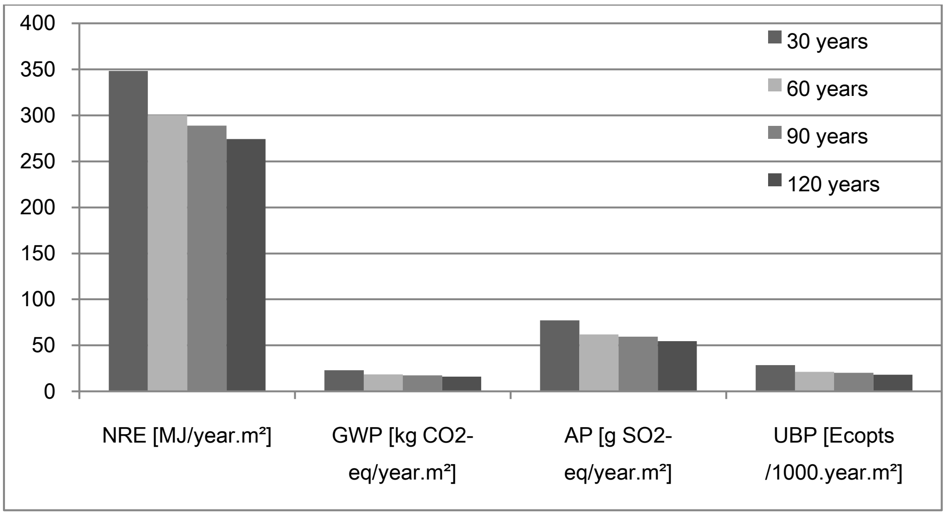

Figure 32 Sensitivity analysis of the building life span with Eco-Bat

The annual environmental impacts decrease for an increasing building life span. This shows that it is useful to take measures to increase the life span because, even with the supplementary environmental effects of the replacement materials and energy use, the annual environmental impacts will be lower if they can be spread over more years.
This way, the case study is a good example, because it has a flexible design. With some minor interventions, it can be made bigger or split into two apartments. Hopefully, this will increase the life span of the dwelling.

The Eco-Bat software allows the export of the impact time evolution graphs, as shown in figure 33. The initial and periodical impacts can be compared. For a building life span of 120 years, the final impacts for the materials are almost double as much as the initial effects. The energy consumption increases linearly.

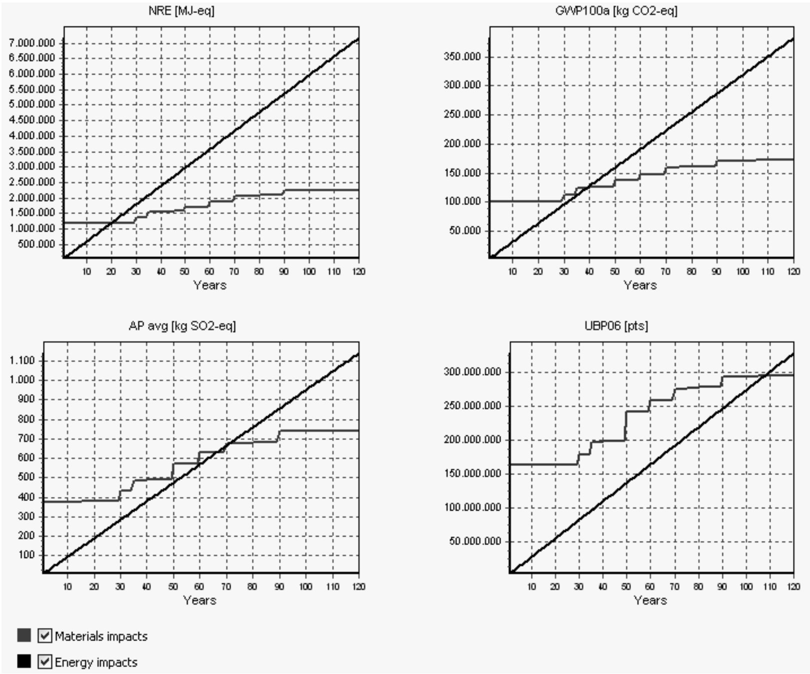

Figure 33 Impacts time evolution with Eco-Bat: materials and energy impacts

This is only a simplified representation of the building life span. The reality is much more complex. Factors such as the quality of the building and its materials, economical aspects etc. have to be taken into account as well.

4.5 Building variants with different building envelope elements

When analysing the impact of different materials in Eco+ and Eco-Bat, it is obvious that reinforced concrete is responsible for the biggest share of the environmental impacts, as illustrated with figure 34 and in Appendix E.

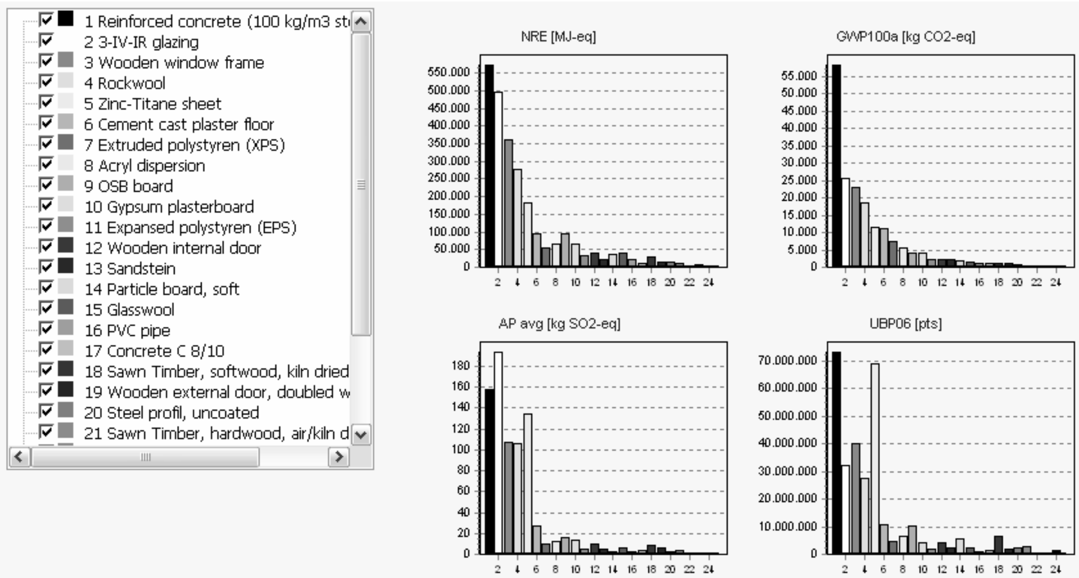

Figure 34 Analysis of the different materials of the building in Eco-Bat

This is because of the great amount of reinforced concrete, used in the dwelling for the structural exterior and interior walls, but also because the environmental impacts of reinforced concrete are rather high in comparison to other construction materials. When comparing a wall of 14 cm of clay brick and 14 cm of reinforced concrete in Eco-Bat, the results are shown in figure 35.

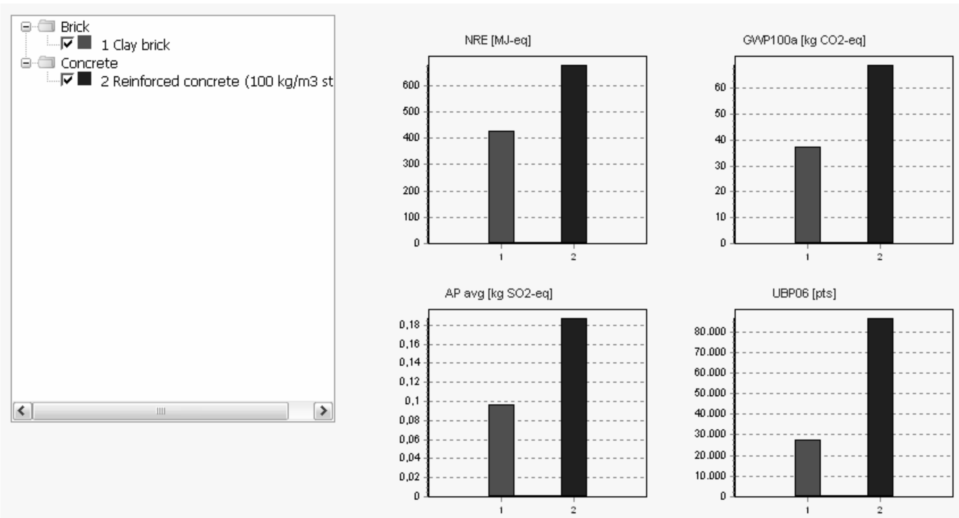

Figure 35 Analysis of clay brick and reinforced concrete in Eco-Bat

The clay brick shows a much lower impact for NRE, GWP, AP and the endpoint indicator UBP. Definitions of these impact indicators can be found in the List of Definitions. In this paragraph, an analysis will be performed on element and on building level for different wall constructions for the exterior and interior walls. The U-values in table 36 are determined with SuFiQuaD. Detailed constructions can be found in Appendix F.

Wall	Exterior walls	Interior wall	U-value [W/m²K]
Wall 1 Concrete- wood	14 cm reinforced concrete 16 cm rock wool 2,2 cm wooden claddings	14 cm reinforced concrete	0,25 W/m²K
Wall 2 Brick- wood	14 cm clay brick 16 cm rock wool 2,2 cm wooden claddings	14 cm clay brick	0,23 W/m²K
Wall 3 Concrete- concrete	14 cm reinforced concrete 14 cm rock wool 10 cm architectural concrete	14 cm reinforced concrete	0,24 W/m²K
Wall 4 Brick- brick	14 cm clay brick 14 cm rock wool 9 cm face bricks	14 cm clay brick	0,22 W/m²K
Wall 5 Wood	14 cm wood frame with rock wool insulation 2,2 cm wooden claddings	14 cm wood frame with gypsum board	0,26 W/m²K

Table 36 Different wall constructions

4.5.1 Analysis with Eco-Bat

Figure 36 gives an overview of the four impact indicators for the five different walls types. These are the total results for a building life span of 120 years for the total surface of exterior walls of the dwelling.

The walls with a concrete structural element (wall 1 and 3) have the highest impacts for all four impact indicators. For the UBP, the brick-wood wall shows a 24,7% lower impact in comparison with the concrete-wood wall and the value for the brick-brick wall is 30,8 % lower than the concrete-concrete wall. The environmental impacts for the wood frame wall are comparable to the brick walls. When comparing the walls with a wooden external finish (wall 1 and 2) to the walls with a massive external finish (wall 3 and 4), the wooden claddings have lower impacts, but the difference remains small.

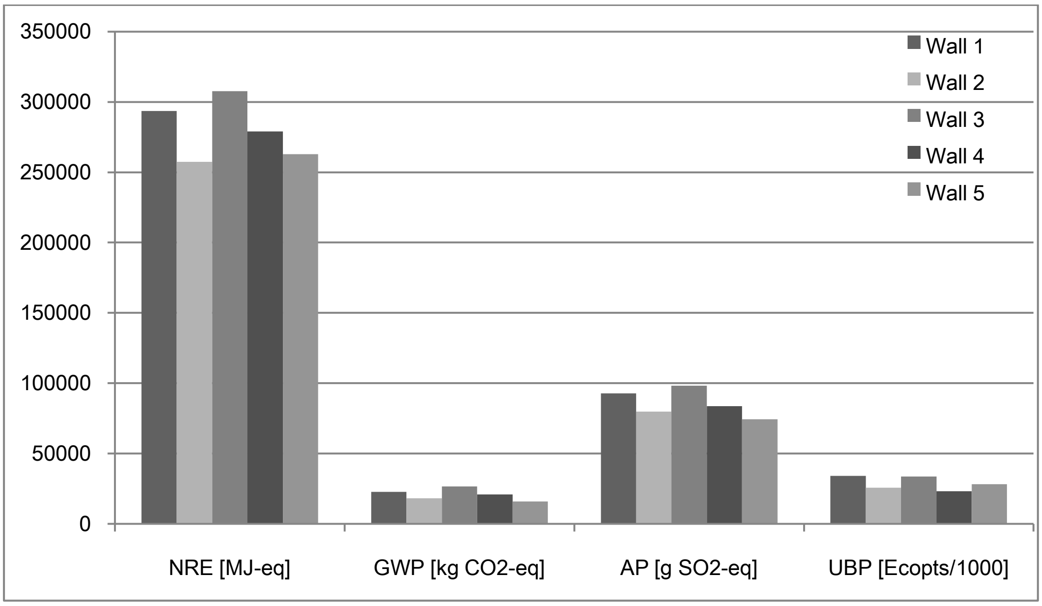

Figure 36 Comparison of the different wall types in Eco-Bat, element level

Figure 37 makes the comparison on building level. Only the environmental impacts for the materials are taken into account. The interior walls are adapted according to table 36. The same tendencies are observed as for the impacts on element level, but the differences are much smaller. The UBP is only 3,9% smaller for the brick-wood wall in comparison with the concrete-wood wall and 4,6% for the brick-brick wall in comparison with the concrete-concrete wall.

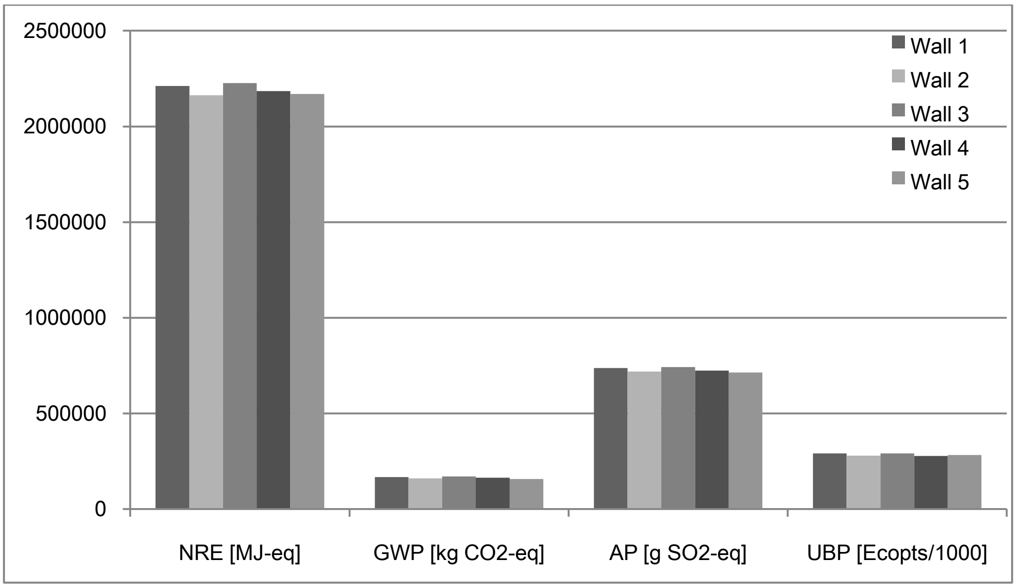

Figure 37 Comparison of the different wall types in Eco-Bat, building level for materials

4.5.2 Analysis with SuFiQuaD

The same analysis was performed with the SuFiQuaD software. The wall constructions as in table 36 are used. Figure 38 shows the financial costs and the monetised environmental impacts as calculated with SuFiQuaD.

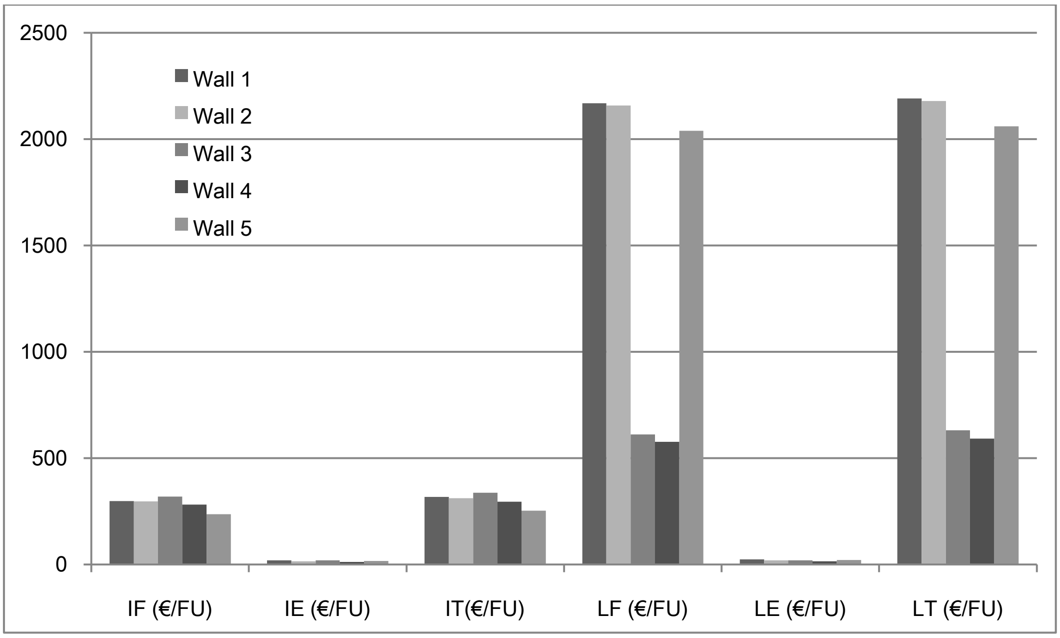

Figure 38 Analysis of the different wall types in SuFiQuaD, element level

The initial environmental impacts (IE) for the different walls show the same proportions as the Eco-Bat software. The brick-wood wall shows a 20% lower impact in comparison with the concrete-wood wall and the value for the brick-brick wall is 32% lower than the concrete-concrete wall.

However, the financial costs are much higher than the environmental costs, so they will have a bigger influence on the total costs. The initial financial costs (IF) are approximately the same for the concrete-wood and the brick-wood wall (wall 1 and 2). The financial cost is slightly higher for the concrete-concrete wall (wall 3) and slightly lower for the brick-brick wall (wall 4). The IF is the lowest for the wood frame wall (wall 5).

The sum of the initial and periodical financial costs is shown in the life cycle financial costs (LF). This shows a significant difference between the walls with an external finish of wooden claddings and the walls with an external finish of massive materials (concrete or brick). In Appendix G, a detailed diagram of the financial and environmental costs of the different life cycle phases on element level is added. The periodical financial cost for small and big maintenance is approximately the same for the five wall types, but the PF for cleaning and replacement is much bigger for the elements with external wooden claddings. And because the financial cost of the cleaning shows a very high value, this has a great influence on the results, leading to much bigger costs for the whole life span for walls 1, 2 and 5 with wood cladding finish.

The results for the comparison of the five wall types on building level for the materials are shown in figure 39.

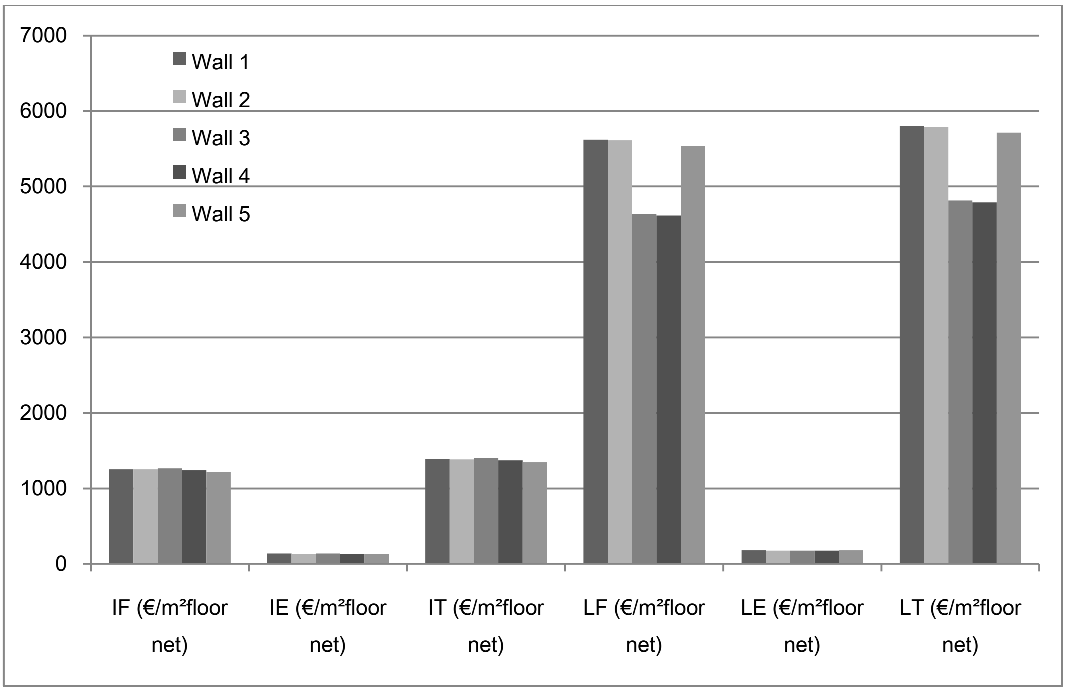

Figure 39 Analysis of the different wall types in SuFiQuaD, building level for materials

The same tendencies can be noticed on building level. The wall variants with the lowest total financial and environmental costs (LT) are the concrete-concrete and brick-brick wall (walls 3 and 4). The total costs (LT) for the walls with concrete or brick finishes are 17% lower when compared to the walls with wooden claddings as external finish.

The detailed diagram of the different life cycle impacts can be found in Appendix G. Once again, the financial costs for the cleaning and the replacement show the biggest differences. The financial and environmental costs for energy use are also shown. But the U-values of the different wall types are similar, so the five types show approximately the same costs for energy use.

4.6 Conclusion

Table 37 compares the net energy demand for space heating as calculated with the CEN and SIA standards in the Swiss climate and the EPB-software in the Belgian climate to the actual net consumption for space heating as calculated in the conclusion of chapter 3. The actual energy demand is higher than the calculated values.

	Net space heating demand
Lesosai CEN (CH)	14,0 kWh/m² (50,5 MJ/m²)
Lesosai SIA (CH)	16,2 kWh/m² (58,4 MJ/m²)
EPB (BE)	9,05 kWh/m² (32,6 MJ/m²)
Actual cons. (CH)	20,7 kWh/m² (74,5 MJ/m²)

Table 37 Net energy demand for space heating of the dwelling

The conclusion of paragraph 4.2 was that the EPB value was probably too low and the Lesosai CEN value was too high. However, the actual consumption as measured by the inhabitants is higher than all the calculated values. It is possible that the heating demand is underestimated because part of the building is arranged as office. Because the husband works from home, the building is occupied during the whole day, so it must be heated all day too. It is also possible that a part of the higher energy consumption is due to the rebound effect. The rebound effect is defined as "the effect that the lower costs of energy services, due to increased energy efficiency, has on consumer behavior. The 'rebound' effect is the extent of the energy saving produced by an efficiency investment that is taken back by consumers in the form of higher consumption, either in the form of more hours of use or a higher quality of energy service."[31]

When comparing the Eco+ and Eco-Bat software, it is noticed that the Eco+ software is not complete. The transportation data and LCA data for some materials are not included. Other materials refer to wrong environmental data. The reason for this is the limitation of the data to the KBOB database. Because KBOB is not very elaborated, not all the construction materials are taken into account.

Furthermore, the electricity consumption is overestimated, despite the detailed calculation. The energy demand for the production of hot water depends on the floor surface of the dwelling. It is illustrated here that the production of DHW should depend on the number of inhabitants, like in the SuFiQuaD software. Eco+ makes a large overestimation by assuming there are 4,39 inhabitants while in reality only two persons live in the building.

[31] http://www.eoearth.org/article/Rebound_effect

Eco+ can be used to get a general idea of the environmental impacts of a building and can advise the designer on the steps he has to take in order to decrease the impacts, but it should be completed in order to make an accurate estimation.
On the other hand, Eco-Bat does not include much options for the window glazing and window frames. There is also a limited number of different doors implemented in this software.

Regarding the comparison of the different wall types with Eco-Bat and SuFiQuaD, the results for the environmental impacts are proportional. However, the integrated approach of SuFiQuaD leads to different conclusions. According to Eco-Bat, the wall types without concrete are preferred, because the environmental impacts of concrete are high. SuFiQuaD takes into account the costs for the whole life span, leading to a preference for the exterior walls with an external finish of concrete or brick, as they require the lowest financial costs for replacement and cleaning.
It must be noticed that changing the type of exterior walls also implies other consequences for the building who weren't discussed here. For example, a wood frame wall does not have the same inertia as a concrete wall, which could cause overheating of the dwelling in summer. This should be investigated further on to make a correct comparison.

Finally, we will have a look at the percentages of transport and maintenance since these life cycle phases are not always included in the Eco+ and Eco-Bat software. Table 38 shows the environmental costs for the dwelling for a life span of 120 years, expressed in €/m² of net floor area. The last two columns show the percentages relative to the total material or energy costs and relative to the total cost of the building. The material impacts are significantly higher than the energy impacts, but it must be noted that the cost for the electricity for lighting and electrical equipment is not included here. The transportation costs, which are not included in Eco+, are responsible for 2,05% of the environmental costs for the materials or 1,5% of the total environmental costs. The cleaning and maintenance, not included in Eco+ and Eco-Bat, represent a bigger share of the total costs. Together, they are responsible for 8,08% of the environmental costs for the materials or 5,92% of the total environmental costs. Because the Swiss software neglects these life cycle phases, they make a significant underestimation of the environmental impacts.

Life cycle phase	€/m²floor	% material/ energy	% total
IE(prod)/m²fl	133,77	69,35%	50,73%
IE(transport)/m²fl	3,95	2,05%	1,50%
IE(constr)/m²fl	-1,15	-0,60%	-0,44%
PE(cleaning)/m²fl	11,18	5,79%	4,24%
PE(small maint)/m²fl	0,26	0,13%	0,10%

PE(big maint)/m²fl	4,18	2,16%	1,58%
PE(replac subelem)/m²fl	45,83	23,76%	17,38%
PE(replac elem)/m²fl	15,84	8,21%	6,01%
EOL(demolition E)/m²fl	2,10	1,09%	0,80%
EOL(transport E)/m²fl	1,22	0,63%	0,46%
EOL(E)/m²fl	-24,29	-12,59%	-9,21%
Total materials/m²fl net	192,89	100,00%	73,15%
EC(space heating)/m²fl	29,84	42,15%	11,32%
EC(hot water)/m²fl	9,19	12,97%	3,48%
EC(electr ventilation)/m²fl	31,77	44,88%	12,05%
EC(total energy)/m2fl	70,79	100,00%	26,85%
E total/m2fl	263,68		100,00%

Table 38 Analysis of the environmental costs in SuFiQuaD

4.7 Bibliography of chapter 4

[1] SIA 381/2, Données climatiques relatives à la recommandation 380/1 'L'énergie dans le bâtiment', SIA, Zürich

[2] EPB Decree, Decree of the Flemish Government on the Determination of the Requirements on the Energy Performance and Indoor Climate in Buildings (in Dutch), March 11th 2005

[3] MOREL, Nicolas; GNANSOUNOU Edgard, *Energétique du bâtiment*, Lausanne, 2009

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[5] FRIEDLI, R. et al, *KBOB Recommandation construction durable: Données des écobilans dans la construction 2009/1*, Office Fédéral des Constructions et de la Logistique, Bern, March 2010
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Chapter 5: Conclusion

The objective of this master thesis was to compare different software programs as developed and used in Switzerland and Belgium to evaluate the energy consumption and the ecobalance of buildings. A comparison was carried out between the Swiss Lesosai and the Belgian EPB software for energy calculation and between the Swiss Eco+ and Eco-Bat software and the Belgian SuFiQuaD project for the calculation of the environmental impacts.

First of all, it must be noticed that a comparison of different energy calculation programs is not evident. Several mistakes can occur when defining a building in the software. Firstly, the input parameters are different in Lesosai and EPB, leading to another implementation in the software. Secondly, the data used in the software are often uncertain. For example, the weather data represent average values over a certain number of years. Finally, the data of the case study are never perfectly known, for example input errors can occur, errors in the building construction can decrease the energy performance, the behavior of the inhabitants can be different etc. The precision of a good energy calculation program is estimated as 10% for the annual net energy demand. This does not yet include the variation on physical data such as the weather data and the user behavior, which is often difficult to evaluate.

This can be illustrated with the steady-state energy calculations according to Lesosai and EPB, based on the same EN ISO standards. When applied to the case study, a significant difference for the net energy demand for heating appears. But neither of the programs gives an accurate estimation of the actual consumption of the energy use.

Studies about the rebound effect ([1],[2]) show that the results of theoretical energy calculations often differ from the actual consumption. “They (…) should be seen as quantification of a building quality, in the case being the energy efficiency of the whole design. They however are of no value when it comes to quantifying energy consumption. Main reason for that are human attitudes and behavior, leading to direct rebound impacting energy usage” ([1], p.6). When parameters for the consumer behavior are not included in the software, the estimation of the energy use will vary from the actual consumption. Overall, this is no problem for the actual use of the software, since most of the time, these are used to make a comparison between building variants in the concept phase of the design. The output of the energy calculation software cannot be considered as an absolute result.

Since it is difficult to compare the output of Eco+ and Eco-Bat to the SuFiQuaD results, only the general principles can be discussed. Eco+ and Eco-Bat show the influence of different impact indicators, whereas SuFiQuaD uses a aggregated and monetised indicator. SuFiQuaD also includes the financial aspects of the dwelling. As illustrated with the five different wall types, the integrated approach of SuFiQuaD leads to other choices when compared to the Eco-Bat software.

The database of the Eco+ software is not complete. The data records for the environmental impacts are only collected from the KBOB 2006 database. Since this is a limited database, materials such as zinc are not included. Eco-Bat also uses the KBOB database, the updated version of 2009, but for missing data, Ecoinvent is consulted. The two Swiss programs do not include cleaning and maintenance during the use phase. As shown in chapter 4, the share of cleaning and maintenance can be up to 8% of the environmental material's impacts. This is not negligible. The impacts for transportation from the factory to the building site, not included in Eco+, is about 2%, so this is a minor share.

The input of Eco+ is very detailed and elaborated. Especially for the rooms, a lot of data is required. For DHW, the calculation method based on the volume of the building leads to an incorrect estimation of the consumption of natural gas. The building is easier to define in Eco-Bat, because for the energy use only the consumptions and installation modes have to be defined. This is very handy when the building consumptions are known. In that case, the output is accurate as well. However, for a building in the design stage, the consumptions have to be estimated with external software or with the pre-dimensioning module. This is of course a less accurate way to estimate the consumptions and will probably lead to a certain variation of the results.

Still, for most of the aspects, Eco-Bat is more flexible than Eco+. For instance, different electricity mixes can be chosen, making the software appropriate to use in other European countries. Eco+ is specialised for the Swiss context, mostly because only the default values of the Swiss SIA standards are implemented.

Including the financial aspects in ecobalance software, like the SuFiQuaD project, should be supported. As illustrated in chapter 4, the addition of the financial aspects will lead to different conclusions regarding the optimal building choices. This way, it is possible for the building owner to choose the measures that are justified for the integrated economical and ecological aspects. Moreover, it will be possible for the authorities to derive the measures that show the highest efficiency for the lowest extra investment. These measures should be encouraged, for example by subsidies. Overall, the addition of the financial costs in SuFiQuaD give a realistic frame to the ecobalance software.

The financial aspects are included in the Swiss context for the Minergie label. The Swiss Minergie label supports the use of inexpensive systems, which provide a high long-term value of buildings. One of the requirements to obtain the label is that the construction costs of a new building cannot exceed 10% of the construction costs of a average conventional building.[32] This way, the builders are forced to take into account the costs of their low energy building and have to consider which measure will be least expensive and most effective. Well-considered measures will be put first.

In order to choose the most economical and ecological solutions for the building, the analysis has to be started from the early stages of the design. The software should be able to guide the architects in these phases too. In that way, the pre-dimensioning module of Eco-Bat can be used. SuFiQuaD also allows the optimisation of the exterior walls, including the transmission losses through the building envelope.

Further research should focus on the development of user-friendly and accurate software, which can advise the architect from the early stages of the design. Both the economical and the ecological impacts have to be evaluated.

[32] http://www.minergie.ch/

Bibliography of chapter 5

[1] HENS, Hugo et al, *Energy consumption for heating and rebound effects*, Laboratory of Building Physics, Department of Civil Engineering, K.U.Leuven, Leuven, 2009

[2] HAAS, Reinhard; BIERMAYR, Peter, *The rebound effect for space heating – Empirical evidence from Austria*, Institute of Energy Economics, Vienna University of Technology, Vienna, 2000

Appendices

Appendix A: Energy calculation for space heating in SuFiQuaD

This appendix gives an overview of the calculation method for the net energy demand for space heating as implemented in the SuFiQuaD software. The calculation procedure is based on the EPB-methodology.

The **heat losses for transmission** are the sum of the transmission losses through the envelope elements.

$\Phi_T = (T_{ext} – T_{int}) . H_T$

Φ_T: transmission heat loss [W]

T_{ext}: outdoor temperature [°C]

T_{int}: indoor design temperature [°C]

H_T: heat transmission coefficient of the building [W/K], calculated as

$H_T = (A_1.U_1 + A_2.U_2 + … + A_n.U_n)$

$A_{1…n}$: area of the heat loss surfaces [m²]

$U_{1…n}$: thermal conductance coefficient [W/(m².K)]

Different indoor design temperatures are possible in SuFiQuaD. The default value is 18°C, but this can be changed by the user. However, it is also possible to take into account the rebound effect. If this is the case, the indoor temperature will be lower than 18°C for badly insulated dwellings and higher than 18°C for well insulated dwellings. It is possible to take thermal bridges taken into account, by filling in the length of the linear thermal bridges and linear coefficient or the number of points and the point coefficient.

The **heat losses for ventilation** are calculated similar to the EPB-software.

$\Phi_V = 0{,}34.V$

Φ_V: ventilation heat loss [W]

V: ventilation air flow [m³/h]

The ventilation air flow depends on the presence of a ventilation system.

Without mechanical ventilation, the calculation procedure is:

$V = \max(V_{inf}, V_{min})$

V_{inf}: infiltration air flow, according to EPB calculated as

$V_{inf} = 0{,}04 \cdot V_{50} \cdot A_T$

V_{50}: leakage air flow at a pressure of 50 Pa per unit of heat loss surface [m³/(h.m²)]

A_T: total heat loss area [m²]

V_{min}: minimum hygienic air flow, according to EPB calculated as

$V_{min} = (0{,}2 + 0{,}5.\exp(-V_T/500)) \cdot m \cdot V_T$

V_T: total volume of the building [m³]

m: correction factor for the quality of the system, default value 1,5 [-]

With mechanical ventilation, the formula is:

$V = V_{inf} + V_{su} \cdot f_V + V_{mech,inf}$

V_{inf}: infiltration air flow [m³/h]

V_{su}: supply of fresh air, equals V_{min} [m³/h]

$V_{mech,inf}$: surplus exhaust air flow, in case of heat pump on extraction air [m³/h]

f_V: temperature reduction factor, caused by preheating or heat recuperation, calculated as

$f_V = (T_{int} - T_{su})/(T_{int} - T_{ext})$

T_{su} : supply air temperature

According to EN 12831:2003, an extra heating capacity has to be added, for heating up a building after a period of night set-back, per m² of floor area. The values for the required capacity for light, medium and heavy weight constructions, are extracted from the German standard DIN EN 12831.

The **internal gains** are calculated according to the EPB-software (chapter 2 [7], p.31)

The calculation of **solar gains** is important for passive and low energy buildings because they use the solar radiation to reduce the energy consumption for heating. In the SuFiQuaD software, two calculation methods are implemented, which are based on the EPB-software. The simplified method uses a default shading factor of 0,6 in order to include the effects of shading. The detailed method analyses the shading effect in detail. Shading elements, such as horizontal angle, vertical overhang angle and left and right lateral screens can be defined in the SuFiQuaD software. They reduce the surface of the visible sky. The calculation of the direct solar gains is executed by controlling each hour for one averaged day per month if the sun falls into the visible part of the sky surface.

Appendix B: Plans and façades of 'Maison Probst'

This appendix shows the plans, façades and one cross section of the analysed dwelling.

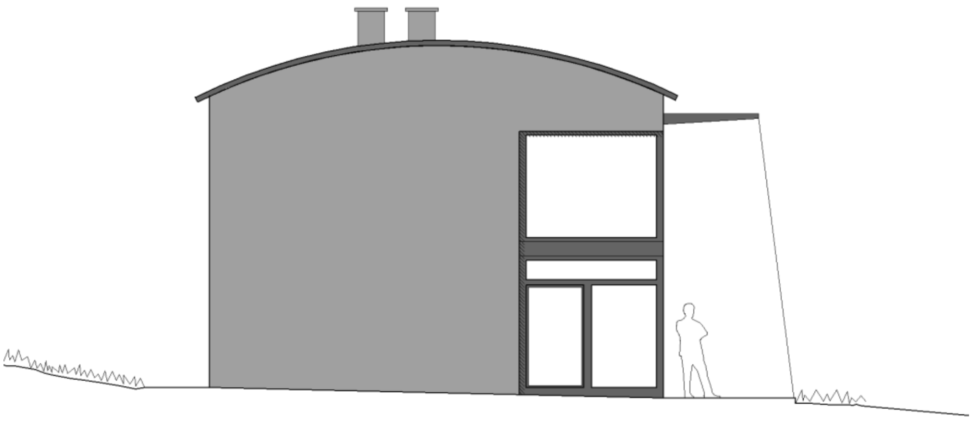


Figure 40 Façade of the east wall

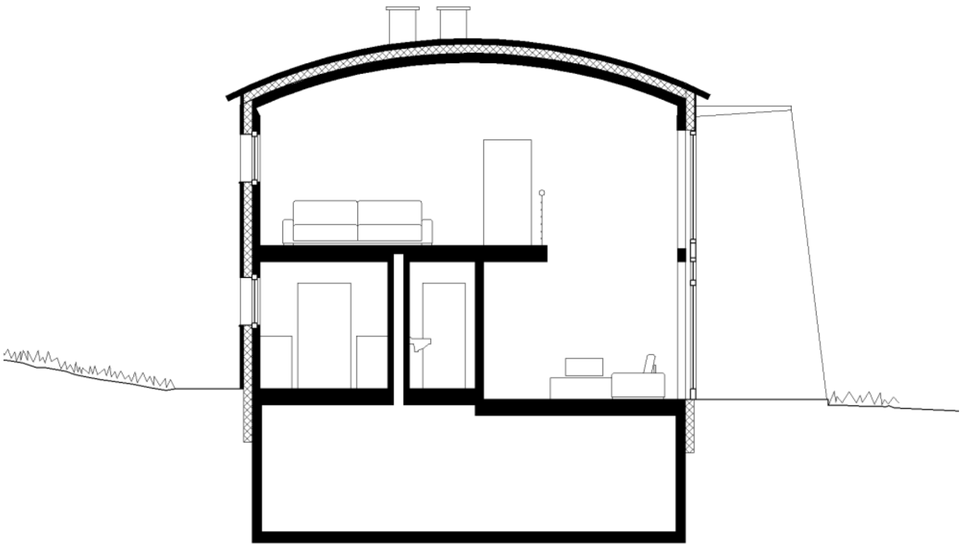


Figure 41 Cross section

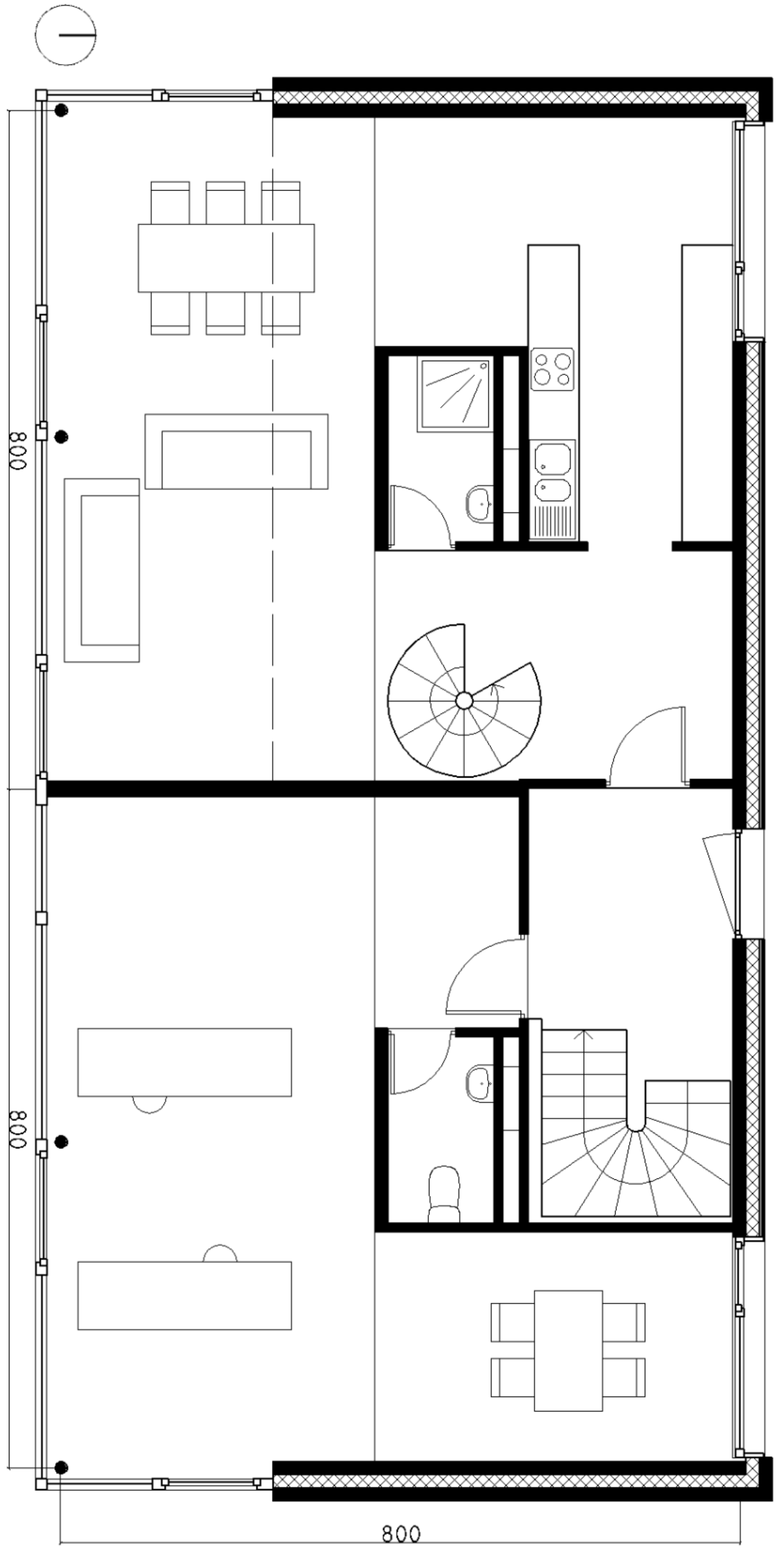


Figure 42 Plan ground floor

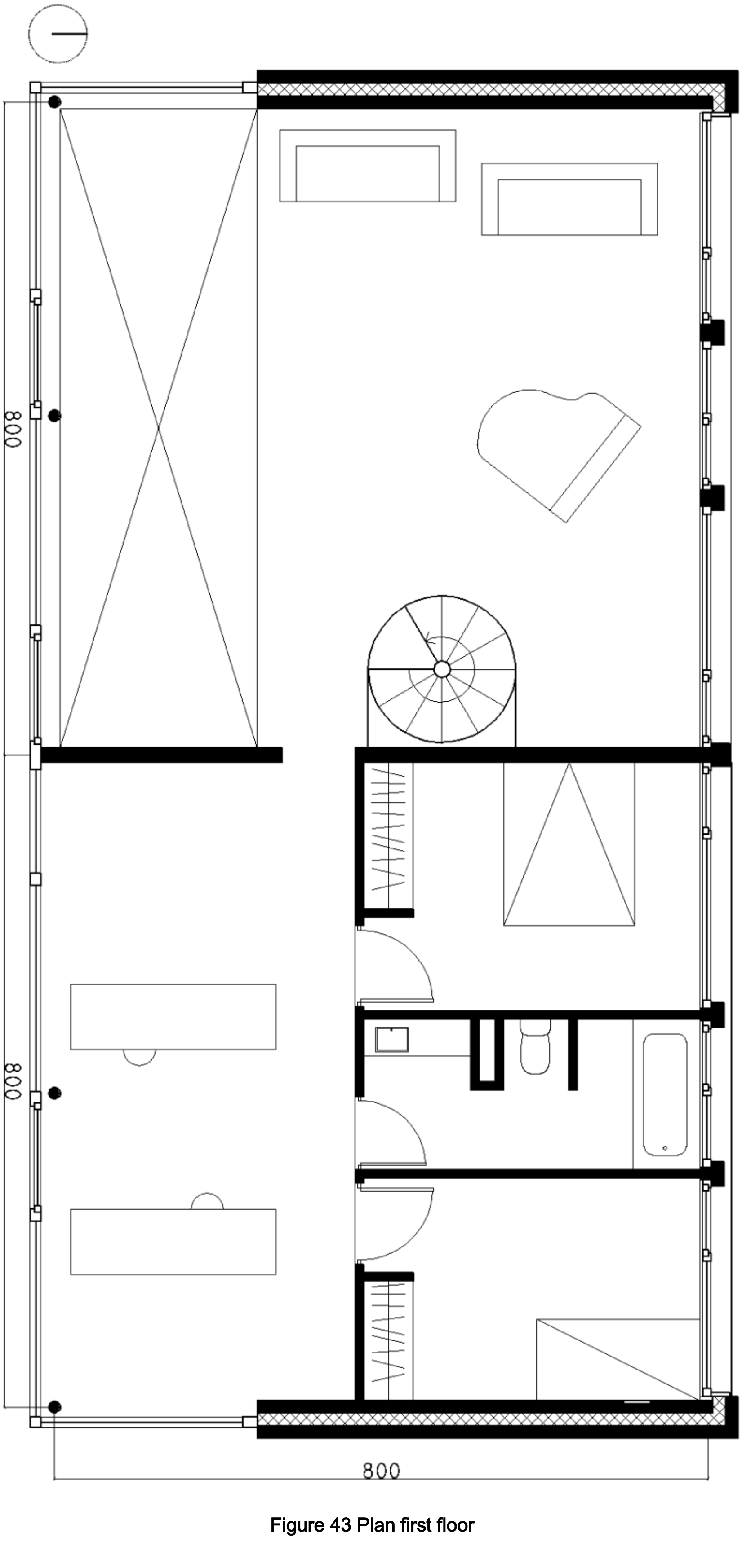


Figure 43 Plan first floor

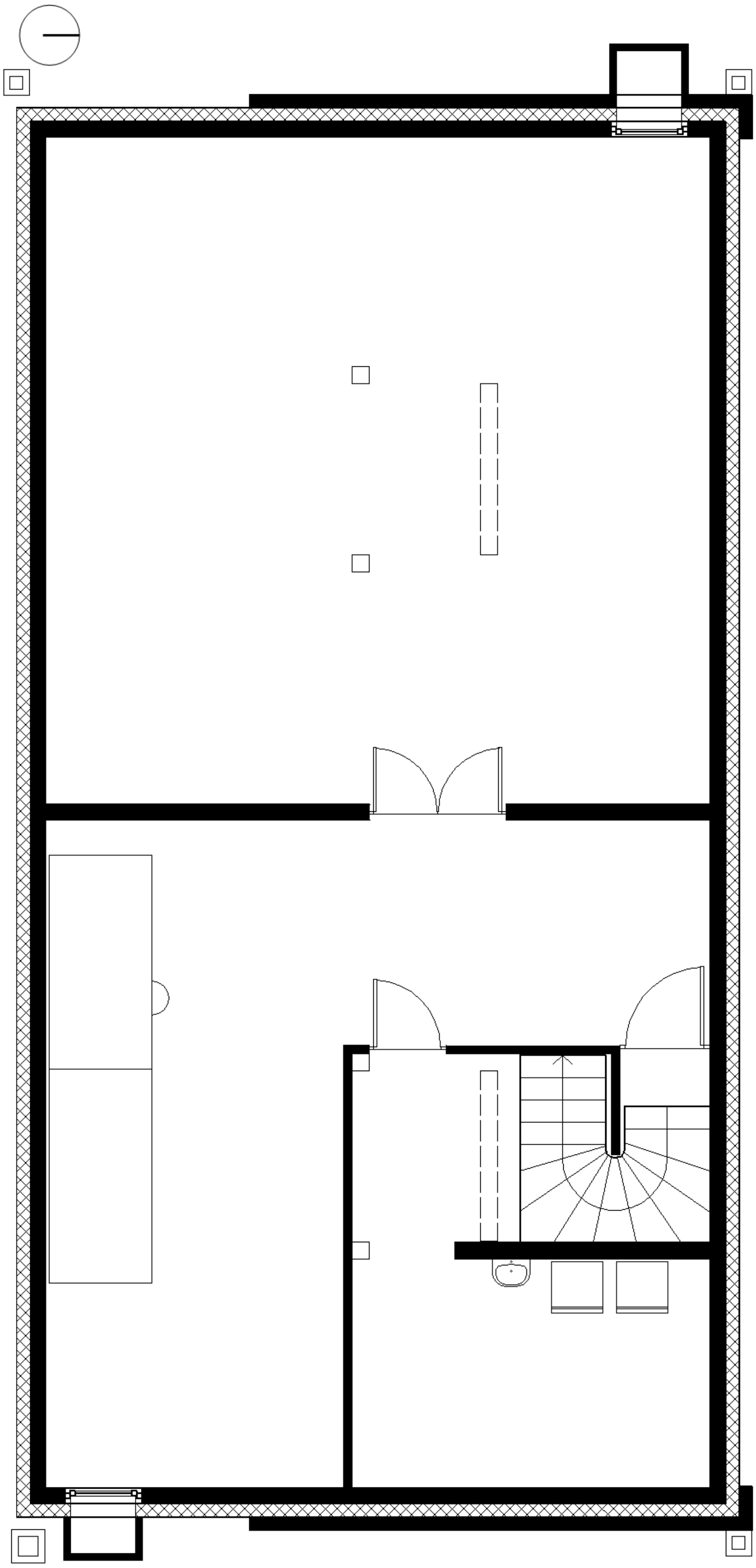


Figure 44 Plan basement

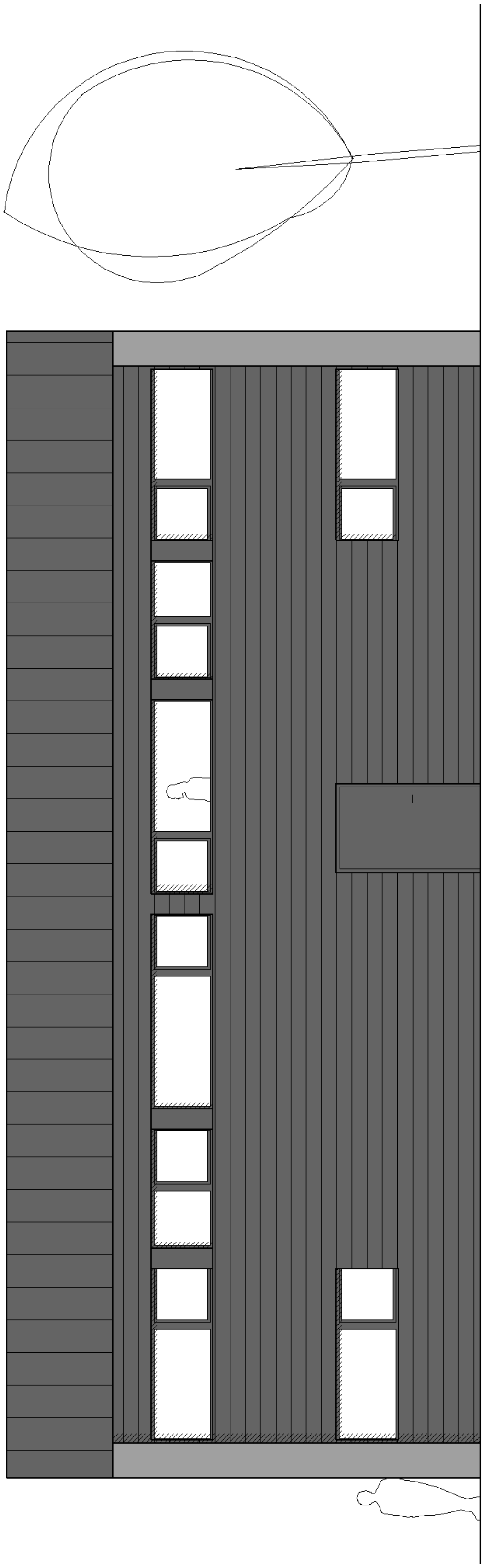


Figure 45 Façade of the north wall

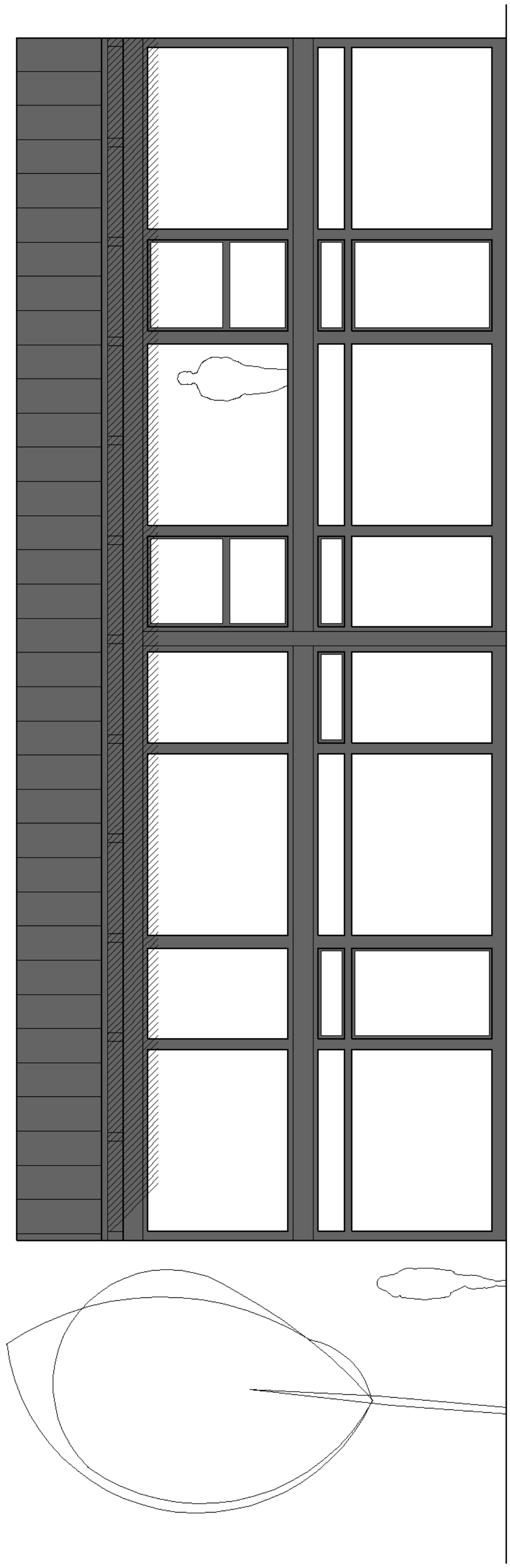
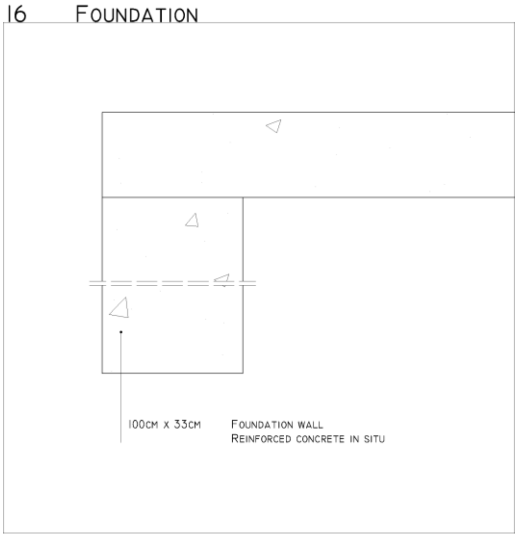


Figure 46 Façade of the south wall

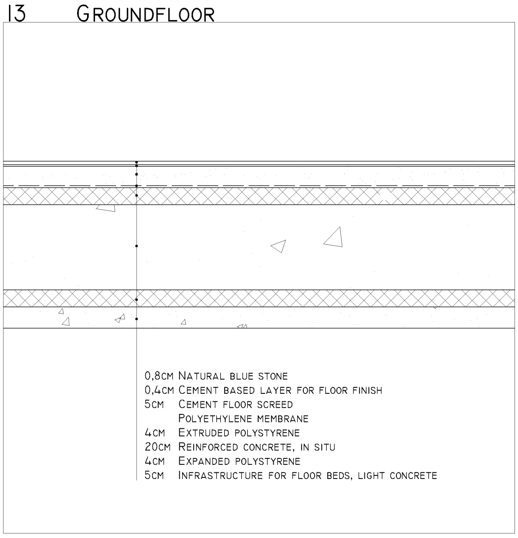
Appendix C: Construction details of Maison Probst

This appendix contains the construction details of the dwelling.

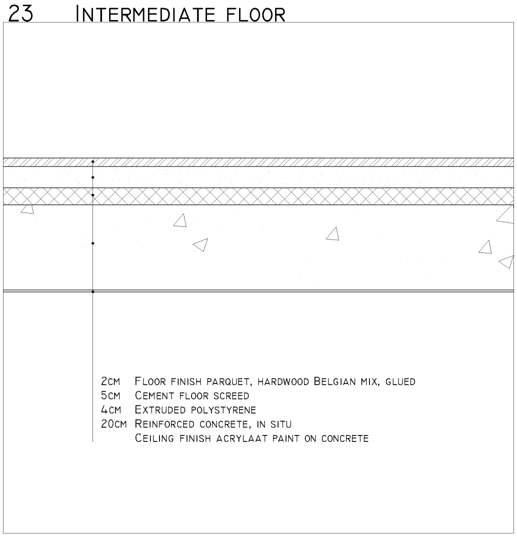
16 Foundation



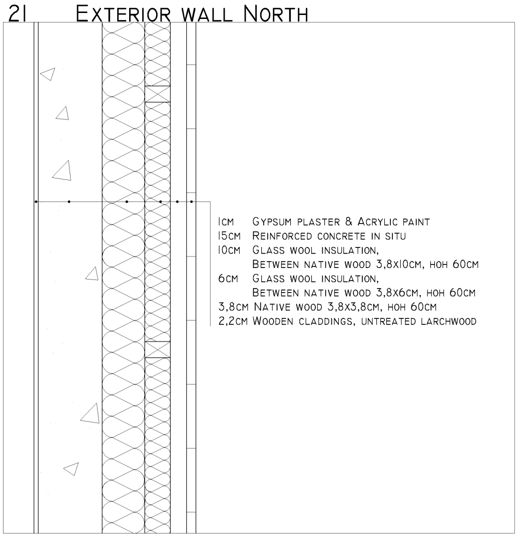
13 Groundfloor



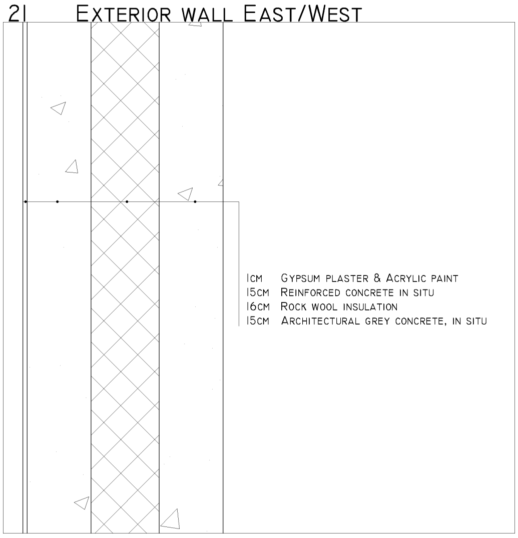
23 Intermediate floor



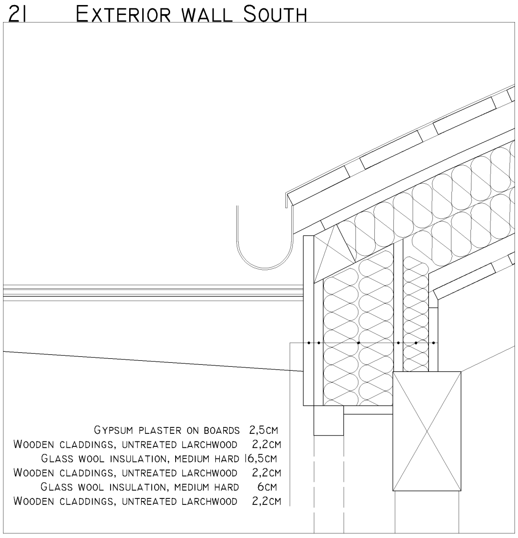
21 Exterior wall North



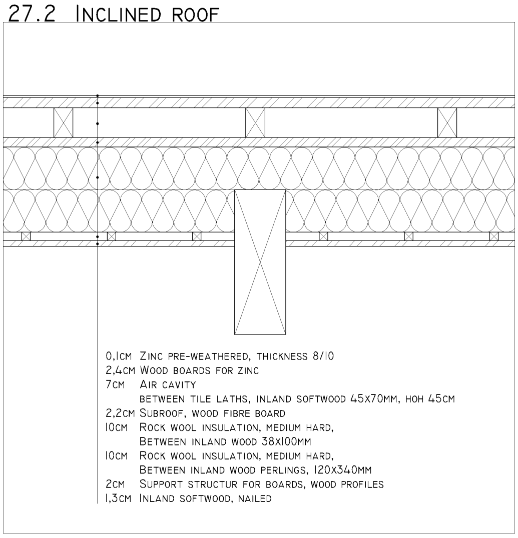
21 Exterior wall East/West



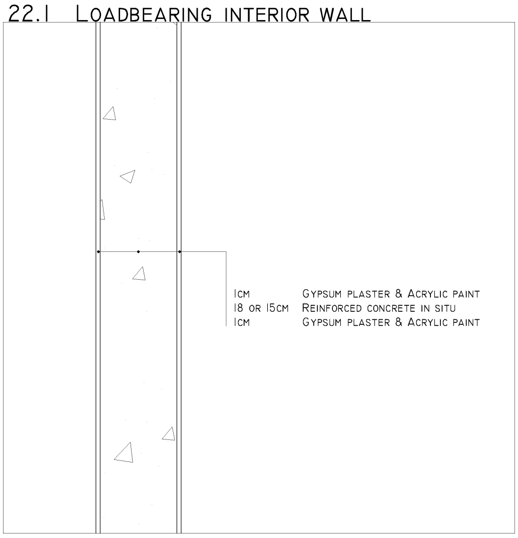
21 Exterior wall South



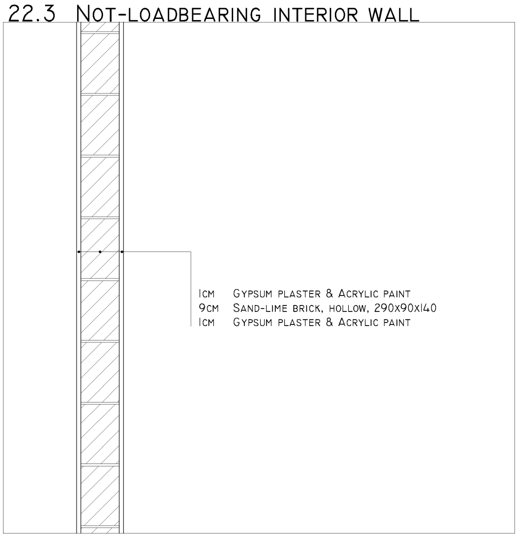
27.2 Inclined roof



22.1 Loadbearing interior wall



22.3 Not-loadbearing interior wall



Appendix D: Consumptions of the dwelling

This table shows the consumptions of the dwelling as registered by the inhabitants for the year 2006. The category natural gas includes the consumption for heating and for the production of domestic hot water.

	PV electricity [kWh]	Electricity Night [kWh]	Electricity Day [kWh]	Natural gas [kWh]
jan/06	51,9	178,5	204,5	2328,8
feb/06	57,2	145,5	184,0	2172,1
mrt/06	116,9	132,0	135,0	965,8
apr/06	183,5	101,0	25,0	134,2
mei/06	199,6	73,0	22,0	18,7
jun/06	269,6	54,0	-58,0	0,0
jul/06	257,8	57,0	-24,0	0,0
aug/06	191,8	90,0	14,0	0,0
sep/06	159,2	112,0	76,5	3,3
okt/06	107,4	106,5	147,3	18,6
nov/06	63,0	140,5	209,2	562,9
dec/06	38,9	184,0	245,5	1288,0
2006	**1696,8**	**1374,0**	**1181,0**	**7492,3**

Table 39 Annual production of photovoltaic electricity, consumption of electricity for day and night tariff and consumption of natural gas, for the year 2006

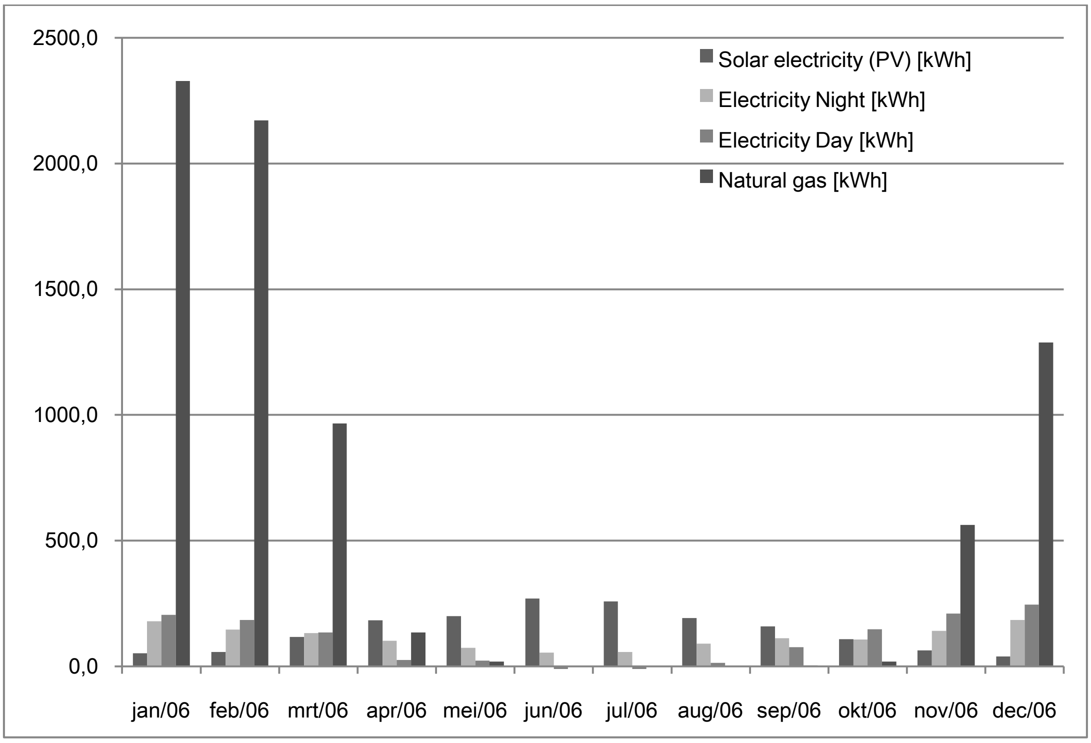


Figure 47 Consumption for electricity and natural gas, for the year 2006

Appendix E: GWP and UBP of the different materials

GWP [kg CO2-eq]	Eco+		Eco-Bat	
Reinforced concrete (100 kg/m3 steel)	34.196,0	24,0%	58.248,6	31,2%
Wooden window frame	18.259,0	12,8%	22.912,3	12,3%
Rockwool	15.676,0	11,0%	18.681,2	10,0%
Zinc-Titanium sheet	0,0	0,0%	11.420,3	6,1%
Cement cast plaster floor	10.311,0	7,2%	11.151,7	6,0%
3-IV-IR glazing/triple glazing with Krypton	26.999,0	18,9%	25.717,9	13,8%
Extruded polystyrene (XPS)	5.079,0	3,6%	7.540,5	4,0%
Acryl dispersion	4.285,0	3,0%	5.734,5	3,1%
OSB board	5.239,0	3,7%	4.206,7	2,3%
Gypsum plasterboard	4.501,0	3,2%	4.030,3	2,2%
Expanded polystyrene (EPS)	3.419,0	2,4%	2.365,5	1,3%
Wooden internal door	521,0	0,4%	2.316,1	1,2%
Sandstone	3.268,0	2,3%	2.126,7	1,1%
Particle board, soft / Isoroof	2.012,0	1,4%	1.738,2	0,9%
Glasswool	1.771,0	1,2%	1.387,9	0,7%
PVC pipe	1.037,0	0,7%	1.195,7	0,6%
Concrete C 8/10	837,5	0,6%	1.172,0	0,6%
Sawn Timber, softwood, kiln dried, planed	905,6	0,6%	1.151,6	0,6%
Wooden external door, doubled with aluminium	411,6	0,3%	985,1	0,5%
Steel profile, uncoated	1.091,0	0,8%	766,0	0,4%
Sawn Timber, hardwood, air/kiln dried, planed	357,6	0,3%	518,1	0,3%
Cement mortar	503,8	0,4%	499,7	0,3%
Polyethylene sheet (LDPE)	224,9	0,2%	437,6	0,2%
Sawn Timber, softwood, air dried, raw	825,7	0,6%	179,0	0,1%
Artificial rock slab	939,5	0,7%	113,2	0,1%
Gips	39,3	0,0%	80,7	0,0%
TOTAL	142709,4	100,0%	186677,1	100,0%

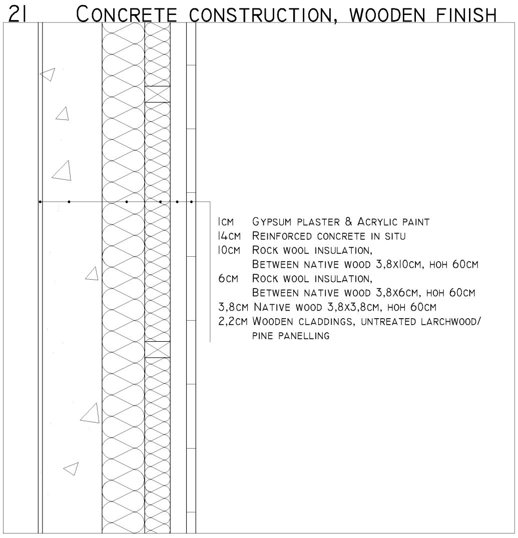
Table 40 GWP for the different materials in Eco+ and Eco-Bat

UBP [Ecopoints]	Eco+		Eco-Bat	
Reinforced concrete (100 kg/m3 steel)	33.715.546,9	15,12%	73.084.174,0	23,43%
Wooden window frame	37.163.171,5	16,66%	39.955.162,0	12,81%
Rockwool	23.220.361,5	10,41%	27.253.196,0	8,74%
Zinc-Titanium sheet	0,0	0,00%	68.906.164,0	22,09%
Cement cast plaster floor	9.778.290,2	4,38%	10.581.583,0	3,39%
3-IV-IR glazing/triple glazing with Krypton	48.011.078,5	21,53%	32.174.651,7	10,32%
Extruded polystyrene (XPS)	3.889.671,8	1,74%	4.884.249,1	1,57%
Acryl dispersion	4.891.435,5	2,19%	6.356.458,2	2,04%
OSB board	14.697.783,1	6,59%	10.298.056,0	3,30%
Gypsum plasterboard	5.085.833,2	2,28%	4.313.883,4	1,38%
Expanded polystyrene (EPS)	2.765.371,7	1,24%	1.799.762,8	0,58%
Wooden internal door	2.630.810,7	1,18%	4.074.467,7	1,31%
Sandstone	3.433.023,3	1,54%	2.112.765,1	0,68%
Particle board, soft / Isoroof	5.758.351,9	2,58%	5.715.297,2	1,83%
Glasswool	2.636.250,4	1,18%	2.096.202,2	0,67%
PVC pipe	1.069.903,1	0,48%	1.042.037,0	0,33%
Concrete C 8/10	1.162.664,3	0,52%	1.571.867,3	0,50%
Sawn Timber, softwood, kiln dried, planed	7.400.282,4	3,32%	6.694.370,6	2,15%
Wooden external door, doubled with aluminium	686.939,6	0,31%	1.858.920,0	0,60%
Steel profile, uncoated	4.787.794,9	2,15%	2.116.152,1	0,68%
Sawn Timber, hardwood, air/kiln dried, planed	3.999.897,3	1,79%	2.752.870,6	0,88%
Cement mortar	449.777,3	0,20%	457.472,0	0,15%
Polyethylene sheet (LDPE)	187.870,1	0,08%	411.526,1	0,13%
Sawn Timber, softwood, air dried, raw	4.707.344,6	2,11%	1.164.160,3	0,37%
Artificial rock slab	809.083,8	0,36%	94.526,9	0,03%
Gips	76.354,0	0,03%	142.596,7	0,05%
TOTAL	223014891,6	100,00%	311912572,0	100,00%

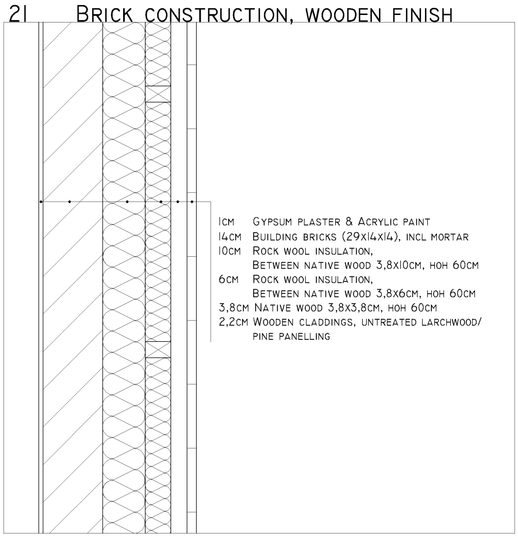
Table 41 UBP for the different materials in Eco+ and Eco-Bat

Appendix F: Construction details of the wall variants

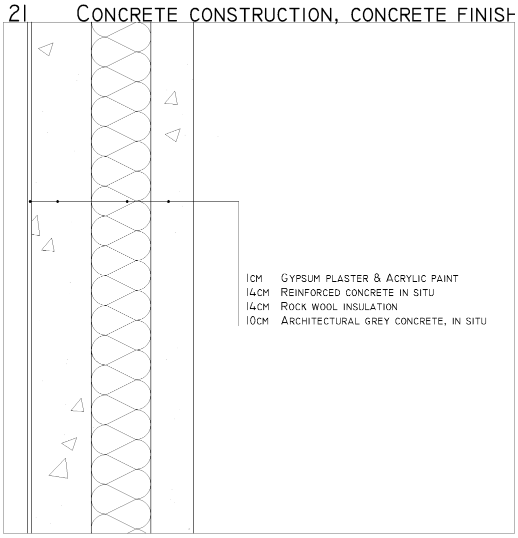
21 Concrete construction, wooden finish



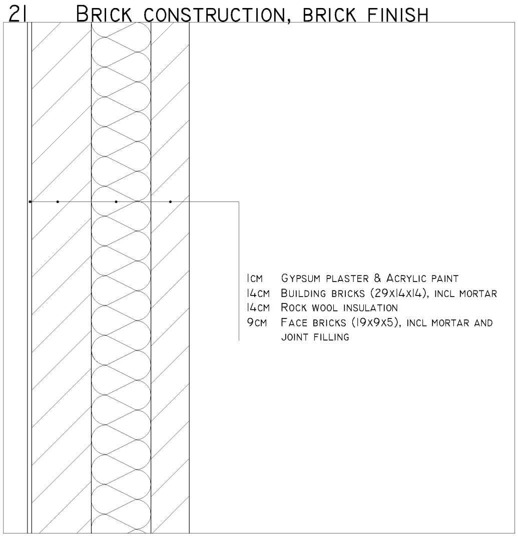
21 Brick construction, wooden finish



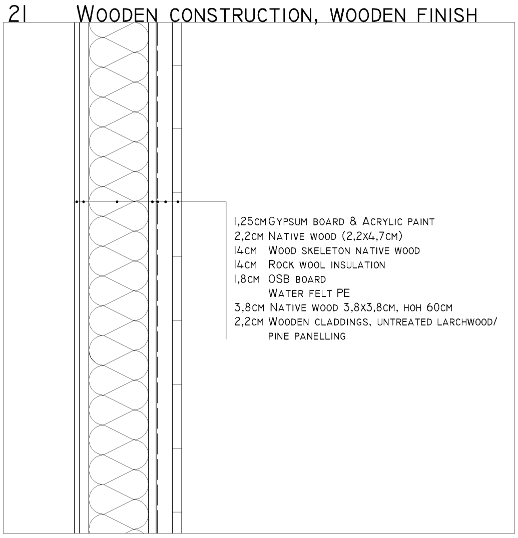
21 Concrete construction, concrete finish



21 Brick construction, brick finish



21 Wooden construction, wooden finish



Appendix G: Analysis of the wall variants with SuFiQuaD

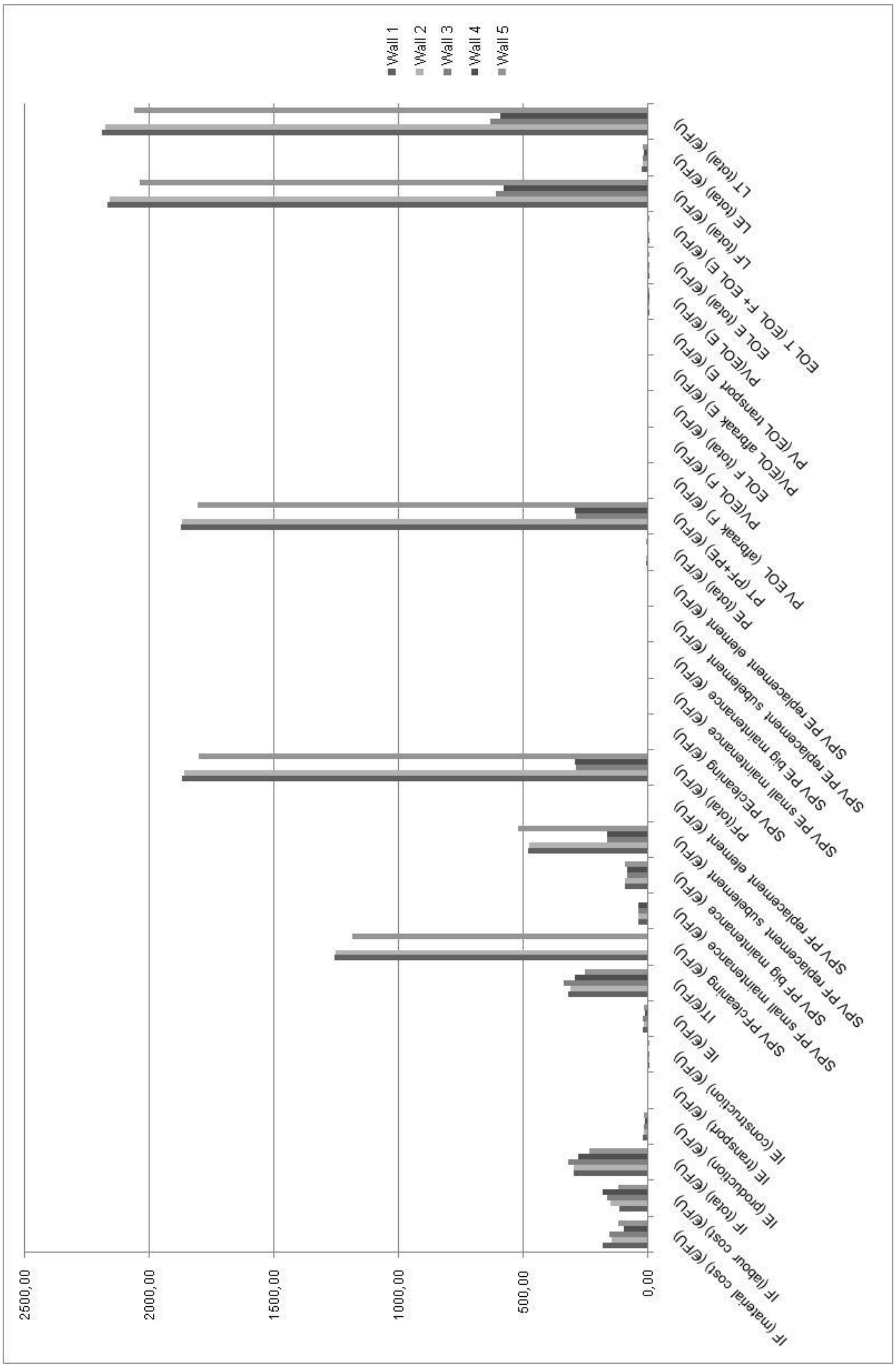


Figure 48 Output of SuFiQuaD for the wall variants on element level

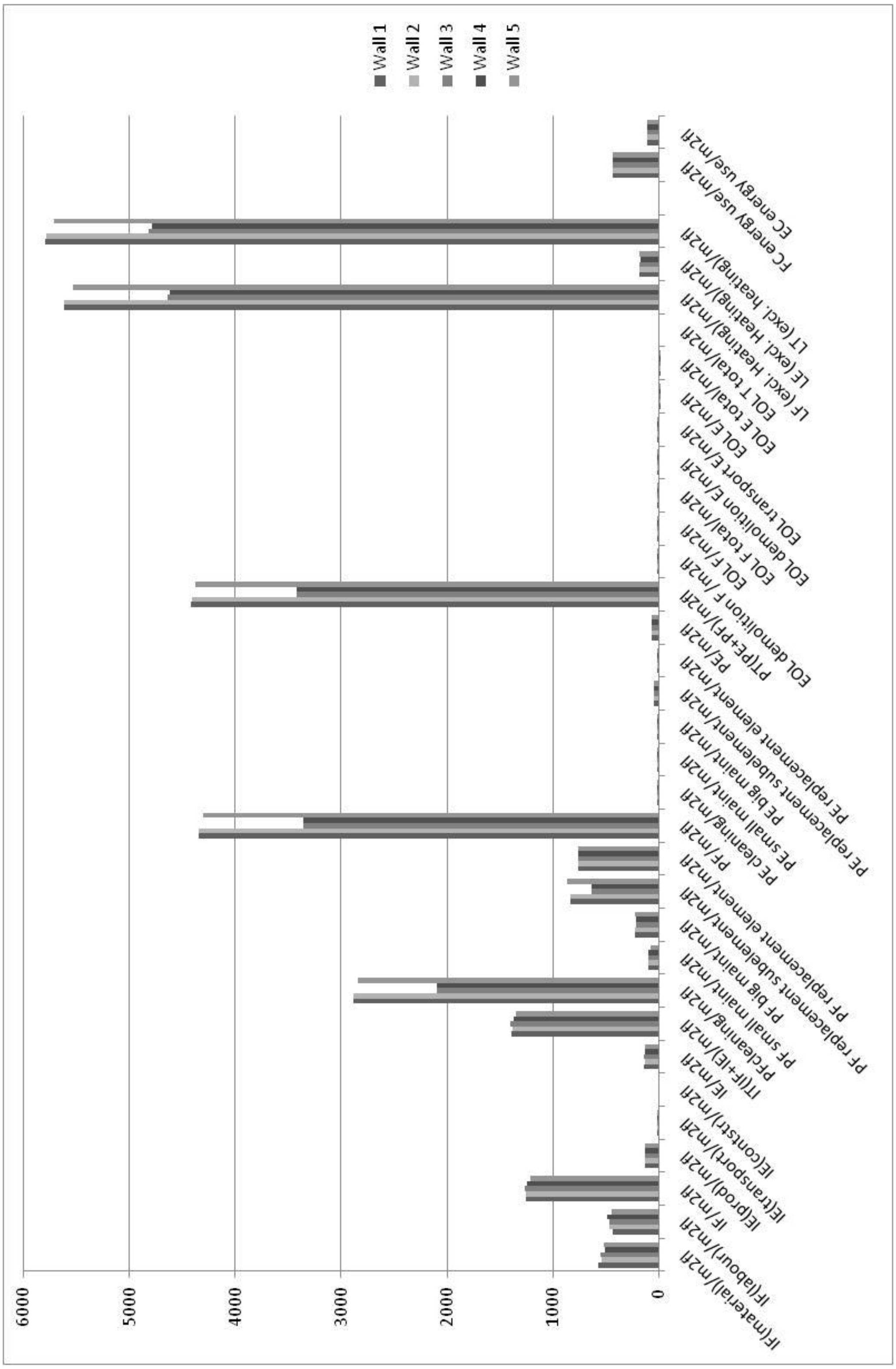


Figure 49 Output of SuFiQuaD for the wall variants on building level

Appendix H: EPB-calculation method for K- and E-value

1. Calculation of the K-value

This explanation is based on the document *Transmissiereferentiedocument*, Belgisch Staatsblad, November 13th 2007. The K-value is an indication of the heat losses through the building envelope and thus characterizes only the insulation of the building. The compactness of the building is also taken into account.

In a first step, the compactness of the building[33] is calculated with the following formula.

$$C = \frac{V}{A_T}$$

C: the compactness of the building [m]

V: the volume of the building, based on the outer measures [m³]

A_T: the total surface area of the envelope elements, based on the outer measures [m²]

In a second step, the average thermal conductance coefficient for the building is determined.

$$U_m = \frac{H_T}{A_T}$$

U_m: the average thermal conductance coefficient [W/m²K]

H_T: the heat loss coefficient for transmission of the building, as calculated in chapter 2.1 [W/K]

A_T: the total surface area of the envelope elements, based on the outer measures [m²]

[33] The building can refer to a building or a part of the building, for example when only a part of the building is renovated.

Finally, the K-value is calculated with the following formula. The calculated value is rounded off to an integer. When the part after the comma is exactly …,5 the value will be rounded off to the higher integer.

$$K = 100\frac{U_m}{U_{m,ref}}$$

U_m: the average thermal conductance coefficient [W/m²K]

$U_{m,ref}$: the reference value for the average thermal conductance coefficient [W/m²K], depending on the compactness of the building:

$$\begin{array}{ll} C \leq 1\ m: & U_{m,ref} = 1 \\ 1\ m < C < 4\ m: & U_{m,ref} = (C + 2)/3 \\ 4\ m \leq C: & U_{m,ref} = 2 \end{array}$$

2. Calculation of the E-value for residential buildings (EPW-method)

This explanation is based on the EPB Decree, Decree of the Flemish Government on the Determination of the Requirements on the Energy Performance and Indoor Climate in Buildings (in Dutch) of March 11th 2005. The E-value is an indication for the primary energy consumption of the building. The calculation method is summarised in the following figure.

input	de software berekent						
tabel 1	warmteverliezen	energiebalans = netto energie-behoefte	bruto energie-behoefte	eindenergieverbruik voor ruimteverwarming	maand-totalen naar jaarlijks eind-energie-verbruik + omzetten naar primair energie-verbruik	karakteristiek jaarlijks primair energie-verbruik en referentie-waarde	E-peil
tabel 2	nuttige warmtewinsten						
tabel 3							
tabel 4	systeemrendement						
tabel 5	opwekkingsrendement						
tabel 6	systeemrendement			eindenergieverbruik voor warm tapwater			
tabel 7	bijdrage thermisch zonne-energiesysteem						
tabel 8	opwekkingsrendement						
tabel 9	energieverbruik van hulpfuncties van de installaties			energieverbruik voor hulpfuncties en ventilatoren			
tabel 10	energieverbruik van de ventilatoren						
tabel 11	eindenergieverbruik voor koeling						
tabel 12	energiewinst door PV-panelen of WKK						

Figure 50 Calculation method of E-value for residential buildings

In a first step, the characteristic annual primary energy consumption is calculated with the formula:

$$E_{charannprimencons} = \sum_{m=1}^{12}\left(E_{p,heat,m} + E_{p,water,m} + E_{p,aux,m} + E_{p,cool,m} - E_{p,pv,m} - E_{p,cogen,m}\right)$$

$E_{p,heat}$: the monthly primary energy consumption for space heating [MJ]

$E_{p,water}$: the monthly primary energy consumption for the production of domestic hot water [MJ]

$E_{p,aux}$: the monthly primary auxiliary energy consumption [MJ]

$E_{p,cool}$: the equivalent monthly primary energy consumption for cooling [MJ]

$E_{p,pv}$: the monthly primary energy savings due to the buildings photovoltaic installation [MJ]

$E_{p,cogen}$: the monthly primary energy savings due to the buildings cogeneration installation [MJ]

In a second step, the reference value for the characteristic annual primary energy consumption is determined with the following formula.

$$E_{char\ ann\ prim\ en\ cons,ref} = a_1 \times A_{T,E} + a_2 \times V_{EPW} + a_3 \times \dot{V}_{dedic,ref}$$

a1: 115

a2: 70

a3: 105

$A_{T,E}$: the total surface area of the envelope elements, based on the outer measures [m²]

V_{EPW}: the total volume of the EPW-volume [m³]

$V_{dedic,ref}$: the reference air flow rate, due to mechanical ventilation, of the EPW-volume [m³/h], calculated as

$$\dot{V}_{dedic,ref} = 1.5\left[0.2 + 0.5\exp(-V_{EPW} / 500)\right]V_{EPW}$$

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Master's Thesis file

Students: Ann-Sophie Goudeseune

Title: Analysis of the financial cost, environmental impact and quality of a passive house

UDC: 72

Content in brief:

The objective of this master thesis is the evaluation of different software programs as developed in Switzerland and Belgium for the calculation of the energy consumption and the ecobalance of buildings.
This comparison is not evident because a lot of uncertainties are encountered when calculating the energy consumption of the dwelling. However, even though the results do not represent the actual energy consumption, interesting results can be obtained from the software and it is possible to use these to optimise the building.
Regarding the environmental impacts of dwellings, the Belgian SuFiQuaD project shows that is useful to include the financial aspects of the building. This will lead to different conclusions regarding the optimal building choices. This allows the building owner to choose the measures that are justified from a point of view that integrates the economical and ecological aspects.

Thesis submitted to obtain the degree of Master in Engineering: Architecture
Promoter: Prof. dr. ir. arch. Frank De Troyer
Assessors: Prof. dr. Jean-Louis Scartezzini and Han Vandevyvere
Supervisor: Karen Allacker