KU LEUVEN

FACULTEIT INDUSTRIËLE
INGENIEURSWETENSCHAPPEN

CAMPUS BRUGGE

Improving the sustainability of buildings by reducing the energy consumption

Keanü JONCKHEERE

Promotor: Luc Boehme

Co-promotor: Kalle Tammi

Masterproef ingediend tot het behalen van de graad van master of Science in de industriële wetenschappen: bouwkunde

Academiejaar 2017-2018

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Announcement

“This thesis was an exam. The comments made during the defence were not inserted.”

Foreword

The thesis can be seen as a final obstacle before earning a diploma. A thesis is a tool for showing all the acquired knowledge through the years of study and of course this is not made overnight. It takes a lot of time, it requires some patience and the help of other people who are more experienced.

First of all, I want to thank Luc Boehme for helping me with to come up with a topic. I also would like to thank him for the great support and energy he has put in to help me throughout the year. But also thank you for your guidance, to keep me on the right path and not to allow me to swerve to much so that I would not tackle it too big. Finally, I want to thank you reading my thesis with a critical eye so that it would improve.
Secondly, I want to thank Kalle Tammi for his guidance in TAMK where I finished my thesis. He made sure that everything happened as smoothly as possible.
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Last but not least I want to thank my parents for their support for the past five years. Not only mentally but also financially. To stand by me again for finishing the thesis. That they gave me the opportunity to continue my studies for two years so that I would get my master's degree, but also the opportunity to go on the Erasmus exchange program. So of the bottom of my heart I want to thank you for all the opportunities you have given me and always being there for me.

Summary

Sustainable buildings are becoming more and more important. It is recommended to define the sustainability during the preliminary design. In this phase it is possible to adjust certain things faster and it is also cheaper for the owner and in some cases for the contractor. If the changes has to be done during the construction phase, the cost would be much higher. It is up to the architect to design a sustainable building as possible. But in Belgium there is also the EPB reporter who checks if the design is sustainable enough with the chosen insulation and techniques. Hereby are energy requirements of the European Union (EU) taken into account. Each country has implemented these requirements in their own way and they are improving them yearly so that the nearly zero energy building (nZEB) requirements are met by 2020. Through a simple project, a bungalow, it is demonstrated what needs to be done to meet the Belgian and Finnish energy requirements and if the bungalow already meets the nearly zero energy building (nZEB) requirements. When this is not the case, there is examined which steps must be taken to meet the nZEB requirements. The Belgian requirements are checked by using the EPB software and for the Finnish requirements are checked by using the energy evaluation option in ArchiCad.

Furthermore, it is tested whether an insulation thicker than the minimum requirements is worth of the additional cost. In Belgium it is possible to put some thicker insulation in walls and roofs because the minimum requirements for the U-value are only 0,24 $\frac{W}{m^2K}$ which is not that strict as those in Finland, 0,16 $\frac{W}{m^2K}$ for the walls and 0,09 $\frac{W}{m^2K}$ for the roof. Because of the slightly higher U-value in Belgium the insulation does not have to be as thick as in Finland. The requirements in Finland have to be stricter due to the much colder climate. The test is done by placing two different types of insulation in the floor, walls and roof, comparing the additional cost for the insulation with the saving of energy to heat the bungalow and then check if the additional cost is earned back within the life span of the condensing boiler.

Extended abstract

Het is algemeen geweten dat de uitstoot moet verminderen. Daarom wordt er geopteerd om bijvoorbeeld: zoveel mogelijk te carpoolen, kiezen voor het openbaar vervoer, de auto laten staan en meer de fiets te nemen … Maar daar stopt het niet. De uitstoot kan ook beperkt worden bij woningen, meer bepaald bij nieuwbouw. Het volledige bouwproces van de woningen moeten zo duurzaam mogelijk verlopen. Bij nieuwbouwwoningen is er immers de mogelijkheid om deze zo te bouwen dat de uitstoot beperkt wordt. Het is niet zo dat de architect iets ontwerpt en hoopt dat er voldoende isolatie aanwezig is. De woning moet aan bepaalde eisen voldoen en deze eisen moeten gecontroleerd kunnen worden. Dit gebeuren wordt het best gedaan tijdens het voorontwerp. In deze fase heeft de architect nog voldoende ruimte om, indien nodig, heel wat zaken aan het project aan te passen. Dit speelt dan ook in de voordelen van de eigenaar doordat de kosten van de aanpassingen beperkt zijn omdat het project nog maar in de voorontwerpfase bevindt.

Het is Europa die de energie eisen heeft opgesteld en die in elke lidstaat van de Europese Unie geïmplementeerd moeten worden. Vervolgens verplicht Europa elke lidstaat ook om tegen 2020 bijna energie neutraal te bouwen (BEN).
De energie eisen in België en Finland worden onder de loep genomen en nagegaan hoe elk van deze landen de eisen opgenomen hebben. Zo zal er in België gebruikt gemaakt worden van een softwareprogramma, genaamd energieprestatie binnenklimaat (EPB) software 3G, om te controleren of dat een project aan de eisen voldoet. Terwijl in Finland zal men gebruik maken van building information modelling (BIM) software, een programma die in Finland ook al gebruikt wordt om onder meer 3D modellen van het project te maken. De gebruikte programma’s zijn niet de enige verschillen, zo is er nog dat er in België heel wat onderscheidingen zijn voor de eisen. Naargelang het type gebouw, aard van de werken en het jaar van aanvraag van de bouwvergunning kunnen de eisen verschillen. Maar het grote verschil kan terug gevonden worden in de eisen voor de U-waardes waaraan gebouwen moeten voldoen. Voor België zijn deze voor zowel muur, vloer en dak 0,24 $\frac{W}{m^2K}$. In Finland zijn de eisen voor de U-waarden strenger. Zo bedraagt de U-waarden voor: muren 0,17 $\frac{W}{m^2K}$, vloer 0,16 $\frac{W}{m^2K}$ en dak 0,09 $\frac{W}{m^2K}$. Dit is ook logisch aangezien het koudere klimaat daar.

Door gebruikt te maken van een case study zal er aangetoond hoe dik er geïsoleerd moet worden om aan de Belgische en Finse energie eisen te voldoen. Dit wordt gedaan voor zowel een typisch Belgische woning uit baksteen en een typisch Finse woning uit hout te simuleren in beide softwareprogramma’s. Elk schildeel in de case zal voorzien worden van twee isolatiematerialen. Voor muur en dak zijn dit polyurethaan en minerale wol en voor de vloer zijn dit polyurethaan en gespoten polyurethaan. In het geval van de Belgische eisen zal er gecontroleerd worden hoe dik er geïsoleerd moet worden om aan de energie eisen van 2017 en 2018 te voldoen. Het is zo dat in België de energie eisen elk jaar wat strenger worden zodat tegen 2020 de BEN eisen behaald worden. Naast de nodige isolatiedikte wordt er ook gecontroleerd of dat de case al aan deze BEN eisen voldoet. Wanneer dit niet het geval zou zijn, wordt er nagegaan wat er nodig is om de case te laten voldoen aan de BEN eisen.

Het is uiteindelijk de bedoeling om de uitstoot van de woning te beperken en een mogelijkheid hiervoor is extra dik te isoleren. Door extra te isoleren is er minder verlies aan warmte. Dit heeft als gevolg dat de warmte aanwezig blijft in de woning en dat er minder gestookt moet worden. Met andere woorden, de boiler zal minder moeten stoken om de woning warm te houden of zelfs op te warmen waardoor het primair energie verbruik voor verwarming zal dalen. Extra dikke isolatie gaat natuurlijk gepaard met een hoger kost aan materiaal. Er moet dan bekeken worden of dat de extra kost voor isolatie wel de moeite waard is. Dit wordt gedaan door het energieverbruik van de minimum isolatie-eisen te vergelijken met die van dikkere isolatie. Er is dus wel een meerkost aan isolatie, maar er wordt gespaard op het energieverbruik. Op een bepaald moment zal de besparing op energie voldoende waardoor de meerkost zichzelf heeft terugbetaald. Het is belangrijk dat de return on investment plaatsvindt voor het einde van de levensduur van de boiler. Hoe vroeger dit gebeurt, is het niet enkel de meerkost aan isolatie die terugbetaalt wordt, maar wordt er ook bespaard op de energiefactuur. Wat toch wel een zeer belangrijke factor is voor de eigenaar die al voldoende zal betaald hebben aan het bouwen van de woning.

Keywords: sustainability, energy performance, EPB, BIM, nZEB, return on investment

Improving the sustainability of buildings by reducing the energy consumption

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***Abstract*—Building sustainable is becoming more and more an important concept. The best moment to achieve this, is in the preliminary design. During this phase there is enough time to make changes if needed. It is up to the architect to design a building as sustainable as possible.**

Europe has set energy performance rules, that by 2020 every building must be a nearly zero energy building and every country in the European Union has to implement these roles as they seem fit, taking in consideration the 2020 requirements. The energy performance of Belgium and Finland will be examined. In order to check the energy performance of a buildings, certain software programs tools can be used. In Belgium this software program is called *energy performance and indoor climate* and in Finland a building information model program is used. A possibility to build sustainable, is by reducing the emission of carbon dioxide. This is can be done by lowering the energy consumption that is needed for heating the building. To lower the energy consumption, the thickness of the insulation can be increased. But the thicker the insulation, the higher the cost for the owner. So, the cost-effectiveness of a thicker insulation needs to be evaluated. To do this, it is important to know what the additional cost is for thicker insulation, how much the decrease of the energy consumption is and what the lifespan of the heater is. When knowing this data, it is possible to determine if there is a return on investment.

This will be simulated by a case study. In the case study different insulation materials will be used and also different building styles. Then will be examined what the minimum insulation thicknesses to meet the minimum requirements for both countries, insulation materials and different buildings styles are met. The next thing, is to determine if there is a return on investment for each simulation when insulating thicker.

Keywords—sustainability, energy performance, energy software, nearly zero energy building, return on investment

I. INTRODUCTION

It is worldwide known that the construction of buildings has a determining role on the environment. The construction is a major consumer of land and raw materials and also generates a large amount of waste. Furthermore, it is also a significant user of non-renewable energy and emitter of various kinds of gasses. For instance, the building industry consumes 40% of the raw materials. In Europe, buildings consume through their life cycle (construction, operation and demolition) 40% of the total demanded energy and also contributes to almost 36% of the CO_2 emission released in the atmosphere. A method that is most used to reduce the environmental impact is the *'life cycle assessment'*. This methodology is used for evaluating the impact of a process or a product through its live cycle.

As buildings are responsible for 40% of the energy consumption and 36% of CO_2 emissions in the European Union, is it very important to reduce this number [1], [2], [3]. Measurements to effectively reduce CO_2 emissions from buildings were written down in the European directive on the energy performance of buildings. This directive wants to stimulate the improvement of the energy performance of buildings in the EU, by taking the climatological and local conditions from outside the building into account with the requirements for indoor climate and cost effectiveness. The European Union obligates all member states to certain obligations. The ones that are most important:

- there must be a method to calculate the energy performance of buildings.
- the feasibility of alternative energy generation must be examined (renewable energy).
- From 2021, all new buildings must be nearly zero-energy building (nZEB) [4].

A first member state, Belgium, will use a software to calculate the energy performance of every building type (office, house, hospital …), but also of every nature of the work (restoration, renovation and newly build). Depending on the building permit or notification for all buildings, the stricter the requirements will be. This starts since 1st of January 2006 and since then there are certain requirements to meet. These requirements are changing every year. They are becoming more and stricter so that from 2021, all new buildings will meet the nZEB requirements. In Belgium a specific software program is used to calculate the energy performance. This program is called the *EPB-software*. It stands for 'energie prestatie en binnenklimaat' or translated: energy performance and indoor climate. The software is used by an EPB reporter and to act as one, an exam has to be taken to have an official recognition by the Flemish government. Besides the exam, a certain diploma is required. Mostly diplomas in the construction, but there are some exceptions such as: bio-engineer and bachelor electro mechanics, specialization in acclimatization [5], [6], [7], [8].

The second member state, Finland, uses Building Information Modelling (BIM) software to calculate the energy performance. The most used software is ArchiCad. BIM software can, besides the calculation of the energy performance, be used as a digital representation of the complete physical and functional characteristics of a built asset. One single BIM model can contain information on design, construction, logistics, operations, budget, schedules and many more [9].

II. METHODOLOGY

A possible solution to build more sustainable and reduce the CO2 emissions is by insulation sufficient and/or by using renewable energy so that the energy consumption reduces. To show how this energy consumption can be reduced, a case study is performed. For case, a bungalow is used as the project. It is simple, but it gives a general idea what needs to be done be done to meet the energy requirements of both countries. The project will be insulated with different insulation materials. These are mineral wool and polyurethane (PUR) for the insulation in the walls and roof and sprayed PUR and PUR boards for the insulation in the floor. Besides the different insulation materials, there will also be a comparison the typical building styles in Belgium and Finland countries. The typical building style in Belgium is that the bungalow is completely made out of bricks. For the Finnish building style, the bungalow will be completely made out of wood. Both software programs will be used to determine the bungalows energy performance. EPB will be used to determine the energy performance in Belgium and ArchiCad the energy performance in Finland. But the EPB and ArchiCad can also be used to determine if the project meets the energy requirements that is linked to the year of the building permit. In Belgium there is a difference between the requirements in 2017 and 2018. When having a building permit in 2017, the energy requirements are less stricter than those from 2018. Because the requirements have to meet the nZEB requirements from 2021. In Finland these requirements are the same since 2012 and because of the colder climate, the insulation thickness and other requirements are sufficient so that every building already meets the nZEB requirements.

So for the case, several combinations will be made. Every wall and roof insulation will be examined with every floor insulation. This for the Belgian and Finnish building style. Except when building to meet the Finnish requirements, sprayed PUR is not used as a floor insulation. This because it has not enough time to dry. It takes too long to dry and such things needs to dry as fast as possible. The same for the foundation floor, this is only 100 mm thick so that it dries faster. There is only use of PUR-like insulation in the floor. Also there is no use of PUR insulation in the wooden/ CLT structure. For this only mineral wool is used.

First of all, there is examined what needs to be done to meet both countries minimum energy requirements for every building style. For Belgium also the minimum requirements for 2017 and 2018. Secondly, what happens when thickening every insulation to the maximum thickness available and what happens when only thickening the walls and roof insulation to its maximum thickness. As for the last simulations, the insulations of the floor is kept at a thickness of 120 mm. Finally, it is calculated if the additional cost for the thicker insulation is worth it. This is done by comparing the energy consumption of the minimum requirements with the saving of on the energy consumption and the additional cost of thicker insulation. The energy consumption must decrease enough so that before the end of the lifespan of the boiler, there is a return on investment (ROI). At a certain point the additional cost for the insulation pays itself back by saving on the energy consumption for heating the building. With the following equations it is calculated if there is a return on investment:

$$C=\frac{I*K_E*(1+r)^j}{(1+a)^j} \quad (1)$$

With:

- C: cost (€)
- I: annual primary energy consumption (MJ)
- K_E: annual energy cost (€/MJ)
- r: change of investment (%)
- a: discount rate (%)
- j: year

With equation 1, the annual cost of heating the project can be calculated.

$$ROI=I_o+\left(\frac{I_{thick}*K_E*(1+r)^j}{(1+a)^j}-\frac{I_{req}*K_E*(1+r)^j}{(1+a)^j}\right) \quad (2)$$

With:

- ROI: return on investment (€)
- I_o: the additional cost for insulating thicker minus the cost for insulation according to the minimum requirements, the investment
- I_{thick}: the cost for insulating thicker
- I_{req}: the cost for insulation according to the minimum requirements

Equation 2 calculates the return on investment. It subtracts the cost for insulating so that the minimum requirements are met with the cost of insulating thicker.

Another purpose of the case study is to demonstrate how useful both software programs can be in the preliminary design phase. How easy and fast it can go to make all the simulations. In the end, it is still up to the owner if he wants to insulate thicker.

III. Results

TABLE I. SUMMARY EPB SIMULATIONS WITH ROI

Building type	Various or continuous	Thickness (mm)	Combination	Year	Point of ROI (years)
Belgian	Various	100	PUR-sprayed PUR	2017	19
Belgian	Various	120	PUR-sprayed PUR	2017	25
Belgian	Various	120	PUR-sprayed PUR	2018	25
Belgian	Continuous	100	PUR-sprayed PUR	2017	21
Belgian	Continuous	120	PUR-sprayed PUR	2017	25
Belgian	Continuous	120	PUR-sprayed PUR	2018	25
Belgian	Continuous	160	Mineral wool-sprayed PUR	2017	17
Belgian	Continuous	180	Mineral wool-sprayed PUR	2017	16
Belgian	Continuous	200	Mineral wool-sprayed PUR	2017	15
Belgian	Continuous	220	Mineral wool-sprayed PUR	2017	15
Belgian	Continuous	240	Mineral wool-sprayed PUR	2017	15
Belgian	Continuous	180	Mineral wool-sprayed PUR	2018	12
Belgian	Continuous	200	Mineral wool-sprayed PUR	2018	11
Belgian	Continuous	220	Mineral wool-sprayed PUR	2018	13
Belgian	Continuous	240	Mineral wool-sprayed PUR	2018	14
Belgian	Continuous	180	Mineral wool-PUR boards	2017	25
Belgian	Continuous	200	Mineral wool-PUR boards	2017	21
Belgian	Continuous	220	Mineral wool-PUR boards	2017	20
Belgian	Continuous	240	Mineral wool-PUR boards	2017	20
Belgian	Continuous	240	Mineral wool-PUR boards	2018	22
Finnish	Continuous	160	CLT structure-sprayed PUR	2017	21
Finnish	Continuous	180	CLT structure-sprayed PUR	2017	20
Finnish	Continuous	200	CLT structure-sprayed PUR	2017	22
Finnish	Continuous	220	CLT structure-sprayed PUR	2017	17
Finnish	Continuous	240	CLT structure-sprayed PUR	2017	18
Finnish	Continuous	200	CLT structure-sprayed PUR	2017	12
Finnish	Continuous	220	CLT structure-sprayed PUR	2017	15
Finnish	Continuous	240	CLT structure-sprayed PUR	2017	16
Finnish	Continuous	220	CLT structure-PUR boards	2018	25
Finnish	Continuous	240	CLT structure-PUR boards	2018	24

TABLE II. SUMMARY ARCHICAD SIMULATONS WITH ROI

Building type	Various or continuous	Thickness (mm)	Combination	Point of ROI (years)
Belgian	Continuous	200	Mineral wool	15
Belgian	Continuous	220	Mineral wool	19
Belgian	Continuous	240	Mineral wool	21
Belgian	Continuous	260	Mineral wool	24
Finnish	Various	140	CLT structure	20
Finnish	Various	160	CLT structure	23
Finnish	Various	180	CLT structure	20
Finnish	Various	200	CLT structure	19
Finnish	Various	220	CLT structure	19
Finnish	Various	240	CLT structure	20
Finnish	Various	260	CLT structure	24
Finnish	Various	280	CLT structure	25
Finnish	Continuous	140	CLT structure	20
Finnish	Continuous	160	CLT structure	23
Finnish	Continuous	180	CLT structure	25
Finnish	Continuous	200	CLT structure	25

After calculating every possible combination with the insulation materials and both building styles, table I and table II represent the simulations where there is a return of investment. The first table contains the results of all the simulations calculated with EPB and the second table the result of the simulations calculated with ArchiCad. Naming of the column are as followed:

- column 1
  This column tells more about the building style. This way it is possible to know if the simulation is with bricks or with the CLT structure.
- column 2
  Contains information about the thickness of the insulation. In case of various, the insulation in the wall, roof and floor will constantly have the same thickness during the simulation. Continuous means that the insulation for the floor is kept at the same thickness, 120 mm. During these simulations, the

insulation in the walls and roof will come thicker but the insulation in the floor will be the same.

- column 3
  Mentions how thick the insulation is for the relevant simulation.
- column 4
  This column represent the combination that is made. As example: mineral wool-sprayed PUR. The mineral wool indicates which insulation is in the walls and roofs and the sprayed PUR indicates the insulation that is used in the floor. In table II, there is only naming of mineral wool or CLT structure. Because there is no use of sprayed PUR, it is known that the insulation in the floor for every simulation in ArchiCad is PUR boards. So, the mineral wool indicates which insulation is used in the walls and roof. For the CLT structure there is only the possibility to use mineral wool.
- column 5
  For table I this is the year of the building permit. This is only important when calculating the results in EPB, because there is the different energy requirements in 2017 and 2018. For table 2 the 5th column indicates at which point there is a return on investment. In this case, the return on investment must be before 25 years because of the heater that is used. A condensing boiler was picked and its lifespan is 25 years.
- column 6
  This is only for the first table and its explanation is the same as column 5 of table II.

For example, the following simulation in EPB: Belgian, continuous thickness, 200 mm thick, mineral wool-sprayed PUR, 2018 and 11. This means that the building style for this example is Belgian (bricks). The thickness of the floor insulation is 120 mm and is sprayed PUR. The insulation for the walls and roof is 200 mm thick and its material is mineral wool. This simulation is only when the buildings permit is from 2018 (stricter rules) and after 11 years there is a return on investment. Meaning after 11 years the additional thickness to 200 mm is paid back after 11 years. Furthermore, until the end of the lifespan of the boiler, there is saving on the heating cost.

IV. Conclussion

It is very clear when examining the simulations mentioned in table I and table II, that keeping the thickness of the floor insulation at 120 mm is the better solution. From this can be concluded that not a lot of the warmth escapes true the floor and that the extra cost for thicker floor insulation does not have to be made. There are only tree simulations that have a return on investment when calculating with the EPB-software for the Belgian building style. These are PUR-sprayed PUR 100 and 120 mm for 2017 and 120 mm2018. In ArchiCad there are multiple simulations that have a return on investment. However it is when thickening the insulation of the Finnish building style. Almost every simulation with a continuous thickness of the floor insulation, have simulations where there is a ROI. Some have only, some have multiple. When there are multiple, the simulation with the earliest ROI is the better solution.

When comparing the building styles, it depends on the used software or the outdoor climate. In the EPB-software, there is a higher chance of return on investment with the Belgian building style. With ArchiCad, there is a higher chance when building with the Finnish style.

A last thing that needs to be compared, are the different insulation materials. For either the building style as the calculation program, mineral wool is the better insulation material in the walls and roof to have a return on investment. With the EPB simulations it is better to use sprayed PUR instead of PUR boards. There are more simulations with a return on investment when using sprayed PUR than PUR boards.

So, in general it is better to use mineral wool to insulate the walls and the roof and sprayed PUR to insulate the floor (when calculating with the EPB-software). With these insulations, there is a bigger chance to have a return on investment. There are also simulations where the return of investment is at 25 years. In this case, it is up to the owner whether or not to choose for thicker insulation and have a profit for one year.

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c	Compactness of a building	[m]
A	Surface of the cross section	[W/mK]
E	Elasticity modulus	[N/mm²]
R_c-value	Total heat resistance	[m²K/W]
U-value	Thermal transmittance	[W/m²K]
U_g-value	U-value of the glass itself	[W/m²K]
λ (lambda)	Thermal conductivity	[W/mK]

List of abbreviations

°C	degrees Celsius
AEC	Architects-Engineering-Construction
BIM	Building Information Modelling
CEN	Comité Européen de Normalisation (French: European Committee for Standardization)
CHP	Combined Heat and Power
CLT	Cross Laminated Timber
CO_2	carbon dioxide
DHW	Domestic Hot Water
E	E-level
EPB	Energieprestatie Binnenklimaat (Dutch: Energy performance and Indoor climate)
EPC	Energy Performance Certificate
EPBD	Energy Performance of Building Directive
EU	European Union
IFC	Industry Foundation Classic
K	K-level
Kh	Kelvin hour
kW	kilo Watt
kWh	kilo Watt hour
LED	Light Emitting Diode
LUBA	Land Use and Building Act
MJ	Mega Joule
NE	Net energy requirement
nZEB	nearly zero energy building
ROI	Return on investment
S	S-level
PUR	Polyurethane
PV	Photovoltaic
Wp	Watt peak

1 INTRODUCTION

Sustainable building is: '*building in such way that during the building phase, the usage phase and the eventual demolition of the construction, as less as possible environmental problems occur'.*

This is a former and old definition of the term sustainable building. When applying this definition in the construction the buildings, the build surroundings and the infrastructure have to be taken into account. Nowadays the meaning and the content of sustainable building comes from of the report of the World Commission on Environment and Development or the Brundtlant report. It has the following definition on sustainable building.

Quote:

> *Is building in such a way that here the present needs are fulfilled, without endangering or limiting the possibilities for other populations and future generations.*

It is worldwide known that the construction of buildings has a determining role on the environment. The construction sector is a major consumer of land and of raw materials and also generates a large amount of waste. Furthermore, it is also a significant user of non-renewable energy and emitter of various kinds of gasses. Due to this all, it is not possible for buildings to outrun their responsibility to contribute to sustainability. This can be done by choosing for sustainable buildings with a minimal environmental impact from start to end. But this is easier said than done. Most of the buildings are designed by a need to meet a set of minimum criteria by the architect, the government and more specifically the owner. Such criteria are often: budget constraints, time scheduling, functionality requirements, room layout, safety regulations and energy codes. Most of the criteria are being accounted for to the minimum except for the energy codes. This has improved a lot over the years, but there is still a long way to go. So, to achieve a building better than average, a building that meets all the requirements, the design team, including architect, the owner and all the other people involved in the design process, need to work together so that in the end they reached the required level of a sustainable building. The earlier in the design the minimum criteria can be determined, the easier it is to implement the criteria and the more sustainable the project will become.

In the beginning of this century, the traditional design progress of a building was done by the owner and the architect. They would create a building program. This document contains the functional, economic and time requirements of the building that becomes the basis for developing the building to the requirements of the owner and the building program. Then project engineers could design the electrical and mechanical system for the project. The architect and the project engineers must try to design a building with as much as possible efficient systems. There were no energy codes to be meet and there was no mentioning 'sustainable'. Over the years the concept of sustainability of traditional house building of houses has changed to the design of a building with a long service life, low operating and maintenance costs and high energy efficiency. Those changes needed to happen. The building industry consumes 40% of the raw materials. In Europe, buildings consume through their life cycle (construction, operation and demolition) 40% [1] of the total demanded energy and also contributes to almost 36% [1] of the carbon dioxide (CO_2) emission released in the atmosphere. The most common method that is used in order to reduce this environmental impact is the *'life* *cycle assessment'*. This is a methodology for evaluating the impact of a process or a product through its life cycle. In order to have a correct overview of the impact of a building it is not enough to only take the environmental impact into account. There is also the impact of the building on the economy and society [2], [3].

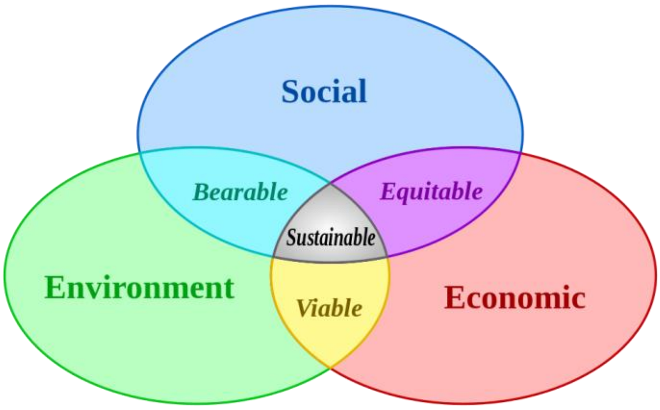


Figure 1: scheme of sustainable development [4]

According to Figure 1 *"sustainable" is the result of the influence of three policy areas*:

- **environment**: build, upkeep and manage the estates with efficient use of natural resources and minimize the environmental impact.
- **social**: provide a safe and healthy environment not only to the house owners, but also to those working on the construction sites.
- **economic**: build cost-effectively while keeping the functionality requirements and keeping the operating costs low.

During the preliminary design, everything must be taken into account. This is done here by using software which can predict the energy performance and building information modelling (BIM) software [5].

2 ENERGY EFFICIENCY

2.1 Europe

2.1.1 Overview

The European Union's policies are driven by three main objectives:

1. secure energy supplies to ensure reliable provision of energy whenever and wherever it is needed.
2. secure that energy providers operate in a competitive environment that ensures prices for homes, business and industries.
3. the energy consumption must be sustainable. This can be done by lowering of greenhouse gas emissions, pollution and fossil fuel dependence.

These objectives are important for Europe because they are importing half of its energy supplies from outside the continent. The importation causes a cost of €350 billion a year. This money is better invested in developing renewable energy sources. Nowadays the use of fossil fuel to make energy is still very high. This contributes to a higher level of CO_2 which is a greenhouse gas.

The European Union (EU) has different policies to achieve the three main objectives. First, the European Union wants to make an energy union. This ensures secure, affordable and clean energy for the EU citizens. It is a big opportunity to bring new technologies and renewed infrastructure to cut household bills, to create jobs, to boost growth and to provide more accessible energy.
Secondly, the EU wants to make a large energy market. This benefits every country in the European Union. When a country has too much energy, the energy can be transported to a country that has a shortage of it. Thanks to this, European cities are becoming producers of domestic energy. All of this is made possible by new techniques for alternative energy [6].

2.1.2 The European directive on the energy performance of buildings

In Europe buildings are responsible for more than 40% of the energy consumption and 36% of CO_2 emissions in the EU. Both the number of buildings and the energy consumption for each building keeps rising. Improving the energy performance of buildings can result in a fairly large energy saving and also a reduction of the CO_2 emission. That is because new buildings need fewer than three to five litres of heating oil per square meter per year, while older buildings consume about 25 litres on average. Some buildings even require up to 60 litres. Currently, about 35% of the European Union's buildings are more than 50 years old. By improving the energy efficiency of buildings, the total EU energy consumption can be reduced by 5-6% and the CO_2 emissions by about 5% [1].

Compelling and specific measures to effectively reduce CO_2 emissions from buildings were written down in the European directive on the energy performance of buildings (EPBD or Energy Performance of Buildings Directive), approved on 16 December 2002. This directive wants to stimulate the improvement of the energy performance of buildings in the EU, by taking the climatological and local conditions from outside the building into account with the requirements for indoor climate and the cost effectiveness [7].

The directive contains five obligations for the EU Member States:

1. they must have a method to calculate the energy performance of buildings.
2. they must formulate the minimum requirements for the energy performance of new buildings.
   The directive obligates the member states for new buildings with a total useful floor area of more than 1,000 m², to examine the technical, environmental and economic feasibility of alternative energy systems. Those alternative energy systems are systems that can contribute to an important energy saving. Examples are: cogeneration combined heat and power (CHP), a city block heater and heat pumps.
3. they also must formulate the minimum requirements for the energy performance of large buildings that undergo a major energetic renovation. The directive considers a major renovation of a large building as a good opportunity to take cost-effective measures to improve the energy performance. An 'existing large building' is an existing building with a total useful floor area of more than 1,000 m²
   The directive provides two examples of a major renovation, namely a renovation in which:
   - the total costs for changes to the outer shell of the building or installations are higher than 25% of the value of the building (excluding the land value);
   - at least 25% of the outer shell of the building is replaced.

   The directive allows the Member States to make a choice about the requirements of a major renovation for the entire building or to formulate the requirements for the individual renovated systems or structural parts, provided that the application of the requirements improves the energy performance of the building.
4. the directive obliges the Member States to introduce an energy performance certificate (EPC) that must be available during the construction, sale or rental of a building. The directive states that the energy performance certificate can only be executed by a qualified and/ or recognized expert. On / in public buildings – which after all serve as examples – must have an energy performance certificate that is hung in a striking place, visible for the public.
5. the directive obliges the Member States to introduce a regular inspection of the central heating boiler with a capacity of at least 20 kilo Watt (kW) that operates on liquid or solid, non-renewable energy. In case of a boiler with a capacity of at least 20 kW that is older than 15 years, the complete heating installation must undergo a one-off inspection. That inspection can give advice to do a replacement of the boiler, other adjustments to the heating system or an alternative solution.
   Also air-conditioning with a nominal cooling capacity of at least 12 kW must be approved regularly. The inspection includes an assessment of the efficiency of the air-conditioning and the ratio between capacity of the cooling system and the cooling requirements of the building. Users are informed about possible improvements or replacement of the system and about alternative solutions.
   Such inspections can only be executed by a qualified and/ or recognized expert.

Member States had to transpose these obligations into their own regulations by 4 January 2006. A Member State could request a three-year extension for the introduction of the energy performance certificate and for the obligation to inspect boilers and cooling equipment, if they can prove that it had too few qualified and/or recognized experts. By 4 January 2009 at the latest, both obligations had to be included in the national or regional regulations of the different Member States.

At the Spring summit of March 2007, in addition to greenhouse gas reduction and renewable energy targets, the European Council set a 20% energy saving target in comparison with a ‘business as usual’ situation in 2020.

In order to achieve the 20% reduction in energy consumption in the Union by 2020, the European Council of March 2007 has pointed out the need to increase the energy efficiency. There has been a demand for thorough and fast implementation of the priorities of the “Energy Efficiency Action Plan – realizing the potential”. This action plan has identified the significant potential for cost-effective energy savings in the construction sector.

The European Commission published a proposal in November 2008 for the revision of the European directive on energy performance of buildings. After a negotiation between the European Parliament and the Council, the revised EPBD Directive was approved on 19 May 2010. The modified directive must be transposed into national regulation no later than two years after coming into effect.

The following changes are the most important:

- for each new building, regardless of its size, the feasibility of alternative energy generation must be examined.
- for existing buildings, the scope is extended. Requirements must be set for every major renovation, regardless of the size of the building. In addition, energy performance requirements must also be determined for smaller renovations where a part of the building envelope is replaced that has a significant impact on the energy performance.
- member States should establish a requirement system in terms of a global energy performance of technical installations that are replaced in existing buildings.
- from 2021 all new buildings must be nearly zero energy buildings, on the basis of its definition in the directive, Member States can fill in this concept to a certain extend. From 2019 the authorities will only be allowed to put new buildings into use that meet the concept of ‘nearly zero-energy buildings’. Member States will have to set up a plan of action to insure an increase in that type of buildings.
- the energy performance certificate must state the technical feasibility and the cost-effectiveness of the recommended measures.
- the scope of the certificate of public buildings extends to all public buildings with a floor area larger than 500 m² that are frequently visited by the public. Five years after the directive coming into effect, the threshold is reduced to 250 m².
- the energy performance indicator must me mentioned in the advertisements before the sale or lease of a building.
- during inspection of the heating and air-conditioning system, a report must be set up that contains the recommendations and handed over to the owner or tenant.
- an independent control system for the certificates and inspections must be introduced.
- member States should lay down penalties for breaches of the legislation transposing the directive [8].

2.2 Belgium

2.2.1 General

In Belgium the implementation of the demands from Europe are divided over the three different governments, these are the:

- Flemish government,
- Government of the Walloon region,
- Government of the Brussels-Capital region.

Each of these governments has to decide what values they are going to use and what they are going to focus on. But the calculation method for new buildings is the same in the three governments. The three governments have an agreement to work together for a further development of the EPBD methodology. In Flanders, it is described in the building regulations and includes heating, cooling, domestic hot water (DHW) for residential buildings, lighting for non-residential buildings, electricity use for pumps and fans and on-site production of electricity from photovoltaic (PV) or CHP. The result is expressed in terms of primary energy. The methodology is based on the Comité Européen de Normalisation (CEN) standards.
The EPBD in Belgium was first implemented in the region of Flanders in 2006, the rest of Belgium followed two years later. The general idea behind the EPBD is the Trias Energetica [7], [9].

2.2.2 Trias Energetica

2.2.2.1 What is 'Trias Energitca'?

The Trias Energetica is one of the most applied strategies to take energy saving measures so that the Trias Energetica works efficiently. Efficient in the following meaning: as sustainable as possible, as energy efficient as possible and with as much use of energy from renewable sources as possible. But also take in the cost effectiveness into account to achieve the Trias Energetica.

The concept was introduced in 1996 by Novem (E. Lysen). This strategy was elaborated by TU Delft and consists of the following three steps:

1. reduce the demand for energy,
2. use sustainable sources of energy instead of finite fossils fuels,
3. produce and use fossil energy as efficiently as possible [10].

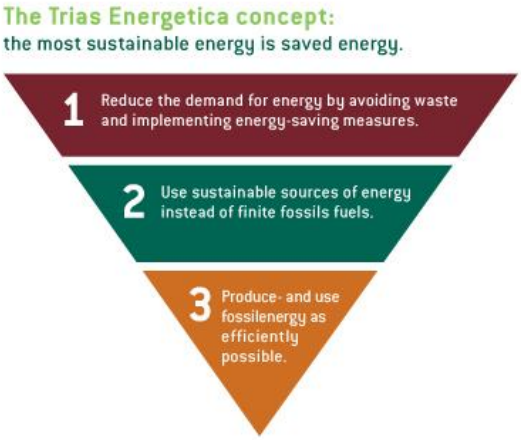


Figure 2: Trias Energetica [11]

2.2.2.2 The three steps of Trias Energetica

Step 1: reduce the demand for energy

These are architectural measures that reduce the energy demand, which means passive measures that do not require auxiliary energy.

Some examples:

- a compact form of the building, with a good ratio between surface of the outer shell and volume of the building. This can be obtained by preventing protruding parts.
- the use of decent insulation, such as the use of insulation with a high R_c-value for floors, walls and roofs and the use of glass, doors and frames with a low U-value.
- preventing thermal bridges, by means of special construction details.
- using building mass as a buffer for the retention of heat and cold.
- building dense, by a good gap sealing and attention to the connection details. In order to maintain and bring in sufficient fresh air into the building, a balanced ventilation system is required.

Step 2: use sustainable sources of energy instead of finite fossils fuels

This step focuses on the use of energy from the residual flows and the use of energy from renewable resources.

Energy from the residual flows can be recovered by means of heat recovery. Here, incoming and outgoing flows are crossed in a heat exchanger, the cold incoming flow being preheated by the warmer outgoing flow. Examples are: heat recovery of ventilation air and shower water.

Solar energy can also be used to heat water through a solar heater and generate electricity through photovoltaic cells (solar panels).

Step 3: produce and use of fossil energy as efficiently as possible

The last step of the Trias Energetica refers to sustainability. When everything has been done to save energy and use renewable energy, it is important to let the installations (for heating, hot water and ventilation) and lighting to work as efficiently as possible.

Examples of efficient applications are:

- high efficiency boilers,
- systems for low temperature heating,
- energy efficient lighting, such as light emitting diode (LED),
- shorter pipe lengths for heating and ventilation systems,
- …

With an energy producing building it is important that the energy consumption is kept as low as possible, so that the consumption of fossil energy sources can be compensated by the generated renewable energy [12].

2.2.3 Implementation of the EPBD

In Flanders you need a building permit or a notification for all buildings since 1st of January 2006 and has to fulfil the requirements. To meet the requirements, several things have to be known about the project. Because in Flanders, the buildings are classified according to their destination and what kind of works is executed. Based on these data, it is possible to determine which requirements the project must meet, depending on the year of permit or notification.

2.2.3.1 Classification of buildings

A correct classification of the buildings is an important step towards achieving a high-quality and truthful energieprestatie binnenklimaat (EPB) declaration. An incorrect classification of a building sometimes leads to incorrect EPB requirements and unjustified indicative fines. As mentioned earlier, there are two methods for dividing buildings, i.e. the destination of the building and the nature of the works.

The destination of a building can also be subdivided into two categories, residential and non-residential buildings.

Residential building:

Is a building or part of a building intended for individual or collective housing with a permanent or temporary occupation:

- either an individual home,
- either a collective accommodation,
- either an apartment building.

Individual home: residential building with one *residential unit*, of which the indoor rooms are reserved for individual use by one family.

Collective accommodation (or collective housing): residential building of which the rooms are partially shared or are intended to provide collective service in the field of restoration or care, such as boarding schools, retirement homes and other structures for collective accommodation. There is an exception of the accommodations which are part of a hospital or an establishment of the catering sector.

Apartment building: residential building with several *residential units* whose common rooms are not intended for the provision of services for residents [13].

Residential unit: part of a building that is used or intended for the housing for one or more persons, i.e. a part of the building that has the necessary (residential) facilities to function autonomously. This means that each residential unit must have the following facilities: a living room, a toilet, a shower, a bath, a kitchen or a kitchenette [14].

Non-residential building:

Are buildings such as: schools, office buildings, shops, collective housing and former other specific destinations.

Other specific destinations are buildings that do not belong to the category residential buildings, office buildings, school buildings or industrial buildings. This also includes hospitals, hotels and restaurants, sports facilities, large and retail buildings and other types of energy using buildings.

Another classification is through the kind of works of the project. A building must form one physical entity and consist of only one kind of works. All the kind of works are:

- **newly build**: a project is newly build if a completely new building (without prior demolition) is realized.
- **rebuild**: a rebuild is a newly build that is preceded by a complete preliminary demolition of an existing building
- **decommissioning**: is defined as working on an existing building with a protected volume of more than 3000 m², in which the supporting structure of the building must be maintained and in which both the installation for the realization of a specific indoor climate and at least 75% of the separation structures that limits the outside environment are replaced.
- **partial rebuild**: A partial rebuild is the reconstruction of a sub volume of an existing building that is preceded by a demolition of the sub volume. Existing construction parts can thereby be retained and together with the new construction parts they can be a part of this rebuilt sub volume.
- **expansion**: an additional protected volume is added to an existing building.
- **refurbishment**: this is all the work on an existing building whereby the volume of the existing building does not increase.
- **function change**: to determine there is a function change, one of the following questions should be answered positive.
    - is it a change of industrial destination to a living, office or school destination?
    - is it a change of industrial destination to a non-residential destination?
    - is originally no energy used to obtain a specific indoor climate and after the function change there is a use of energy to obtain a specific indoor environment.
- **major energetic renovation**: This is a renovation in which at least the exciters, to realize a specific indoor climate, are completely replaced and at least 75% of the existing and new separation structures that surround the protected volume, and limited to the outside environment, are being insulated [13].

2.2.3.2 EPBD requirements in Belgium

The first requirements were in 2006. Over the years these requirements have become stricter and the regulations were modified to make several cases clearer. The most important ones are these of the year 2017 and these of the following year (2018), because in Belgium the regulations and requirements are changing again. They are becoming stricter to achieve the nearly zero-energy buildings.

In 2017 the regulations for buildings are:

U/R-values

To determine the K-level of a building, the insulation scores of each individual construction component are required. These scores express the U-value of a construction component. The U-value is the heat transfer through a building structure and is expressed in $\frac{W}{m^2*K}$. The lower the value, the less heat loss occurs and the better the structure is insulated.

Table 1: U/R requirements 2017 in Belgium

Construction type		U_{max} [W/m²K]
Windows		1,5 and $U_{g,max}$ = 1,1
Opaque constructions	Roofs and ceiling	0,24
	All type of walls	
	All type of floors	
	Doors and gates	2,0
Wall between two houses		0,6
Wall between apartments		1,0
Renovating the exterior wall		0,24

The values in Table 1 are based on [15].

K-level (K)

This shows the total insulation level of a house. The lower the K-level, the better the house is insulated. It is calculated using insulations values of various construction components and takes heat losses through exterior walls, roofs, floors, windows and construction nodes into account.
The K-level is regulated to K40 in 2017 and this is the same for a nZEB (nearly zero energy building). The K-level for an nZEB has not changed since 2012 [16].

E-level (E)

This score expresses the global energy performance of your building. It gives insight how much energy the building consumes. The lower the E-level, the lesser energy a house needs for heating, heating of sanitary water and electricity. It is mandatory for newly built houses since 2006 and for renovations since 2015. The E- level changes every two years. It began in 2006 at a value of E100 and in 2017 the level is regulated to E50. These changes will continue until 2021 when every building must have an E30, which is nZEB. For renovations the E-level has to be E90 [17].

Net energy requirement (NE)

This is an important intermediate step to calculate the E-level. The net energy requirement represents the energy need for both heating and cooling. They express, in

$\frac{kWh}{m^2}$, how much energy is needed on annual basis to keep a house warm in the winter and cool in the summer months. The net energy requirement depends on transmission losses, ventilation losses and solar gains. So, these factors are the only thing that can reduce the net energy factor. Placing solar panels or a heat pump does not change a thing. Things that have an effect on the net energy requirement are: good insulation and avoiding construction nodes, choosing a conscious ventilation to create a healthy indoor climate and placing awnings and blinds to create shade. The requirement is 70 $\frac{kWh}{m^2}$ but this only counts for newly built houses and there is an exception for very small houses and apartments. Therefore, they determined a maximum of (100-25*c) $\frac{kWh}{m^2}$. There are no requirements for renovating [18].

Ventilation

According to the requirements there has to be a minimum ventilation provision for newly built and for major energetic renovations. This means that there should be a ventilation system that ensures that fresh air enters the house through dry rooms (bedroom, living room …) and that vapour, polluted air is drained from the wet areas (bathroom, kitchen, toilet …). The most common ventilation systems to achieve these minimum ventilation provisions are: ventilation system C and D. System C is a combination of natural supply of air and a mechanical drainage and system D comprises a mechanical supply and a mechanical drainage of air [19].

Overheating

During the winter months the solar gains and the internal heat gains through daily activities such as cooking and washing, are more than welcome save energy. However, in the summer months there is a reversed affect and there is a risk of overheating in residential buildings. The higher the indoor temperatures are, the more use is made of energy -consuming air- conditioning equipment. The requirement states that the overheat indicator must be below a maximum value. This value has been the same since 2014 and amounts to 6500 Kh. The term Kh, meaning Kelvin hour, expresses the not usable solar gain or the solar gain stored in the construction. The higher the value of overheating is, the greater the risk of discomfort due to overheating. It is allowed to have a maximum overheating of 6500 Kh, but according to the requirement extra attention is required. This means that certain measures must be taken into account, for example: shading, blinds, glazing with a low g-factor, construction type (timber frame construction) and being able to open windows. When having an overheat indicator of 1000 Kh or lower, there is not any extra attention required. The overheating only applies for new buildings [20], [21].

Renewable energy

Since 2014 there has to be a minimum amount of energy that has to be generated from renewable energy sources. In 2017 this was at least 15 $\frac{kWh}{m^2*year}$ for new buildings and 10 $\frac{kWh}{m^2*year}$ for major energetic renovations. To achieve these minimums: photovoltaic panels, solar heated water, biomass, a heat pump, district heating and/or participation in a green project, can be used [22].

In 2018 the regulations are:

U/R- value

These are the same as in 2017.

S-level (S)

This is a new term in 2018. The S-level or shell level replaces the K-level and the net energy requirement. Because the S-level is all-encompassing by including all gains and losses related to shell quality: the solar gains, the air tightness and the ventilation and infiltration loss. The level is also meant to give an indication of the quality of the shell of a building unit. This is the sum of the net energy demand for heating and the net energy equipment for cooling, but they are not the same energy requirements as the one for E-level calculation. It is only the energy demands that relates to the shell quality. The S-level requirement starts with a value of S31 for new buildings and by 2021, nZEB, a value of S31 [23].

E-level

It becomes a bit stricter. The value has to be E40 instead of E50 [24].

Ventilation

These are the same as in 2017.

Overheating

These are the same as in 2017.

Renewable energy:

These are the same as in 2017 for new buildings. For major energetic renovations this is also 15 $\frac{kWh}{m^2*year}$ instead of 10 $\frac{kWh}{m^2*year}$ [24].

2.2.3.3 Calculation of the EPBD

In Belgium a specific software program is used to calculate all the previous terms. This program is called the EPB software. It is used by EPB reporter. All the known information about the building, such as: the structural information (structure of walls, roofs and windows), the technical information (heating and ventilation) and the use of alternative energy (photovoltaic panels, heat pump …) is filled in. Once this is all inputted in the software, the energy efficiency is calculated

Figure 3: logo EPB software [25]

As said before, all of this has to be inputted by an EPB reporter. He is appointed by the owner of the building. To act as EPB reporter, one must hold one of the following diplomas:

- architect,
- civil engineer-architect,
- civil engineer,
- industrial engineer,
- technical engineer,
- bio-engineer,
- interior architect,

- graduate construction,
- bachelor construction,
- bachelor electro mechanics, specialization in acclimatization,
- architect-assistant or bachelors in applied architecture.

The EPB legislation is constantly evolving and its follow-up is a course on its own, an official recognition by the Flemish government is necessary to act as a reporter. This is done by taking an exam to become an EPB reporter in the first place and a continuous follow-up of energy performance and ventilation matter [26], [27].

2.2.3.4 Exceptions to the EPB

There are a few cases that make exception to the EPB requirements and there are certain situations in which only partial compliance to the EPB requirements is required. These are [28]:

- **specific cases with full exemption of the EPB requirements**:
    - buildings with an easy dossier and a protected volume that does not exceed the 3000 m³.
    - agricultural buildings with a low energy requirement.
    - buildings with a temporary permit for maximum two years and standalone buildings with a total useful floor area of less than 50 m².
    - renovations or function changes where the existing boiler remains [29].
- **protected monuments**:
  For this applies a partial exemption. There are only two conditions that has to be taken into account. Firstly, there are the maximum U-values and minimum R-values for converted or post-insulated roofs and floors. Secondly, there are also minimum requirements for new or renewed installations.
  This only applies on normal renovation or change of function. In case of an extension, partial rebuilding or major energetic renovations of protected monuments, the normal EPB requirements apply [30].
- **buildings on inventory of immovable heritage**:
  It is almost the same as for protected buildings. The first condition is different because now the maximum U-value and the minimum R-value applies on rebuilt or non-insulated façade parts that are invisible from the public road and for converted or non-insulated floors and roofs. There must also be provision of ventilation in rooms where the windows are replaced and that are not visible from the public road. There are also minimal requirements for new or renewed installations.
  In summary, there is an exemption on the EPB requirements for the walls and windows that are visible from the public road [31].

2.3 Finland

The following information is based on: [7], [32], [33].

2.3.1 General

The implementation of the EPBD in Finland is based on laws and decrees published in 2007. It is the overall responsibility of the Ministry of the Environment for the transposition and implementation of the Energy Performance of Buildings. Finland has had building energy efficiency regulations in the National Building Code since 1976. These regulations have been tightened several times, among others due to implementing the EPBD.

Due to the European directive in 2010, minimum energy performance requirements for the construction of new buildings have been revised and minimum requirements for existing buildings undergoing renovation and retrofitting have been developed. The revised regulations for new buildings came into force in 2012, whereas regulations for existing buildings on 1 June 2013, together with the revised legislation on energy performance certificate for buildings. Finally, in 2014 the Ministry of the Environment has issued the decree on nearly zero energy building. This laid out the basis for the national definitions on nZEB.

It is so in Finland, when applying for a building permit, there must be an energy performance certificate. This certificate is valid for ten years and must be made by an authorised person. The EPC contains a label which indicates how energy efficient the building is. This is done on a scale from A to G, A being the most efficient and G being the less efficient. The label that the building receives, is based on the calculated value of the energy consumption per m² per year. Every newly built house must be built according to the nZEB principal.

2.3.2 The National Building Code

In 2017:

> The National Building Code consists of technical regulations and instructions, which are given by the Ministry of the Environment or Government decree under the Land Use and Building Act (LUBA). It regulates the use of land areas and building activities conducted on them. The regulations are binding and concern mainly the construction of new buildings. They are applicable to renovation and alteration works on existing buildings only insofar as the type and extent of the measure and possible change of use of the building requires. The LUBA completely consists of sections. Following sections are important.
>
> **Section D3**
>
> > This section mentions the requirements concerning buildings' energy performance and mentions that the building's total energy consumption (E-number) shall be calculated. The number refers to the annually purchased amount of energy weighed by the fuel-specific factors and divided by net heated area. The fuel specific factors are as follows:

Table 2: the fuel specific factors

Energy generator	Electricity	District heating	District cooling	Fossil fuels	Renewable energy
Fuel specific factors	1,7	0,7	0,4	1	0,5

The section also sets out the maximum values for E-numbers by the size and type of the building. The E-number does not aim to represent the actual energy consumption of a building, but it functions as an indicator of energy use calculated according to specific rules.

Sections 117

This section of the LUBA sets down more direct energy efficiency requirements. According to it, a building shall be built and designed so that is spends as little energy and natural resources as possible. Fulfilment of the energy efficiency requirements shall be stated by calculations based on energy se, energy loss and form of energy. The energy performance shall be improved when renovating the existing buildings if this is technically, financially and functionally possible.

In 2018:

There was a revision of the National Building Code. And building permits from 2018 have to meet the requirements of the National Building Code. Currently (May 2018) there is no English version of the Building Code. For this reason, the revision is not implemented in the thesis.

2.3.3 Implementation of the EPBD in Finland

2.3.3.1 Requirements in Finland

The requirements for the overall energy consumption of a building were set with the new building code that came into force in July 2012. The overall energy consumption is calculated using standard user profiles and primary energy factors for different energy scores (Table 2). The aim of the new requirements is to reduce the energy consumption of all new buildings by 20% compared to previous requirements.
Minimum energy performance requirements have also been developed for existing buildings undergoing renovations and/or retrofitting that is subject of a building permit, or when the use of a building is altered, or technical systems are repaired. It is also important that actions to improve the energy performance are taken in consideration of special features and intended uses of the building. The approach to improving energy efficiency is chosen in the planning phase of the renovation or retrofitting project, and it dictates the calculation methods, as well as minimum energy requirements to be used. The feasibility of measures to improve the energy efficiency of an existing building are assessed based on technical, operational and financial considerations. Energy efficiency improvements can be done using three alternative ways:

1. energy efficiency requirements for each building,
2. energy consumption requirements for a building by class,
3. E-level requirements of a building by building type (see Figure 4).

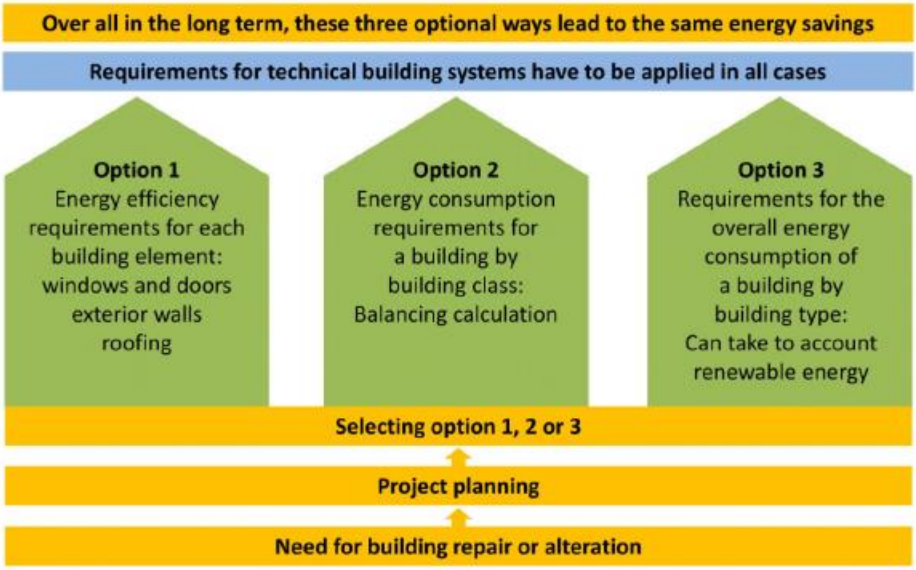


Figure 4: energy efficiency improvements for renovation and retrofitting projects

In 2017, the regulation for buildings is:

U/R-Values

Table 3: U/R requirements 2017 in Finland

Construction type	U_{max} [W/m²K]
Walls	0,17 0,40 log wall
Roof	0,09
Floor	0,09/ 0,16/ 0,17
Window	1
doors	1

The floor has various U_{max}-values. This is because for the different U-value belongs specific boundaries. For the 0,09 $\frac{W}{m^2K}$ the boundaries are outside air, 0,16 $\frac{W}{m^2K}$ when the building component is against the ground and 0,17 $\frac{W}{m^2K}$ when the floor is borders to a crawl space.

Note: the surface area of the windows are limited. The percentage of window surface cannot be higher than 15% of the floor area or more than 50% of the external wall area.

E-level

The E-level depends on the type of building and heated net area.

Table 4: maximum E-level in different building types

Type of building	Maximum value for energy consumptions per year, primary energy	
	Heated net area, A_{net} [m²]	E-level [kWh_E/m²*year]
Single-family houses	A_{net} < 120 m² 120 m² < A_{net} < 150 m² 150 m² < A_{net} < 600 m² A_{net} > 600 m²	204 372 – 1,4* A_{net} 173 – 0,07* A_{net} 130
Single-family houses (log houses)	A_{net} < 120 m² 120 m² < A_{net} < 150 m² 150 m² < A_{net} < 600 m² A_{net} > 600 m²	229 397 – 1,4* A_{net} 198 – 0,07* A_{net} 155
Terraced houses	150 kWh_E/m² per year	
Apartment buildings	130 kWh_E/m² per year	

In small residential buildings, the calculated energy consumption includes space and water heating, all electricity consumption and cooling energy. In large residential building, household electricity is not included in the energy consumption.

Technical building systems:

The Finnish National Building Code states that, when technical systems of any type of existing buildings are renovated, modernised or replaced, the following requirements must be met:

1. the minimum annual efficiency of heat recovery must be at least 45%.
2. the maximum specific fan power of a mechanical supply and exhaust system is $2 \frac{kW}{m^3/s}$.
3. the maximum specific fan power of a mechanical exhaust air system is $1 \frac{kW}{m^3/s}$.
4. the maximum specific fan power of an air-conditioning system is $2{,}5 \frac{kW}{m^3/s}$.
5. the efficiency of heating systems must be improved where possible when the related equipment and systems are renewed.

Minimum requirements have also been set for oil and gas fired boilers. These are superseded by the eco-design requirements set for boilers.

For new buildings, the calculation method is based on the E-level. It takes the building as a whole into account.

2.3.3.2 Calculation

An applicant for a building permit has to ensure that the construction fulfils the requirements. This is done through calculations whereby the results must be shown to the municipal building inspection authorities responsible for inspections the compliance of building permit applications. The calculations are based on a national calculations method that follows the main principals of CEN standards. Both CEN standards, as well as other, more detailed calculation and simulation methods, can be used. Requirements are given as a fixed value. Calculations include thermal comfort requirements, indoor air quality requirement and infiltrations, thermal bridges and shading devices. Evaluation of infiltration is either based on a site test, a quality audit or an accepted building industry quality control method. The calculation of the E-level and U/R-value is done by different programs. It can be done by the site of *laskentapalvelut* and another tool that can be used is BIM software, such as ArchiCad and Revit from the Autodesk program.

3 BIM

3.1 What is BIM?

BIM stands for Building Information Modelling and can be described as follows:

Hardin, 2009

> "*Is a revolutionary technology and process that has quickly transformed the way buildings are conceived, designed, constructed and operated.*"

The National Building Information Modelling Standards (NBIMS), 2010

> "*Is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource of information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition. A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update of modify information in the BIM support and reflect the roles of that stakeholders.*"

The Associated General Contractors of America (AGC), 2005

> "*Is the development and use of a computer model to simulate the construction and operation of a facility. The resulting model, a Building Information Model, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analysed to generate information that can be used to make decisions and improve the process of delivering the facility.*"

So, in short, BIM is a digital representation of the complete physical and functional characteristics of a built asset. According to the definitions BIM a revolutionary development that is quickly reshaping the Architecture-Engineering-Construction (AEC) and is both a technology and a process.

One single BIM model can contain information on design, construction, logistics, operation, budgets, schedules and many more. It is a revolutionary development that is quickly reshaping the AEC. BIM is both a technology and a process [34].

3.1.1 BIM as a technology

Seen from a technology perspective, a building information model is a project simulation consisting of the 3D models of the project components with links to all required information connected with the project planning, design construction or operation.

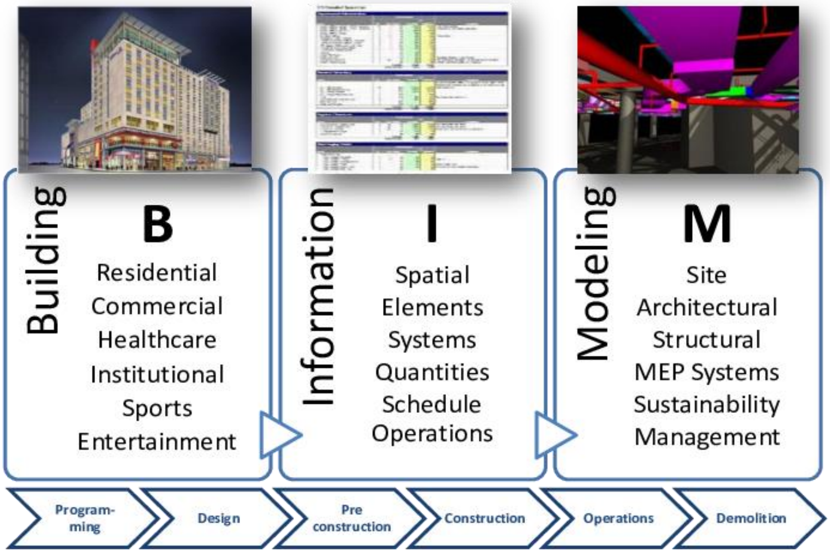


Figure 5: visual representation of the BIM concept

But there are risks to the technology side of the BIM.

- A first risk is the lack of BIM standards for model integration and management by multidisciplinary teams When integrating a multidisciplinary information in a single BIM model requires a multiuser access to the BIM model. To do is, there has to be an establishment of protocols in the project programming phase so that the information context and formatting style is consistence. For the moment there are no standard protocols so every firm uses his own standards. Because each firm has his own standards could lead to inconsistencies in the BIM model and when these are not detected, could lead to inaccurate and inconsistent BIM model.
- A second risk is interoperability. This is the ability to exchange data between applications to facilitate automation and avoid re-entry of the data. The interoperability is helped by introduction of Industry Foundation Classic (IFC) and XML Schemas. However, both approaches of their limitations. It is up to the user to decide which software application he prefers to use.
- The last risk of technology is when that team members, other than the owner and architect/ engineer, contribute data into the BIM so that a licensing issues can occur.

3.1.2 BIM as a process

Here is BIM viewed as a virtual process that includes all aspects, disciplines and systems of a facility within a single model, allowing all team members to collaborate more accurately and efficiently than traditional processes. When the model is being created, team members can constantly refine and adjust the model to the requirements and demands of the owner so that the model is as accurate as possible before building of the project begins.

As with technology, there are process-related risks.

- A first risk is the lack of determination of ownership of the BIM data and the need to protect it through copyright laws.
- Secondly there is the contractual issue. Who controls the entry of data into the model and be responsible for any inaccuracies. This person has to take responsibility for update the building information and ensure the accuracy means a great deal of the risk.
- The third risk and final risk is the organizational risk. The integrated concept of BIM causes a blur of the level of responsibility. This blur is so much that risk and liability are likely to be increased. Consider a scenario where the owner mentions a design error. Architect, engineer and other contributors of the BIM process will look at each other wondering who was responsible. When a disagreement occurs, the lead professional will not only be held responsible but may have difficulty proving fault with others.

In order to reduce these risks, it is better to have collaborative, integrated project delivery contracts in which the risks of using BIM are shared among the team members along with the rewards.

3.1.3 Benefits of using BIM

There are countless benefits of using BIM for the project, but these are the main benefits:

- **ultimate collaboration**
  It is very important to share and collaborate throughout the AEC sector. But in the past, collaborative working has often led to several problems. There were different designs and different versions of the design of the project. So now to prevent confusion, team members can rely on the BIM's cloud functionality to ensure a smoother process when working team wise.

Figure 6: collaboration with BIM

- **better visualization**
  A problem with paper design or even 2D design, is that they fail to comprehend the entirety of a project. It is not possible to imagine everything of the project in real-world scenario. Because of this the owners can find the designs somewhat disappointing. But by using BIM allows the users to visualize the project in real-world situations. It is possible to see the project at different times of day and even view its energy performance.

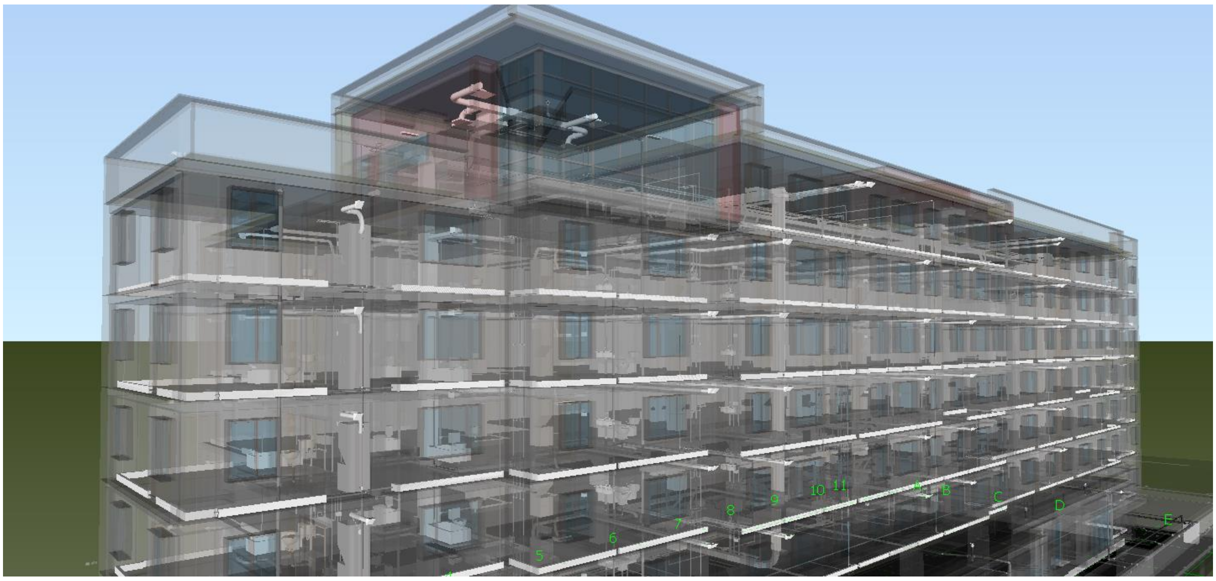


Figure 7: example of the visualization of BIM

- **cost effective**
  An overall issue in the AEC sector is the cost. For example, the project has going forward in the construction phase and then realize that there is a collision in the structure. This can be a pipe going through a wall or some other problem, but the thing is their will be an extra cost to solve this problem. This is where BIM will have a big advantage, it can detect these collisions early on. Even before moving into the building phase.
- **step-by-step process**
  When building there are a lot of people (architect, drafters, engineers …) involved into the project. This can be an issue because for example a drafter makes some changes to the design and notices that some of the team members are using an older version. The main problem is to keep everyone up-to-date with the correct documentation. When using BIM each phase of the design and construction is completely coordinated. BIM makes it possible to see the step-by-step process for materials or crew, and so on. Each process is available for every team member through the cloud.

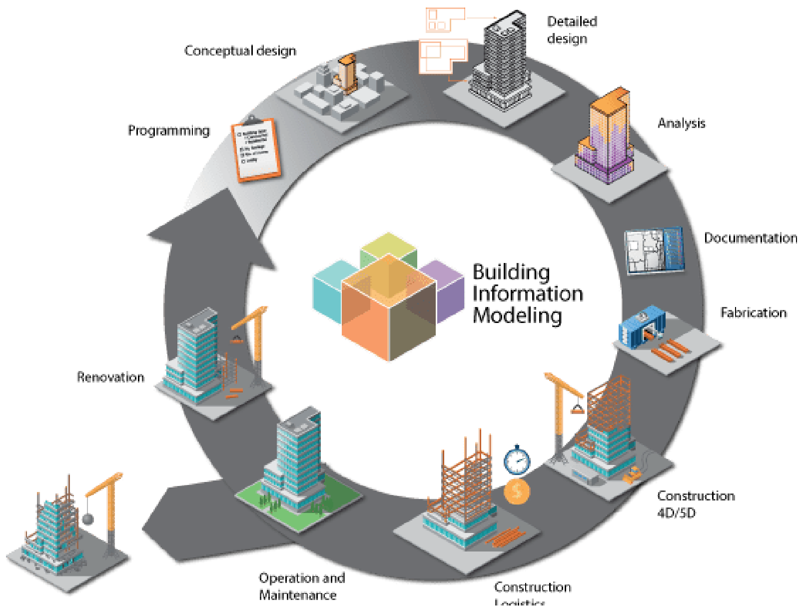


Figure 8: step-by-step process of BIM

- **improved productivity**
  When building in the AEC sector time is of the essence, because time is money. When messed up a stage in the building process, the whole entire has a setback. With the use of BIM there is no time loss, because every phase can be planned in such an efficient way. This is due the connection of each object to the database. Every change that is made to an aspect of the project has an influence on the other aspects.
- **support energy efficiency**
  As said earlier, BIM can be used to integrate sustainability into the design process and look at the energy efficiency. This is very important because an environmental analyse should be carried out after the designing is completed. If any issues occur during the building phase would be very costly and problematic. That's why it is important to check if the requirements are meet. When this is not the case, the design can easily be changed in the model.

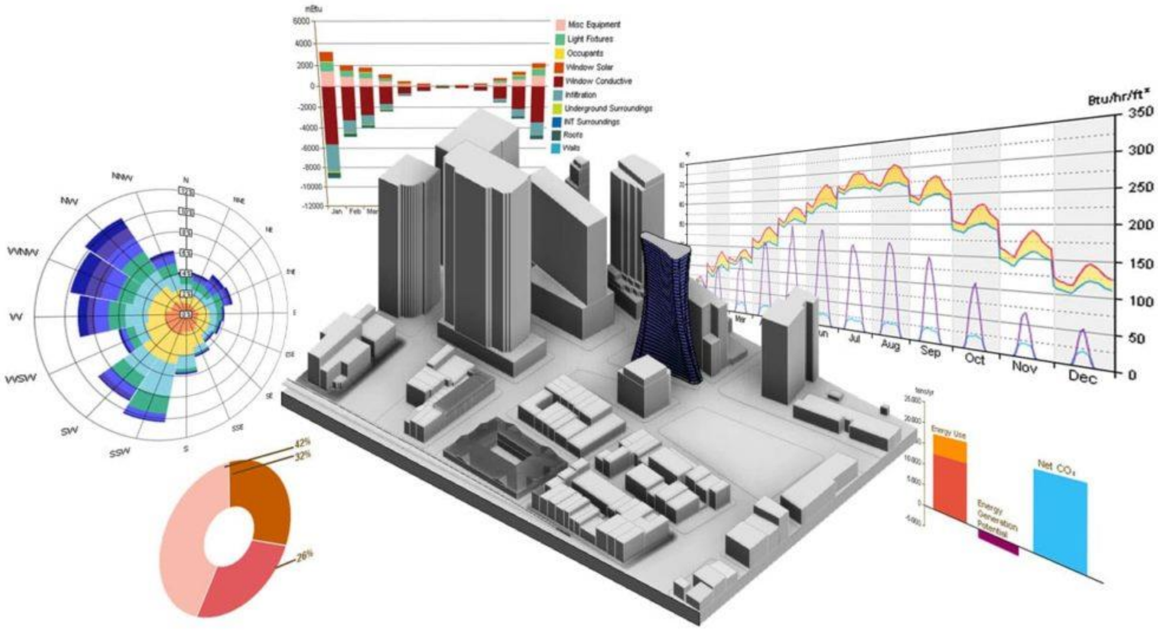


Figure 9: energy efficiency in BIM

- **better coordination**
  Due to BIM's collaboration capabilities, it is possible to stay updated of even the slightest change. There is no need to worry that team members are not aware of the changes that have been made. By using BIM everyone involved in the project stays updated of even the smallest changes. This ensures that coordination and management is a lot more smother than traditional design methods.
- **continuity**
  As is clear by now is that BIM supports the entire building lifecycle process, from its inception to its beginning even to its demolition. In essential, there is a model or document for each phase of the project's lifecycle. It is possible to optimize aspects like material usage and labour deployment to ensure an efficient design and construction process. This al is very useful so that no data ever gets lost. So, continuity can be ensured from the inception phase all the way to an eventually demolition of the structure.
- **communication**
  A major difficulty in the AEC is the relationship between an architect and owner and their communication. Architect, engineers or designers forget that they are trained in the world of construction and that the owner has sometimes has now knowledge about this. So when an architect want to show a 2D plan, most of the clients only see lines on a plan. BIM is a really helpful tool for the clients. It is possible to show the design in 3D to the client and present all of the information in a more efficient way.
- **on the go**
  An extra benefit of BIM is that is possible to take the projects and models everywhere. Thanks to the cloud there are accessible everywhere and everything is attached to a database. Al the information can be accessed at any time and on any device. Because of this, the coordination between teams and clients is going to be much easier [34]–[36].

4 CASE STUDY

The purpose of the case study is to show how useful the software programs EPB and ArchiCad can be. For making the preliminary design and determine if the project meet the energy requirements. Besides that, EPB and ArchiCad can also be used to determine if it is useful to insulate more than said in the requirements. This is be done by comparing the additional cost of the extra insulation with the primary energy consumption.
First, the EPB software is used to figure out what has to be done so that the project meets the Belgian energy standards. In a next step, ArchiCad is used to determine if the project meets the Finnish energy standards. Finally, it is possible to determine which program is faster to implement the project into the software and determine if it meets the standards, but also how long it takes to make the study of the additional cost of the insulation.

4.1 The project

For the project a bungalow is used to make the case study. This is just for the simplicity of it. It gives a general idea what needs to be done to meet the requirements and if over-insulating is useful. The obtained results can generally be interpreted. This means that for a normal two storey family house with a normal structure, no irregular forms, the results and the conclusions will be more or less the same.
There is a comparison of the typical Belgian building style, the bungalow is completely made of bricks, and the typical Finnish building style, the bungalow is then completely made out of wood and cross laminated timber (CLT). CLT is not a common material that is used as a construction material in Finland. But CLT is being used more and more. The use of CLT was taught in the course design project 2 during the Erasmus exchange program in Finland. For this course, a family home had to be designed and the structure that must be used was CLT. What was learned during this course, was used in the thesis. That is why CLT structure is used and not the common wooden structure. The styles only refers to the way of building with material. The Belgian style is with the bricks and the Finnish style with wooden walls. It does not refer how the buildings would be built in both countries. The methods of building a bungalow are different in each country.
Besides the comparison of the styles, several comparisons of the insulation materials are also made. A first comparison is between the two most common types of insulation for walls and roofs, i.e. PUR and mineral wool. Polyurethane (PUR) and mineral wool are used to insulate the walls and roofs in a typical Belgian building while with the Finnish buildings it is recommended to use mineral wool for the walls. Because the most common Finnish building style is wood, PUR is not recommended to use as an insulation material. A wooden external wall (Figure 10) is made of sections. This means the sections needs to be filled up with insulation. When filling these sections with PUR, the PUR needs to be cut to the right measurement. If this is not the case, there is a big chance that an airgap occurs between the insulation and the vertical wooden board. This problem does not arise with mineral wool. Mineral wool can be compressed together so no airgaps can occur.

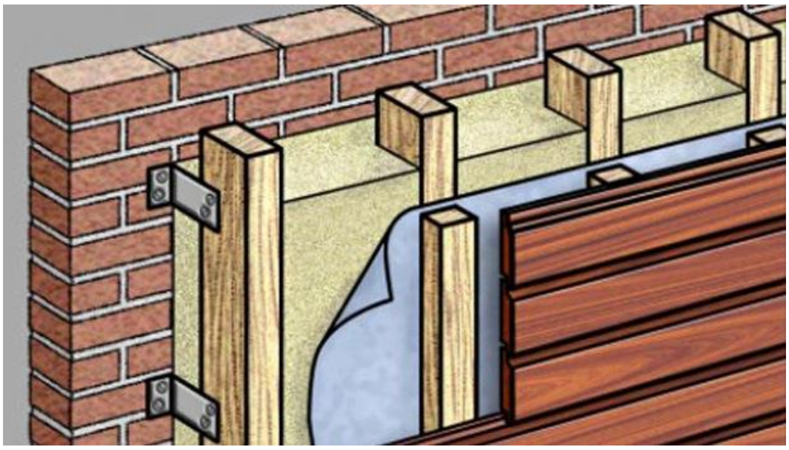


Figure 10: sections of external wooden wall [37]

The second comparison that is made, is between the different floor insulation, i.e. sprayed PUR and PUR insulation boards. The third comparison that is made, is what the differences are when all the insulation of the bungalow thickens everywhere and when the floor insulation is kept at a thickness of 120 mm. For every simulation it is checked whether the bungalow is nZEB. When this is not the case, adjustments are made to the installations of the bungalow so that it is a nZEB building. The last comparison is examining how thick the insulation must be to meet the minimum requirements in both countries. For the Belgian requirements, it is examined what the minimum thickness must be for the requirements of 2017 and the requirements of 2018.

4.2 Formula extra cost vs primary energy consumption

In order to calculate and determine if placing more insulations is worth the extra cost. The first formula that is used, can calculate the annual cost for heating the project:

$$C=\frac{I*K_E*(1+r)^j}{(1+a)^j} \tag{1}$$

With:

- C: cost (€)
- I: annual primary energy consumption (MJ)
- K_E: annual energy cost (€/MJ)
- r: change of investment (%)
- a: discount rate (%)
- j: year

Next there must be calculated how much it costs to insulate the bungalow. For this the prices of each type insulation were taken from the website of *isolatieshop.be*. When the cost for every type of insulation is calculated, the additional cost can be determined. This is subtracting the cost for insulating so that the minimum requirements are met of the cost of insulating a thicker. The formula can then be written as follows:

$$ROI=I_o+\left(\frac{I_{thick}*K_E*(1+r)^j}{(1+a)^j}-\frac{I_{req}*K_E*(1+r)^j}{(1+a)^j}\right) \tag{2}$$

With:

- ROI: return on investment (€)
- I_o: the additional cost for insulating thicker minus the cost for insulation according to the minimum requirements, the investment
- I_{thick}: the cost for insulating thicker
- I_{req}: the cost for insulation according to the minimum requirements

Some of the terms in the formula are fixed value or assumed values, these are:

- K_E = 0,01472 €/MJ
- r = 2,65%
- a = 3%

These values are general values to perform the calculations. There may be different for every energy supplier. Another thing that is assumed is that there are no maintenance costs to the boiler and that it’s life span is between 15-25 years according to data of Daikin [38]–[40].

4.3 EPB results

When entering a project in the EPB software it is not only the construction parts that have to be filled in, but also the installations, such as the heat generator (for example boiler), ventilation, photovoltaic solar panels …

To have a general picture of the project, the simple and most common technical installations were chosen. There were also chosen so that the minimum requirements were met. These installations are:

- for the generation of hot water and heating the project
  - **kind of device:** condensing boiler
  - **energy carrier:** natural gas
  - **power:** 30 kW
  - **return at 30% partial load:** 108% (2017) and 98% (2018)
  - **boiler inlet temperature at 30% partial load:** 30 degrees Celsius (°C)
  - **energy efficiency class:** A
- the heating is done by radiators which can be regulated in each room
- the ventilation unit
  - **sort ventilation system:** system D
  - **heat recovery device present in the unit:** yes
  - **thermal efficiency heat recovery:** 75%
- photovoltaic solar panels
  - **number of panels:** 5
  - **peak power of the photovoltaic system:** 250 Wp (Watt peak)
  - **area of one panel:** 1,6x1,05 m^2
  - **angle of the panels:** 15°
  - **orientation of the panels:** south

These installations are used as a starting point for every simulation and are enough to meet the Belgian energy standards.

Every material used (insulation, bricks, wood …) and all its properties are standard in the EPB software. No material had to be added.

4.3.1 Belgian building style

The structure of the construction parts of the Belgian style are as follows:

- the walls

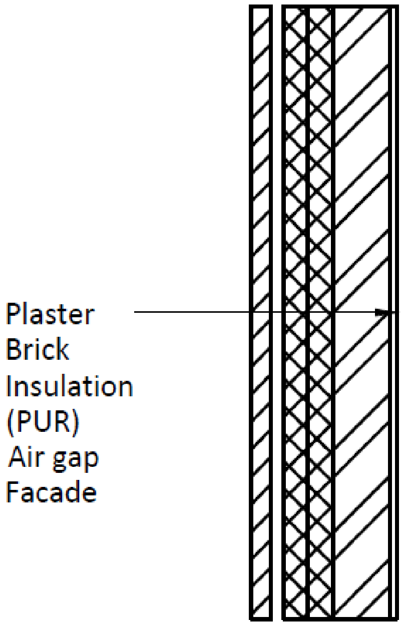


Figure 11: cross section of a wall with PUR

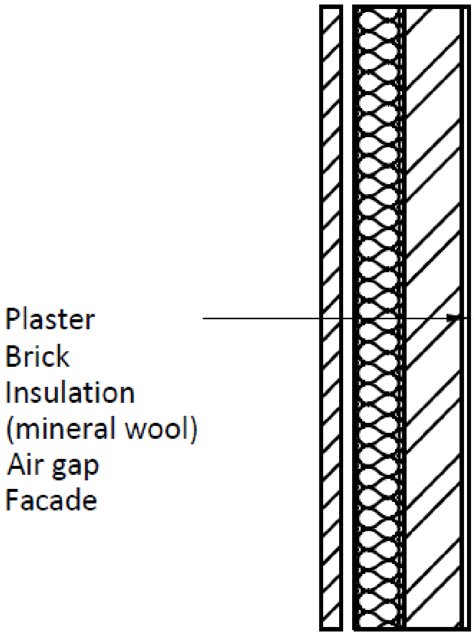


Figure 12: cross section of a wall with mineral wool

- floor

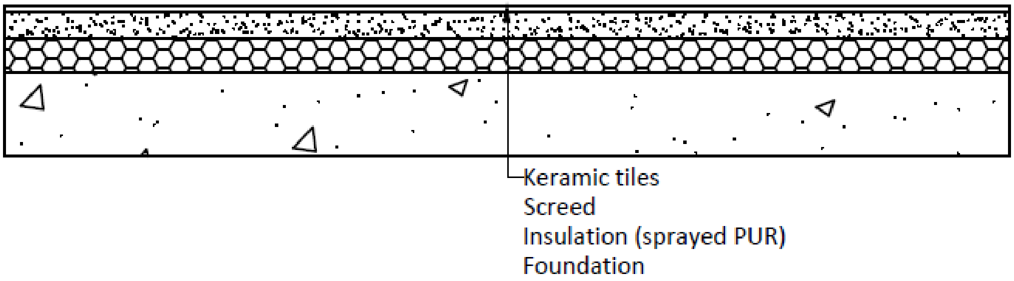


Figure 13: cross section of a floor with sprayed PUR

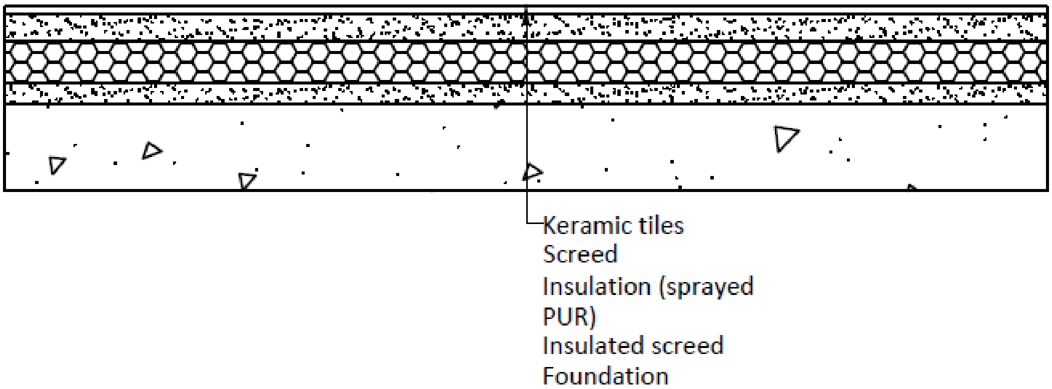


Figure 14: cross section of a floor with sprayed PUR and insulated screed

With the continuous thickening of the insulation, a maximum thickness of 240 mm is obtained with mineral wool. This thickness cannot be realized with only sprayed PUR. This insulation has a maximum thickness of 120 mm and when going for a thicker floor insulation, it has to be supplemented with insulated screed. By doing this an extra insulating effect is created.

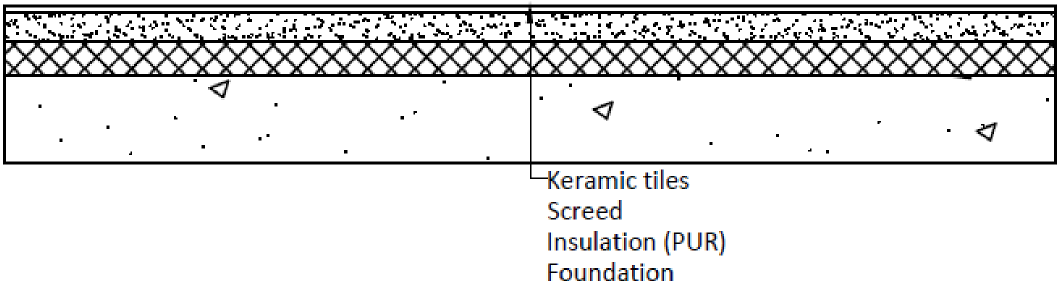


Figure 15: cross section of a floor with PUR insulation boards

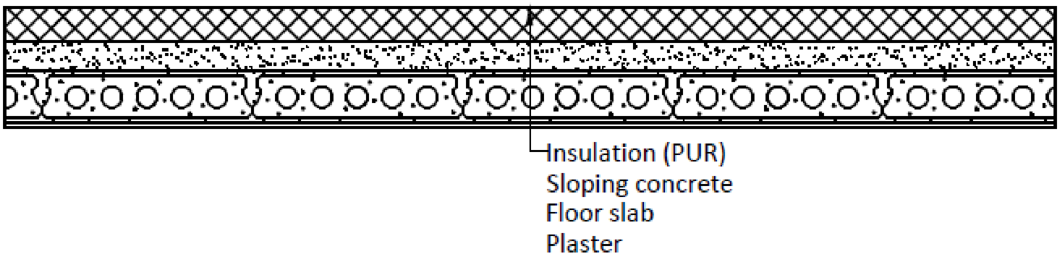


Figure 16: cross section of a roof with PUR

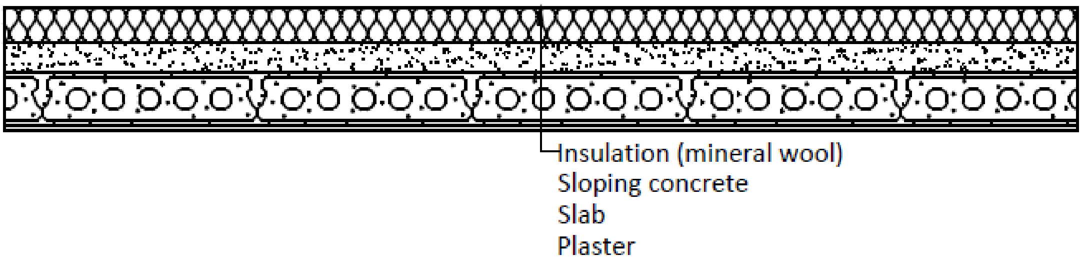


Figure 17: cross section of a roof with mineral wool

These cross sections show how the typical Belgian building style is entered in the EPB software. It is not always how it would be done in real life. The roof for example has no bitumen on top of the insulation to protect it against the sun. Because the bitumen layer has no extra insulating value.

The results of every simulation made in EPB can be seen in *annex B*. The first row with results always shows the results of the minimum requirements. In the second until the fourth column, the thickness of the wall, floor and roof in mm. These thicknesses mention how much needs to be insulated to meet the minimum requirements of the year in question. The fifth column mentions what the primary energy consumption is and the last column shows the results as they are shown in the EPB software when all the information is filled in.
The results makes it clear that the chosen technical equipment is sufficient to meet the requirements for NE≤70 and E≤50 for the year 2017 and S≤31 and E≤40 for the year 2018. In some cases, the simulations meet the nZEB requirements, then the simulation does not need any extra attention to make it meet the nZEB requirements. But most of the simulation do not

meet the nZEB requirements. It is the E-level that is always not low enough, this has to be lower than 30. The K-level, for 2017, and the S-level, for 2018, are low enough for every simulation to meet the nZEB requirements. K≤40 and S≤31. So, for all these case it is checked what is needed to make them nZEB. To make them nZEB, the same measurements were taken to show that for some simulations a bigger effort has to be done to make it nZEB than others. The used measurements are:

- change the energy efficiency class of the condensing boiler from A to A+,
- change the thermal efficiency heat recovery from 75% to 85%,
- input of some extra solar panels.

A 'X' is used in the tables to indicate if the measurements for change of the energy class and/or heat recovery where chosen. In the column for extra solar panels, a number is used to indicate how many extra solar panels were entered in the EPB software. There is always chosen to change the energy efficiency class to A+. When the possibility occurs not to choose the 85% heat recovery then this is done. By adding extra solar panels, it is ensured that the E-level decreases further. Using solar panels to decrease the E-level is a more popular solution in Belgium.

In the simulations there is an increase of the thickness of the insulation. The more insulation that is added, the better the results are. This is shown in all the results. There are several things that stand out when there is more insulation:

- decrease of K-level, E-level and NE,
- the primary energy consumption also decreased,
- there is an increase of the overheating.

The decrease of the K-level, E-level, NE and the primary energy consumption is a normal thing to happen when insulating more and better. This is because more of the warmth of the building stays inside which insures that there is less to be fired. Because there is less to be fired, the boiler does not have to make an extra effort to maintain a constant temperature, which means less energy consumption. But it also has a side-effect and that is an increase of the overheating. The better and/or thicker it is insulated the less gaps and cracks are for the warmth to escape. So, more warmth remains in the building. As long its value does not exceed 6 500 Kh, then there is no problem.

So, the thicker the insulation the better the EPB results will be. The main question now is, is insulating thicker worth the additional cost? The thicker the insulation, the more it costs. Because there are less insulation boards in a package. As example: for insulation boards of 100 mm thick, there are 5 boards in a package and for insulation boards of 50 mm thick, there are 10 boards in a package. The number of package increases when insulating the same area. To see if insulating thicker is worth the additional cost, a graph is made. The graph represents at which point the additional insulation is profitable and money is saved. The x-axis represents the number of years and the y-axis represents the return on the additional cost of the insulation thanks to the savings on the heating costs. Parallel with the x-axis, the red line, is the cost of insulating with the minimum standards and each sloping line represents the additional cost of each thickness. These lines are declining because of the saving of the heating costs. Where the declining lines cross the red line is the point when profit is made. This is the moment when the additional cost for insulation yields and start to save money.

Take in consideration that the lifespan of a boiler is between 15-25 years, so the declining lines have to cross the line of the min. demands before the 25-year mark and even better, before

15-year mark. So, it is better that the declining lines of additional insulation the horizontal line of the minimum requirements intersects as soon as possible. The sooner the lines intersect, the bigger the return on investment is. Because then, the investment for additional insulation is worth the extra cost and there is a saving of the heating cost. As said earlier, the expected life span of a boiler is maximum 25 years. In order to take advantage of the investment, the lines must intersect before the 25-year mark. In the graphs, the following cases occur:

- a first possibility is that several lines intersect the horizontal line of the minimum requirements around the 15-year mark. The first reaction is then that the line who intersects the horizontal line first is the best one, but this is not always the case. For instance, an insulation thickness of 200 mm can intersect at the 13-year mark and a thickness of 220 mm intersects at the 15-year mark. At first sight a thickness of 200 mm would be better solution, but in this case, it is better to see what the further course of the graphs are. There is a big chance that the line of 220 mm declines much faster. This means a bigger return on investment when reached the 25-year mark and that 220 mm is the better option. Besides the declining of the line, the total sum of return of investment must be taken into account. Using the same example, the 200 mm intersects sooner which means that the return on investment starts already on the 13-year mark and there is the possibility that at the 25 year the return on investment for 200 mm is bigger because of the two years of extra saving. A precise calculation is needed then.
- another possibility is that the lines intersect each other at the 23-25-year mark. In this case it is up to the owner to choose if he wants the extra insulation or not. If everything goes right, the owner would have a profit of 1-3 years, but this is only if the boiler lasts for 25 years. Choosing for the additional insulation in this case can be seen as a risk.
- the last possibility is that the line intersects just after the 25-year mark, much later or not at all. In all these cases it would not be interesting to choose for the additional insulation and would it be better just to insulate so that the minimum requirements are met.

Table 5, Table 6 and Graph 1 are an example of how the results of EPB are represented.

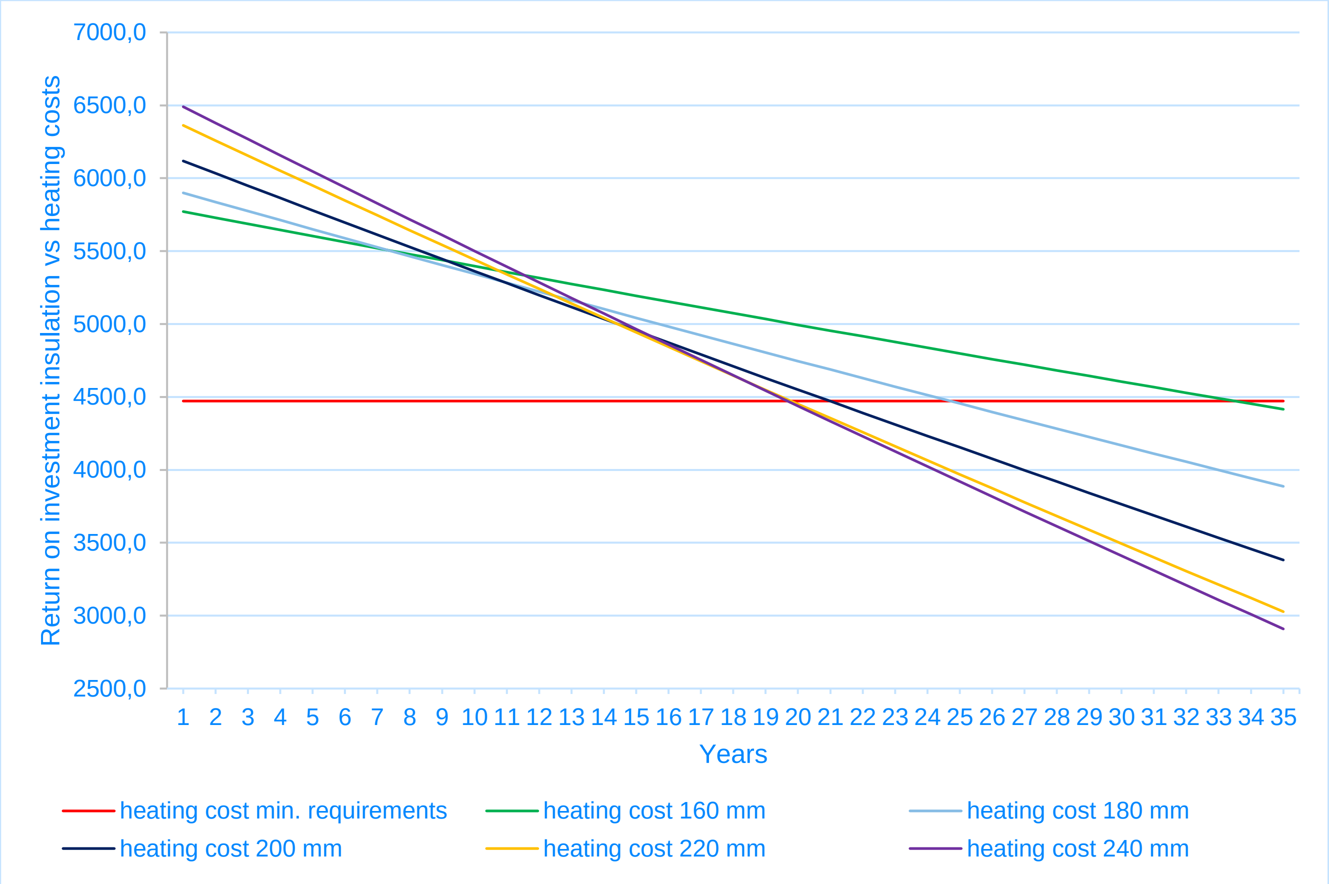
Note: every simulation where the lines intersect at or before the 25-year mark are marked *green cursive*.

Table 5: example table with EPB results

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results
Minimum requirements	140	80	180	41 079,62	U ✓ / K 30 / E 41 / Et - / NE 65 / V ✓ / O 1.378, / HE ✓
160 mm	160	120	180	38 196,17	U ✓ / K 28 / E 39 / Et - / NE 60 / V ✓ / O 1.509, / HE ✓
180 mm	*180*	*120*	*180*	*36 799,18*	U ✓ / K 27 / E 38 / Et - / NE 58 / V ✓ / O 1.580, / HE ✓
200 mm	*200*	*120*	*200*	*35 529,69*	U ✓ / K 26 / E 36 / Et - / NE 56 / V ✓ / O 1.666, / HE ✓
220 mm	*220*	*120*	*220*	*33 986,49*	U ✓ / K 25 / E 35 / Et - / NE 54 / V ✓ / O 1.744, / HE ✓
240 mm	*240*	*120*	*220*	*33 463,13*	U ✓ / K 25 / E 35 / Et - / NE 53 / V ✓ / O 1.779, / HE ✓

Table 6: example table with measurements for nZEB

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results
Minimum requirements	X		5	U ✓ / K 30 / E 30 / Et - / NE 63 / V ✓ / O 1.378, / HE ✓
160 mm	X		4	U ✓ / K 28 / E 30 / Et - / NE 60 / V ✓ / O 1.509, / HE ✓
180 mm	X		4	U ✓ / K 27 / E 29 / Et - / NE 58 / V ✓ / O 1.580, / HE ✓
200 mm	X		3	U ✓ / K 26 / E 29 / Et - / NE 56 / V ✓ / O 1.666, / HE ✓
220 mm	X		2	U ✓ / K 25 / E 30 / Et - / NE 54 / V ✓ / O 1.744, / HE ✓
240 mm	X		2	U ✓ / K 25 / E 29 / Et - / NE 53 / V ✓ / O 1.779, / HE ✓



Graph 1: example graph refund additional cost from EPB results

When studying Table 5, Table 6 and Graph 1, the following can be concluded:

- in Table 5 and Graph 1 it is clear that only one of the simulations, 160 mm, is not a return on investment. In the graph can this been seen because it intersects after the 25-year mark and in the table because it is the only simulation that is not green cursive. A following study that must be made, which simulation is the better solution. As can been seen in the graph, a couple of simulations intersect before the 25-year mark. It is then important to study the declining of the lines. In this example, it is 240 mm that is the better insulation thickness. The other information that can be seen in the table: the thickness of all the insulations, primary energy consumption and the EPB results. It is clear from the date of the floor insulation that the thickness is the same throughout the simulations.
- Table 6 represents the measurements that were taken in order to make the simulations nZEB. It was only necessary to change the energy efficiency class to A+ and add extra solar panels. Some simulations have the same measurements to make it nZEB, but the EPB results are not the same. For example 160 and 180 mm. It was done so that the nZEB requirements are met, meaning an E-level of 30. The combination of the energy class A+ and four solar panels were enough for 160 mm to obtain an E-level of 30. With the same measurements 180 mm was made nZEB and an E-level of 29 was obtained. When reducing the number of solar panels to tree, to see if it is possible to use less solar panels, an E-level of 31 was obtained. Therefore also four solar panels are needed for this simulation.

Table 7: summary refundable EPB simulations Belgian building style

Various or Continuous	Thickness (mm)	File name	Year	Point of ROI (years)
Various	100	PUR-sprayed PUR	2017	19
Various	120	PUR-sprayed PUR	2017	25
Various	120	PUR-sprayed PUR	2018	25
Continuous	100	PUR-sprayed PUR	2017	21
Continuous	120	PUR-sprayed PUR	2017	25
Continuous	120	PUR-sprayed PUR	2018	25
Continuous	160	Mineral wool-sprayed PUR	2017	17
Continuous	180	Mineral wool-sprayed PUR	2017	16
Continuous	200	Mineral wool-sprayed PUR	2017	15
Continuous	220	Mineral wool-sprayed PUR	2017	15
Continuous	240	Mineral wool-sprayed PUR	2017	15
Continuous	180	Mineral wool-sprayed PUR	2018	12
Continuous	200	Mineral wool-sprayed PUR	2018	11
Continuous	220	Mineral wool-sprayed PUR	2018	13
Continuous	240	Mineral wool-sprayed PUR	2018	14
Continuous	180	Mineral wool-PUR boards	2017	25
Continuous	200	Mineral wool-PUR boards	2017	21
Continuous	220	Mineral wool-PUR boards	2017	20
Continuous	240	Mineral wool-PUR boards	2017	20
Continuous	240	Mineral wool-PUR boards	2018	22

Table 7 is a summary of the simulations with the Belgian building style calculated in EPB where there is a return on investment. The first column shows the relation between wall, floor and roof insulation. In case of various, they all have the thickness that is mentioned in the second column. If it is continuous, the wall and roof have the thickness mentioned in the second column and the floor has a standard thickness of 120 mm. The third column shows what the insulation in the wall and roof (PUR or mineral wool) and in the floor (sprayed PUR or PUR boards). The fourth column mentions the year of building permit (2017 or 2018) because of the different requirements for each year. The last column mentions when the return on investment is. This is for example after 11 years for: continuous thickness-200 mm mineral wool-sprayed PUR 2018.

4.3.2 Finnish building style

The structure of the construction parts of the Finnish style are as follows:

- wall

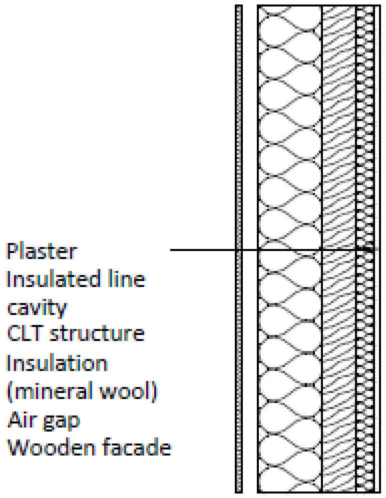


Figure 18: cross section of a CLT structure with mineral wool

- roof

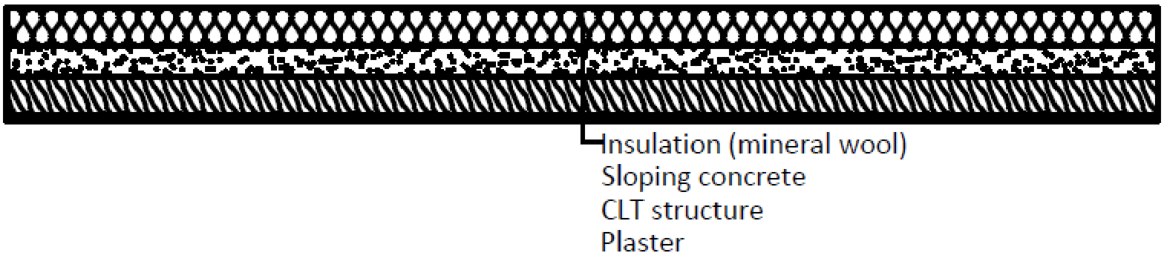


Figure 19: cross section of a CLT structure with mineral wool

This cross section shows how the typical Finnish building style for the wall and roof is entered in the EPB software. The insulation of the wall consists of two insulting parts. The first insulating part is the normal 180 mm, 200 mm, 220 mm … thick insulation that can be found more on the outside of the wall and the 60-mm thick insulation is the insulation more on the inside of the wall. When looking at Figure 18, the first insulating part is the *Insulation (mineral wool)* in the figure and the 60-mm thick insulation is *Insulate line cavity* in the figure. The inner insulation can also be used for placing electrical cables. So, the thickness in the walls are for example be referred as 180+60 mm. The 180 is than the outside insulation after the airgap and the 60 refers to the insulation in the area where cables can be placed. The floor is the same cross section as the Belgian buildings style except that the thickness of the foundation floor is only 100 mm thick. This is 150 mm less thick because the concrete requires otherwise more time and additional heating energy for drying due to the cold climate in Finland.

Note: every simulation where the lines intersect at or before the 25-year mark are marked *green cursive*.

Table 8: summary refundable EPB simulations Finnish building style

Various or Continuous	Thickness (mm)	File name	Year	Point of ROI (years)
Continuous	160	CLT structure-sprayed PUR	2017	21
Continuous	180	CLT structure-sprayed PUR	2017	20
Continuous	200	CLT structure-sprayed PUR	2017	22
Continuous	220	CLT structure-sprayed PUR	2017	17
Continuous	240	CLT structure-sprayed PUR	2017	18
Continuous	200	CLT structure-sprayed PUR	2018	12
Continuous	220	CLT structure-sprayed PUR	2018	15
Continuous	240	CLT structure-sprayed PUR	2018	16
Continuous	220	CLT structure-PUR boards	2018	25
Continuous	240	CLT structure-PUR boards	2018	24

Just as Table 7, Table 8 is a summary of the simulations of the Finnish building styles that have a return of investment. There are less simulations as with the Belgian building style and they are all continuous.

4.4 ArchiCad results

When calculating the energy evaluations in ArchiCad a couple of things must filled in:

- the right climate should be filled in. It is possible to fill in different countries and its associated climate. For this case study Helsinki is filled in.
- there is also a possibility to fill in the technical equipment. Here only two things need to be filled in, heating and ventilation.
  For the heating a “Wall-mounted gas boiler” is selected. There is chosen for a “Boiler or Furnace” with a nominal capacity of 30 000 W or 30 kW, the same as in the EPB. The ventilation system is a “Heat recovery ventilation”. To have the same settings as in EPB, mechanical supply and exhaust are chosen and that the system has heat recovery.
- doors and windows need to have overall U-value of 1 $\frac{W}{m^2K}$. For the doors it was enough to fill in 1 $\frac{W}{m^2K}$ for the opaque U-value and 0,9 $\frac{W}{m^2K}$ for the glazing U-value. The filled in values for the windows are lower. For most of the windows it is enough to have 0,6 $\frac{W}{m^2K}$ for the opaque U-value and 0,03 $\frac{W}{m^2K}$ for the glazing U-value.

As in the EPB software, all materials and its properties are standard except the cellular concrete. This material was added in ArchiCad. Its properties can be found in *Annex A*.

4.4.1 Belgian building style

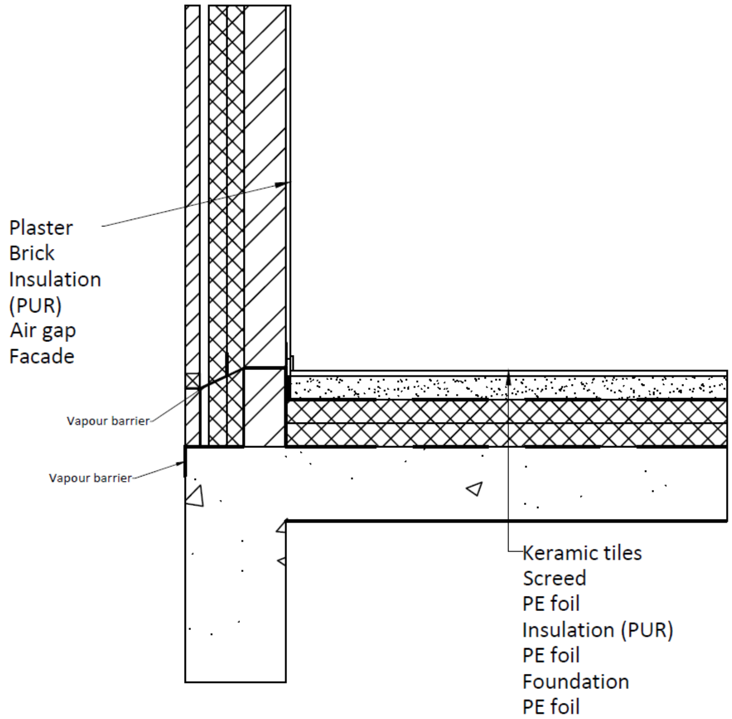


Figure 20: cross section wall-floor with PUR boards

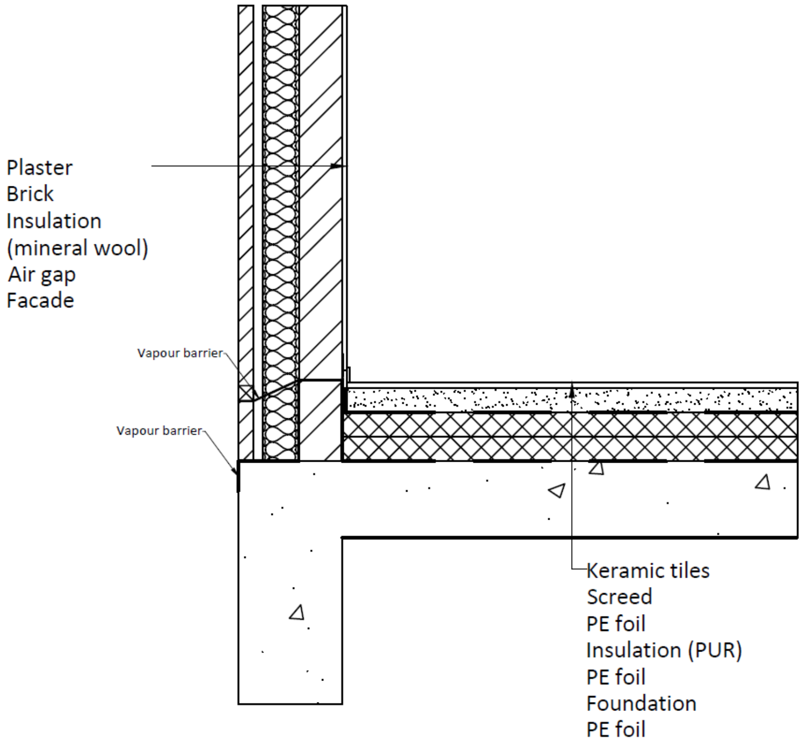


Figure 21: cross section wall-floor with mineral wool and PUR boards

In Figure 20 and Figure 21 can been seen how the walls and floor are made in ArchiCad. Because ArchiCad is a program mostly used by architects to make a 3D model of the project, every layer has to be filled in. So therefore, all membranes, foils and barriers also need to be a part of the cross sections. Besides that, the foundation beneath the wall also should be taken into consideration in the model.

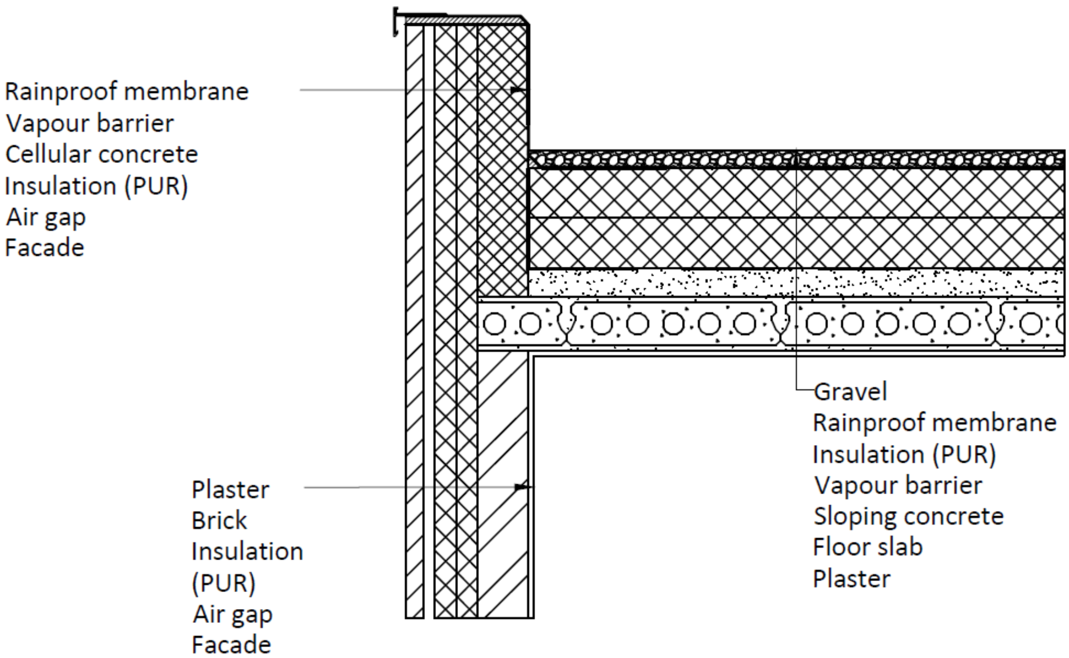


Figure 22: cross section wall-roof with PUR boards

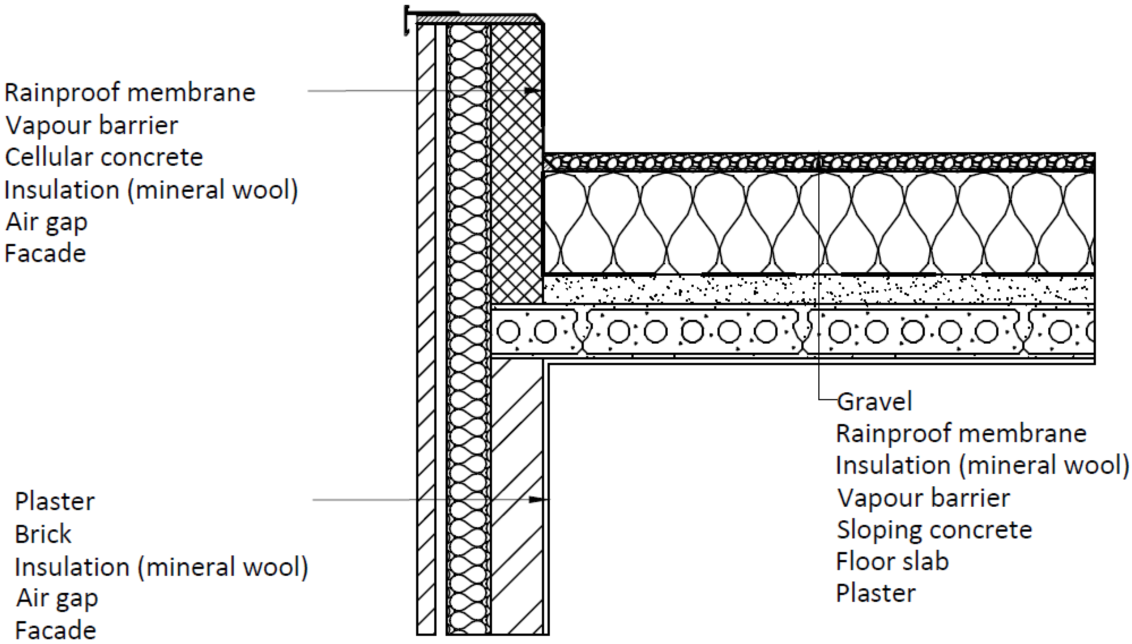


Figure 23: cross section wall-roof with mineral wool and PUR boards

Same as with the implementation of the wall and floor, a detailed implementation of the wall and roof is done in ArchiCad. There is also the extra layers of membranes and barriers, but what is most important here is the curb. Instead of regular bricks, cellular bricks are used. These have a higher insulation value what helps avoiding the thermal bridge.

As with the results from EPB, the results from ArchiCad are shown in annex. The tables are the same as the one from EPB, with the difference that the last column is the one with primary energy consumption. So, the first row shows results of the minimum requirements. In the second until the fourth column, the thickness of the wall, floor and roof in mm. These thicknesses mention how much needs to be insulated to meet the minimum Finnish requirements. In comparison with EPB there is no need to determine if the simulations meets the nZEB requirements, they already do from the start. Because the Finnish requirements for the U-values are lower than what the minimum nZEB requirements are.

As with the EPB the same cases occur:

- some lines intersect around the 15-year mark. Then the course of the lines at the 25-year mark has to be checked which one is the lowest one.
- lines intersect around the 25-year mark. The owner makes the decision whether or not to put some additional insulation a make the cost.
- the lines intersect behind the 25-year mark. Then it is better to insulate so that the minimum requirements are met.

There is no thickening of the insulation of the roof because the U-value that hast to be met is 0,09 $\frac{W}{m^2K}$ what is already a very good value. The thickening of the insulation of the walls and floor are stopped when they reached the same U-value as the insulation for the roof, 0,09 $\frac{W}{m^2K}$. Besides no thickening of the roof insulation, there is no simulation with sprayed PUR. Because sprayed PUR is rarely used if not used at all in floor insulation in Finland. The temperatures for this are not ideal for the sprayed PUR to dry fast. This is also the reason why the floor foundations are only 100 mm thick and not 200-300 mm thick as in Belgium. The structure of Figure 20, Figure 21, Figure 22 and Figure 23 are based on [41].

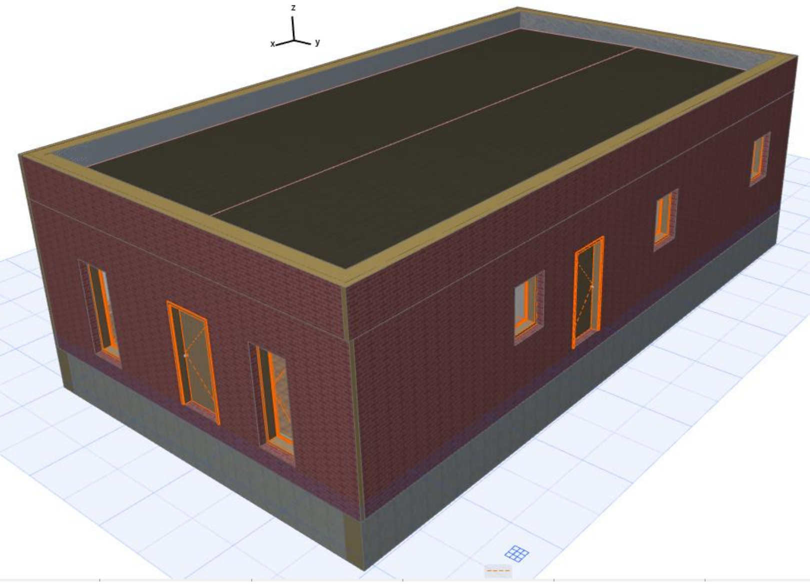


Figure 24: 3D visualisation of Belgian building style in ArchiCad

Figure 24 represent how the case looks in ArchiCad. It is a 3D visualisation of the case when built according to the Belgian building style.

Note: every simulation where the lines intersect at or before the 25-year mark are marked *green cursive*.

Table 9: example table with ArchiCad results

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)
Minimum requirements	120	160	280	38 044,8
140 mm	140	160	280	37 350
160 mm	160	160	280	36 806,4
180 mm	180	180	280	36 097,2
200 mm	200	200	280	35 506,8
220 mm	220	220	280	35 006,4
240 mm	240	240	280	34 574,4
260 mm	260	260	280	34 200

Energy Consumption by Targets

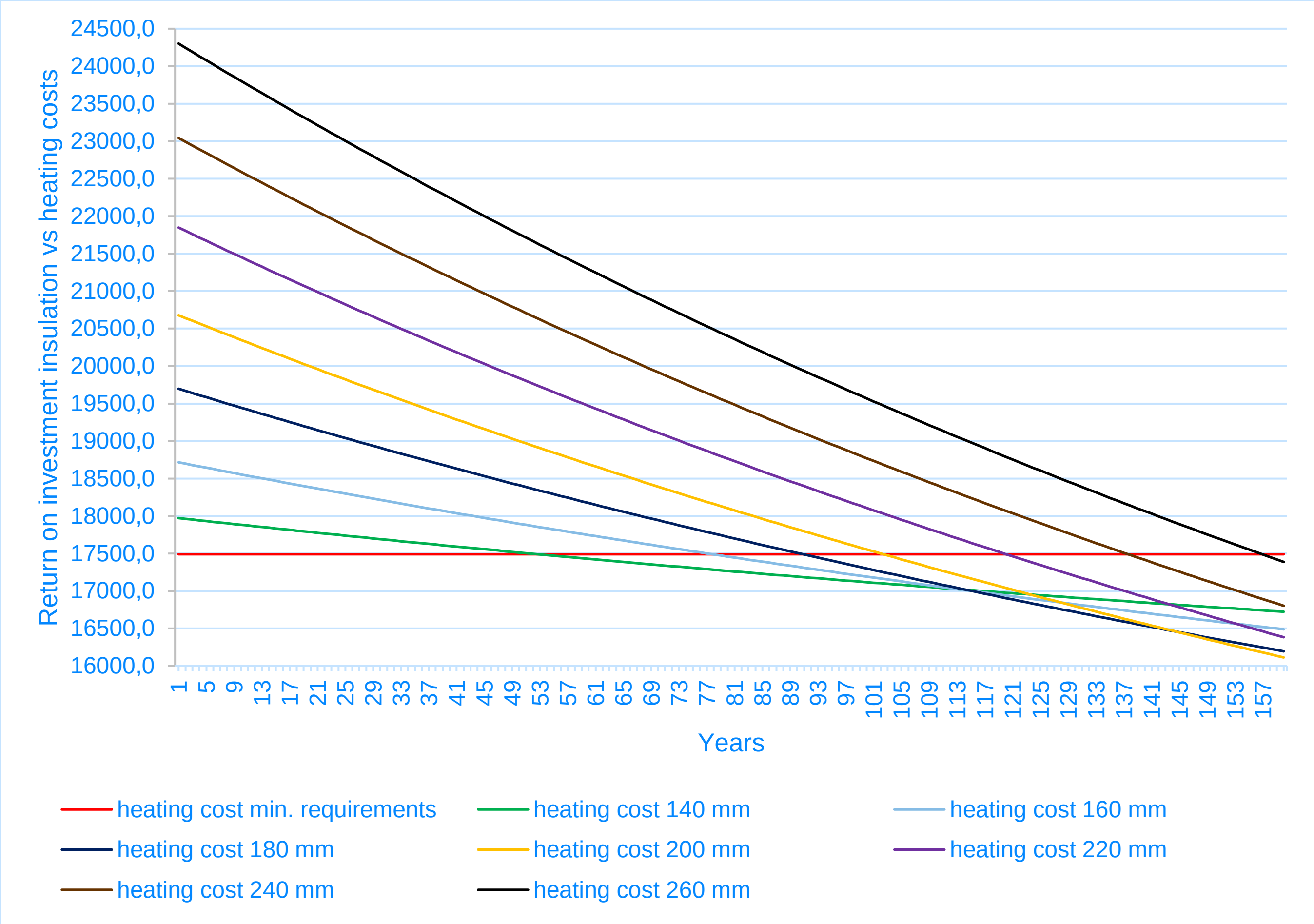
Target Name	Energy Quantity kWh/a	Energy Primary kWh/a	Energy Cost €/a	CO_2 Emission kg/a
Heating	9295	10224	136	2007
Cooling	0	0	0	0
Service Hot-Water	10993	12092	161	2374
Ventilation Fans	302	908	0	65
Lighting & Appliances	795	2385	0	171
Total:	**21386**	**25611**	**NA**	**4619**

Figure 25: results energy consumption from ArchiCad

Figure 25 is a screenshot of the results the energy consumptions get from ArchiCad. This is a screenshot from one of the simulations in Table 9. More particular the simulation with 160 mm thickness for walls and floor. The energy consumption for the heating is 10 224 kWh. But for the calculations, see *Annex C*, MJ is used. This means it must be converted. To go from kWh to MJ, there must be multiplied by 3,6. Because 1 kWh is 3,6 MJ. For this simulations the following calculation is done:

10 224*3,6= 36 806,4

The result 36 806,4 MJ can also be seen in Table 9. This action has to be done for every energy consumption for heating result of every simulation in ArchiCad.
The full file of the result of this simulation can be seen in *Annex D*.



Graph 2: example graph with refund additional cost from ArchiCad results

When examining Table 9 and Graph 2, none of the simulations have a return of investment. The simulation in this example, is a simulation of the Belgian building style with continuous insulation thickness and PUR used as insulation. So, whenever trying to meet the Finnish energy requirements with this building style and insulation material, it is better insulate so that the minimum requirements are met.

Table 10: summary refundable ArchiCad simulations Belgian building style

Various or Continuous	Thickness (mm)	File name	Point of ROI (years)
Continuous	200	Mineral wool	15
Continuous	220	Mineral wool	19
Continuous	240	Mineral wool	21
Continuous	260	Mineral wool	24

Table 10 is a summary of the simulations with the Belgian building style calculated in ArchiCad where there is a return on investment. The explanations of the columns are the same as in Table 7. Different here is that there is no column for the year of the building permit. The Finnish energy requirements do not depend on in which year the building permit is requested.

4.4.2 Finnish building style

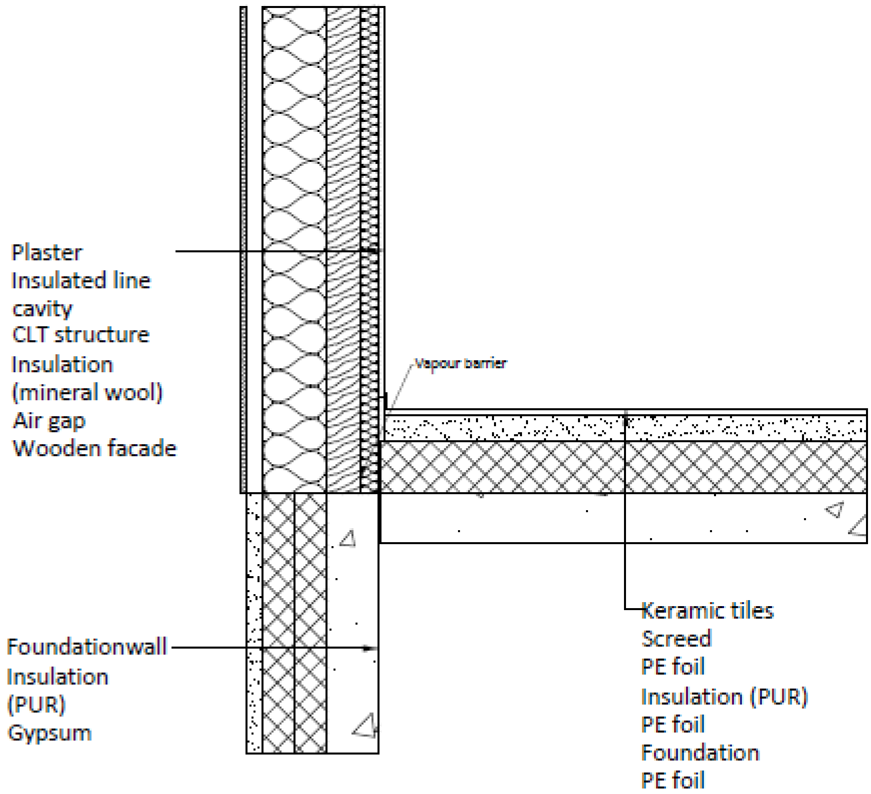


Figure 26: cross section wall-floor with CLT structure and mineral wool

Same as in the EPB, the CLT structure for the walls. The difference with the Belgian building style here is that the foundation wall is also insulated, is not as thick and there is also a façade present. This is because the terrain in Finland does not have the same level everywhere. To have descent look of the building, a gypsum or something else is placed on the outside of the foundation wall. The rest is the same as with the Belgian style, a more detailed implementation with all the membranes and foils. The structure of Figure 26 is based on [42].

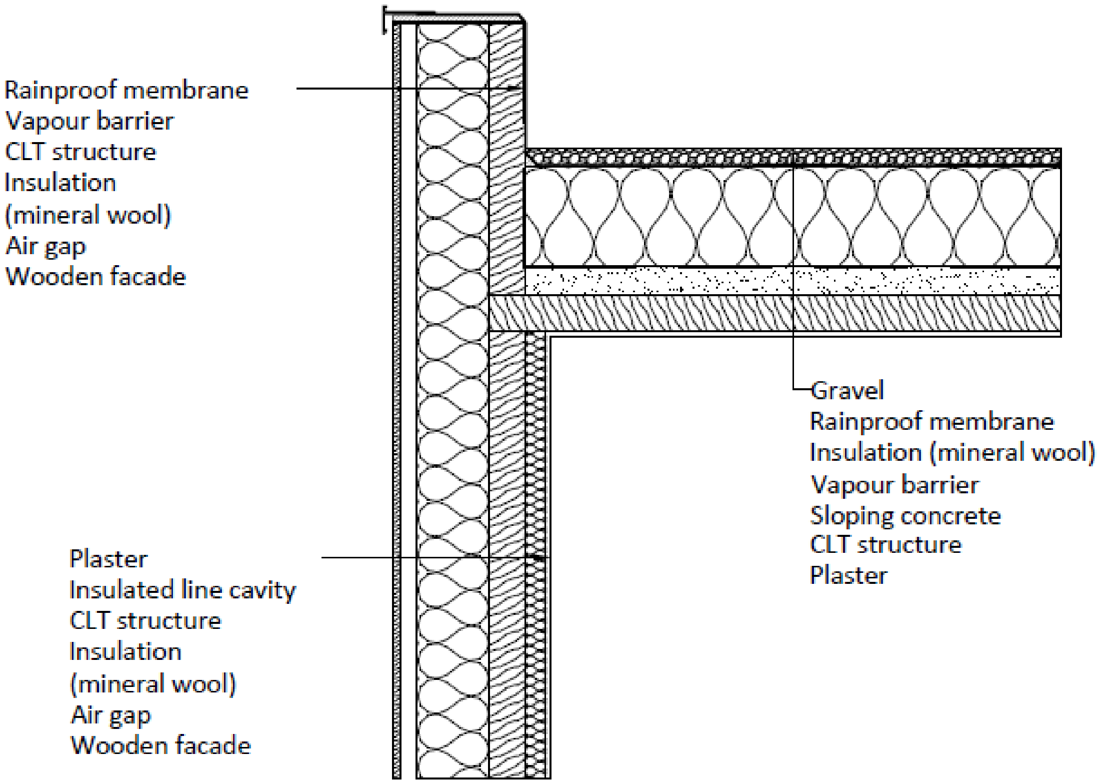


Figure 27: cross section wall-roof with CLT structure and mineral wool

A CLT structure is also used as the bearing floor. The structure in Figure 27 is based on [41].

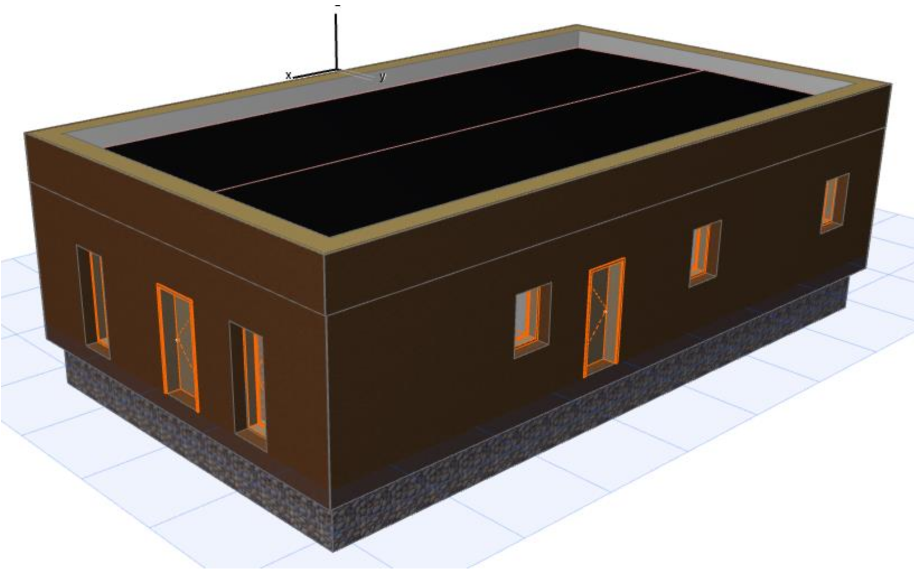


Figure 28: 3D visualisation of Finnish building style in ArchiCad

Note: every simulation where the lines intersect at or before the 25-year mark are marked *green cursive*.

Table 11: summary refundable ArchiCad simulations Finnish building style

Various or Continuous	Thickness (mm)	File name	Point of ROI (years)
Various	140	CLT structure	20
Various	160	CLT structure	23
Various	180	CLT structure	20
Various	200	CLT structure	19
Various	220	CLT structure	19
Various	240	CLT structure	20
Various	260	CLT structure	24
Various	280	CLT structure	25
Continuous	140	CLT structure	20
Continuous	160	CLT structure	23
Continuous	180	CLT structure	25
Continuous	200	CLT structure	25

5 CONCLUSION

After calculating the simulations of the bungalow in EPB and ArchiCad, the following conclusions can be made:

- the thicker the insulation, the more the primary energy consumption decreases. This applies for both the results in EPB and ArchiCad. For the Belgium requirements it is also so that the simulations, whit each thicker insulation, are getting closer to the nZEB requirements. As well as for the 2017 as for the 2018 requirements.
- there is more, thicker, insulation needed to meet the 2018 Belgium energy requirements.
- as can been seen in 2017-2018 and PUR-mineral wool, PUR boards are the better floor insulation. Its λ-value is lower and because of this, the energy consumption is lower. Due to all of this, the case meets the nZEB requirements even faster and less has to be done to make the case nZEB. But when looking at the return on investments, sprayed PUR has more simulations that have a return on investment. It would be better than to choose for sprayed PUR
- in order to meet the minimum requirements with mineral wool, the insulations thickness has to be thicker when compared to the thickness of the PUR insulation. This is because of its higher λ-value. What stands out furthermore is that the primary energy consumption for the minimum requirements are lower for mineral wool than for PUR. Besides this, which each additional insulation thickness the energy consumption declines fast with PUR. Because of the higher thickness of the mineral wool for the minimum requirements, the primary energy consumption is lower. But when increasing the thickness of the insulation, a higher thickness has a bigger influence on the primary energy consumption with PUR then with mineral wool due to its lower λ-value.
- the conclusion between the different building styles is the same as the one with mineral wool and PUR for the primary energy consumption. Because in the Finnish building style, with CLT structure, there is more mineral wool present to meet the requirements. Due do this, the primary energy consumption is lower when compared to the Belgian building style with mineral wool but at the thickest insulation thickness, the Belgian style has a lower primary consumption. The same cannot be said when using PUR boards. For this case it is completely the opposite. The Belgian style has a lower primary energy consumption for the minimum requirements and for the thickest insulation simulation.
- the following can be said about the results of various and continuous insulation thickness. In general, can be said that keeping the thickness of the floor insulation the same is the better solution. This means that not a lot warmth escapes true the floor and the extra cost for thicker floor insulation does not have to be made. After doing the simulations, none of the various thickness has a return on investment expect for PUR-sprayed PUR 2017 and 2018 for the Belgian building style calculated with EPB and the Finnish building style calculated with ArchiCad. For 2017 there are two simulations, 100 mm and 120 mm. Here it is the 100 mm that is the better solution. The intersection of the 120 mm is at the 25-year mark and the one of 100 mm around the 18-year mark. This one is better because only the insulation in the walls and floor were changed, which means there was a saving on the cost of insulation. Due to the saving of the cost and enough decreasing of the energy consumption, there could be a return on

investment. It is a similar situation for 2018, there was only the thickening of the floor insulations. In ArchiCad there are five simulations where there is a return on investment.

For almost every simulation with a continuous thickness of the floor insulation, there are simulations with a return on investment. In some cases, there is only one, but for others there are simulations where every single one is a return on investment. Then most of the time it is the thickest insulation thickness that is the better result. In other cases, a sum of the return of the investment has to be made to see which thickness has the biggest return on investment and is the better solution.

A next thing is that mineral wool has a bigger chance of having simulations with a return of investment. This is because the price for thicker insulation is cheaper for mineral wool than it is for PUR. The energy consumption decreases similar for both, but the cost for insulation with mineral wool does not increase as fast as it does with PUR.

So, insulating thicker than the minimum requirements can be a good investment. Only when working with mineral wool and sprayed PUR. Mineral wool and PUR boards as floor insulation is also a possibly, but there is a bigger chance that insulating with the sprayed PUR there is a return on investment.

What wants to be expected is a big as possible decrease of the primary energy consumption and a little as possible increase of the insulation cost. When these terms are fulfilled, the thickening of insulation is profitable.

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7 ANNEXES

Annex A: Floor plans

Annex B: Technical data sheet

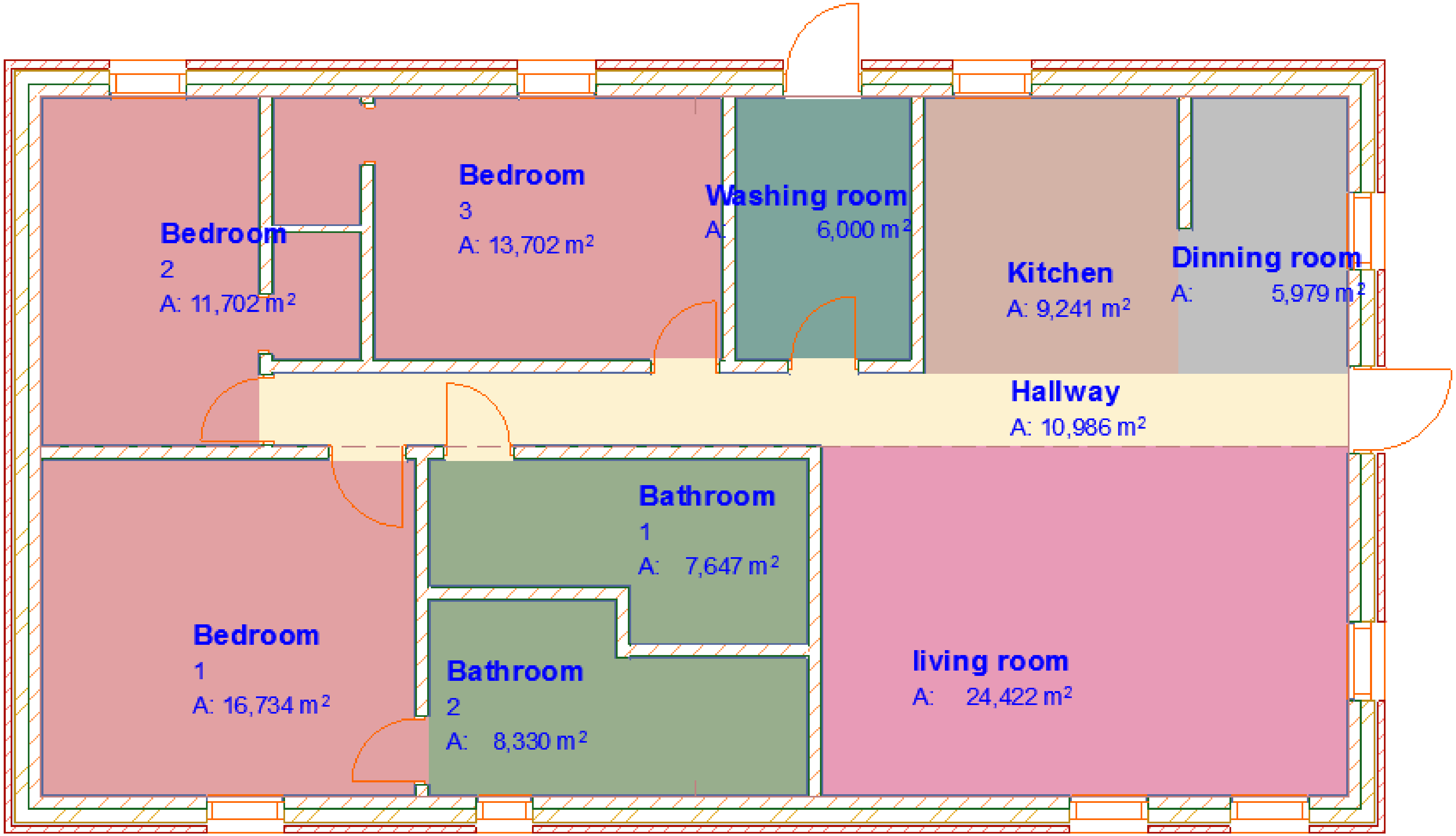
Annex C: Calculation and results

Annex D: Energy performance report from ArchiCad

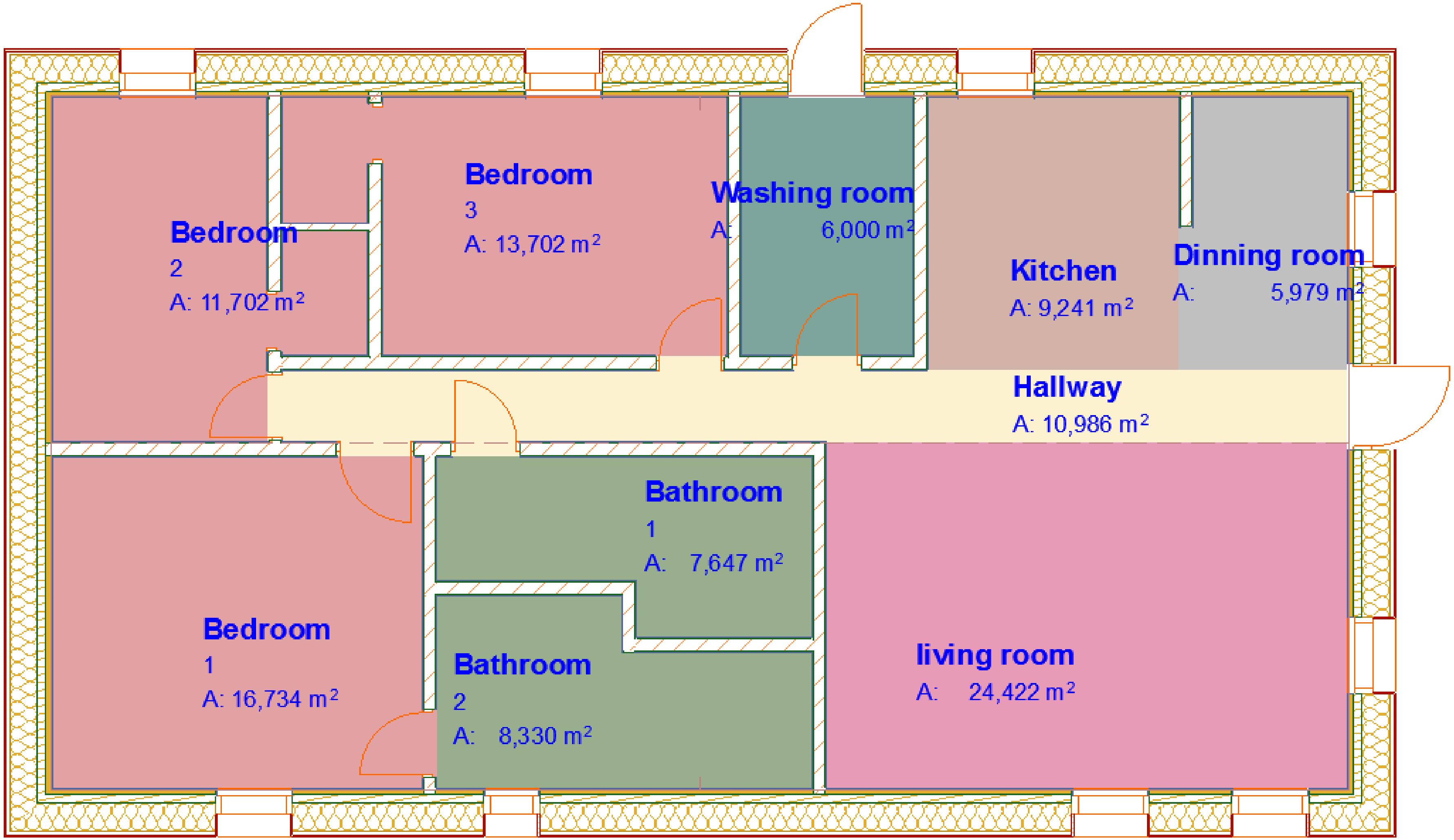
ANNEX A FLOOR PLANS BUNGALOW

- Floorplan bungalow Belgian building style
- Floorplan bungalow Finnish building style

- Floorplan bungalow Belgian building style



- Floor plan bungalow Finnish building style



ANNEX B TECHNICAL DATA SHEET

- Ytong block

TECHNISCHE DATA YTONG

Gamma Ytong kimblokken (gehydrofobeerd#)

Gewichts-klasse	Formaat mm	Dikte mm	Aantal per palet	Aantal/m²	Gewicht kg/blok **	Transport-gewicht kg/palet *	Profilering ***
C4/500	600x150	90	156	11,1	6,08	964	G
	600x200	90	130	8,3	8,11	1069	G
	600x250	90	104	6,7	10,13	1069	G
	600x150	100	144	11,1	6,76	988	G
	600x200	100	120	8,3	9,03	1099	G
	600x250	100	96	14,4	11,88	1098	G
	600x150	140	96	11,1	9,46	923	G
	600x200	140	80	8,3	12,65	1027	G
	600x250	140	64	6,7	15,77	1024	G
	600x150	150	96	11,1	10,14	988	G
	600x200	150	80	8,3	13,55	1099	G
	600x250	150	64	6,7	14,62	1080	G
	600x300	150	48	5,5	20,33	991	G
	600x150	175	72	11,1	11,84	867	G
	600x200	175	60	8,3	15,79	962	G
	600x250	175	48	6,7	19,74	962	G
	600x200	190	60	8,3	17,12	1042	G
	600x250	190	48	6,7	21,40	1042	G
	600x200	200	60	8,3	18,07	1099	G
	600x300	200	40	5,5	27,10	1099	G
	600x150	215	60	11,1	14,55	888	G
	600x200	215	50	8,3	19,40	985	G
	600x250	215	40	6,7	24,25	985	G

G = glad
* inclusief houten palet (15 kg)
** exclusief houten palet
*** verlijming van de kopse voegen

Gehydrofobeerd = vermijdt te snelle opname van vocht tijdens de ruwbouwfase. Gebruik van een waterkerende laag blijft noodzakelijk. De kopse voegen moeten steeds verlijmd worden.

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YTONG

TECHNISCHE DATA YTONG

Algemene technische gegevens Ytong kimblokken

		Eenheid	C4/500
Volumieke massa	Drooggewicht	kg/m^3	450 - 500
	Rekengewicht	kg/m^3	535
Gemiddelde genormaliseerde druksterkte f_b		N/mm^2	4,5
Karakteristieke druksterkte Ytong eerste laag f_k * (berekend voor gemetselde muur)		N/mm^2	3,0
Warmtegeleidingscoëfficient λ_{Ui}		W/mK	0,125
Soortelijke warmte c		J/kgK	1000
Diffusieweerstandgetal µ		-	5/10
Lineaire uitzettingscoëfficiënt α		m/mK	$8x10^{-6}$
Elasticiteitscoëfficiënt E		N/mm^2	3000

* Bepaling f_k volgens NBN EN 1996-1-1-ANB
γ_M (veiligheid materiaal Ytong) niet inbegrepen

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ANNEX C CALCULATION AND RESULTS

Calculation

- Cost insulation
- EPB Belgian style various thickness PUR-sprayed PUR 2017
- EPB Belgian style various thickness PUR-sprayed PUR 2018
- EPB Belgian style various thickness PUR-PUR boards 2017
- EPB Belgian style various thickness PUR-PUR boards 2018
- EPB Belgian style various thickness mineral wool-sprayed PUR 2017
- EPB Belgian style various thickness mineral wool-sprayed PUR 2018
- EPB Belgian style various thickness mineral wool-PUR boards 2017
- EPB Belgian style various thickness mineral wool-PUR boards 2018
- EPB Belgian style continuous thickness PUR-sprayed PUR 2017
- EPB Belgian style continuous thickness PUR-sprayed PUR 2018
- EPB Belgian style continuous thickness PUR-PUR boards 2017
- EPB Belgian style continuous thickness PUR-PUR boards 2018
- EPB Belgian style continuous thickness mineral wool-sprayed PUR 2017
- EPB Belgian style continuous thickness mineral wool-sprayed PUR 2018
- EPB Belgian style continuous thickness mineral wool-PUR boards 2017
- EPB Belgian style continuous thickness mineral wool-PUR boards 2018
- EPB Finnish style various thickness CLT structure-sprayed PUR 2017
- EPB Finnish style various thickness CLT structure-sprayed PUR 2018
- EPB Finnish style various thickness CLT structure-PUR boards 2017
- EPB Finnish style various thickness CLT structure-PUR boards 2018
- EPB Finnish style continuous thickness CLT structure-sprayed PUR 2017
- EPB Finnish style continuous thickness CLT structure-sprayed PUR 2018
- EPB Finnish style continuous thickness CLT structure-PUR boards 2017
- EPB Finnish style continuous thickness CLT structure-PUR boards 2018
- ArchiCad Belgian style various thickness PUR
- ArchiCad Belgian style various thickness mineral wool
- ArchiCad Belgian style continuous thickness PUR
- ArchiCad Belgian style continuous thickness mineral wool
- ArchiCad Finnish style various thickness CLT structure
- ArchiCad Finnish style continuous thickness CLT structure

- Cost insulation

P U R

	Wall insulation						
	Recticel Eurowall						
	Thickness	Width	Rd-value	m²/pak	# packs	€/m²	€
	60mm	1200mm	2,7	5,76	26	11,64	1731,33
	95mm	1200mm	4,3	3,6	41	17,28	2570,23
	100mm	1200mm	4,5	3,6	41	18,18	2704,09
	120mm	1200mm	5,45	2,88	52	21,46	3191,96
	140mm	1200MM	6,35	2,16	69	24,77	3684,29
60+100mm	160mm	1200mm	/	/	/	/	4435,43
60+120mm	180mm	1200mm	/	/	/	/	4923,29
2*100mm	200mm	1200mm	/	/	/	/	5408,19
100+120mm	220mm	1200mm	/	/	/	/	5896,05
2*120mm	240mm	1200mm	/	/	/	/	6383,92
100+160mm	260mm	1200mm	/	/	/	/	7139,52
120+160mm	280mm	1200mm	/	/	/	/	7627,39

	Roof insulation						
	Recticel Eurothane Bi 4						
	Thickness	Width	Rd-value	m²/pak	# packs	€/m²	€
	80mm	1200mm	3,1	4,32	32	17,69	2631,21
	100mm	1200mm	3,8	3,6	39	21,54	3203,86
	120mm	1200mm	4,6	2,88	49	26,38	3923,76
	140mm	1200mm	5,35	2,88	49	31,42	4673,41
2x80mm	160mm	1200mm	6,32	4,32	32	17,69	5262,42
	180mm	1200mm	/	/	/	/	5835,07
2x100mm	200mm	1200mm	/	/	/	/	6407,72
100+120mm	220mm	1200mm	/	/	/	/	7127,62
2x120mm	240mm	1200mm	/	/	/	/	7847,52
100+160mm	260mm	1200mm	/	/	/	/	8466,28
80+2x100mm	280mm	1200mm	/	/	/	/	9038,93

Floor insulation						
Eurofloor						
Thickness	Width	Rd-value	m²/pak	# packs	€/m²	€
20mm	1200mm	0,9	27	5	6,8	952,20
30mm	1200mm	1,35	36	4	8,3	1162,25
40mm	1200mm	1,8	27	5	10,02	1403,10
50mm	1200mm	2,25	21	7	11,8	1652,35
60mm	1200mm	2,7	18	8	13,65	1911,41
80mm	1200mm	3,6	12	12	18,78	2629,76
100mm	1200mm	4,5	9	16	22,38	3133,87

Total cost floor insulation	
Thickness	€
80mm	2629,76
100mm	3133,87
120mm	3822,82
140mm	4536,97
160mm	5259,53
180mm	5763,63
200mm	6267,74
220mm	6956,69
240mm	7670,84
260mm	8179,15

Sprayed PUR + insulating creed

Floor insulation

Sprayed PUR		
Thickness	€/m²	€
80mm	25,00	***3500,75***
100mm	27,50	***3850,83***
120mm	30,00	***4200,90***

Insulating creed		
Thickness	€/m²	€
40mm	30,00	***4200,90***
60mm	31,25	***4375,94***
80mm	32,50	***4550,98***
100mm	33,75	***4726,01***
120mm	35,00	***4901,05***

Total cost insulation	
Thickness	€
80mm	3500,75
100mm	3850,83
120mm	4200,90
160mm	8401,80
180mm	8576,84
200mm	8751,88
220mm	8926,91
240mm	9101,95

mineral wool

Wall insulation

	Isover isonconfort 35						
	Thickness	Width	Rd-value	m²/pak	***# packs***	€/m²	€
	60mm	1200mm	1,7	8,4	***18***	3,55	***528,03***
	80mm	1200mm	2,25	6,36	***23***	4,17	***620,25***
	100mm	1200mm	2,85	5,4	***28***	5,15	***766,01***
	120mm	1200mm	3,4	4,68	***32***	5,62	***835,92***
	140mm	1200mm	4	4,08	***36***	6,5	***966,81***
	160mm	1200mm	4,55	3,12	***48***	7,5	***1115,55***
	180mm	1200mm	5,1	2,76	***54***	8,5	***1264,29***
	200mm	1200mm	5,7	2,64	***56***	9,19	***1366,92***
	220mm	1200mm	6,25	2,52	***59***	10,12	***1505,25***
	240mm	1200mm	6,8	2,4	***62***	11,03	***1640,60***
	260mm	1200mm	/	/	/	/	***1802,73***
	280mm	1200mm	/	/	/	/	***1933,62***
140+160mm	300mm	1200mm	/	/	/	/	***2082,36***
2*160mm	320mm	1200mm	/	/	/	/	***2231,10***
160+180mm	340mm	1200mm	/	/	/	/	***2379,84***

Roof insulation

	Isover rollisol plus						
	Thickness	Width	Rd-value	m²/pak	***# packs***	€/m²	€
	180mm	450mm	4,5	3,6	***39***	6,25	***875,19***
	200mm	450mm	5	3,15	***44***	7,24	***1013,82***
	220mm	450mm	5,5	2,88	***49***	8,13	***1138,44***
2x220mm	440mm	450mm	/	/	***/***	/	**2276,888**

- EPB Belgian style various thickness PUR-sprayed PUR 2017

Minimum requirements

Energy consumption heating	43255,83 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	95	2570,23
Floor	80	3500,75
Roof	100	3203,86
Total		***9274,84***

100 mm

Energy consumption heating	41439,91 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	100	2704,09
Floor	100	3850,83
Roof	100	3203,86
Total		***9758,78***

120 mm

Energy consumption heating	37428,14 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	120	4200,90
Roof	120	3923,76
Total		***11316,62***

140 mm

Energy consumption heating	35269,89 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	140	4435,43
Floor	120	4200,90
Roof	140	4673,41
Total		***13309,74***

160 mm

Energy consumption heating	33335,85 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	4435,43
Floor	160	8401,80
Roof	160	5262,42
Total		***18099,65***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results							
					U	K	E	Et	NE	V	O	HE
Minimum requirements	95	80	100	43 255,83	✓	32	43	-	68	✓	1.292,	✓
100 mm	*100*	*100*	*100*	*41 439,91*	✓	31	42	-	66	✓	1.363,	✓
120 mm	*120*	*120*	*120*	*37 428,14*	✓	28	38	-	59	✓	1.546,	✓
140 mm	140	120	140	35 269,89	✓	26	36	-	56	✓	1.666,	✓
160 mm	160	160	160	33 335,85	✓	24	35	-	53	✓	1.787,	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results							
				U	K	E	Et	NE	V	O	HE
Minimum requirements	X	X	7	✓	32	29	-	66	✓	1.292,	✓
100 mm	X	X	5	✓	31	30	-	63	✓	1.363,	✓
120 mm	X		4	✓	28	30	-	59	✓	1.546,	✓
140 mm	X		3	✓	26	29	-	56	✓	1.666,	✓
160 mm	X		2	✓	24	29	-	53	✓	1.787,	✓

- EPB Belgian style various thickness PUR-sprayed PUR 2018

Minimum requirements

Energy consumption heating	38131,03 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	100	3850,83
Roof	120	3923,76
Total		***10966,55***

120 mm

Energy consumption heating	37104,31 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	120	4200,90
Roof	120	3923,76
Total		***11316,62***

140 mm

Energy consumption heating	34964,74 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	140	4435,43
Floor	120	4200,90
Roof	140	4673,41
Total		***13309,74***

160 mm

Energy consumption heating	32930,32 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	4435,43
Floor	160	8401,80
Roof	160	5262,42
Total		***18099,65***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results								
					U	K	S	E	Et	NE	V	O	HE
Minimum requirements	120	100	120	38 131,03	✓	-	31	38	-	-	✓	1.496	✓
120 mm	*120*	*120*	*120*	*37 104,31*	✓	-	31	37	-	-	✓	1.546	✓
140 mm	140	120	140	34 964,74	✓	-	29	36	-	-	✓	1.666	✓
160 mm	160	160	160	32 930,32	✓	-	27	34	-	-	✓	1.795	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results								
				U	K	S	E	Et	NE	V	O	HE
Minimum requirements	X		4	✓	-	31	29	-	-	✓	1.496	✓
120 mm	X		3	✓	-	31	30	-	-	✓	1.546	✓
140 mm	X		2	✓	-	29	30	-	-	✓	1.666	✓
160 mm	X		1	✓	-	27	30	-	-	✓	1.787	✓

- EPB Belgian style various thickness PUR-PUR boards 2017

Minimum requirements

Energy consumption heating	41596,56 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	95	2570,23
Floor	80	2629,76
Roof	100	3203,86
Total		***8403,85***

100 mm

Energy consumption heating	40337,68 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	100	2704,09
Floor	100	3133,87
Roof	100	3203,86
Total		***9041,82***

120 mm

Energy consumption heating	36435,77 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	120	3822,82
Roof	120	3923,76
Total		***10938,54***

140 mm

Energy consumption heating	34059,6 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	140	3684,29
Floor	140	4536,97
Roof	140	4673,41
Total		***12894,67***

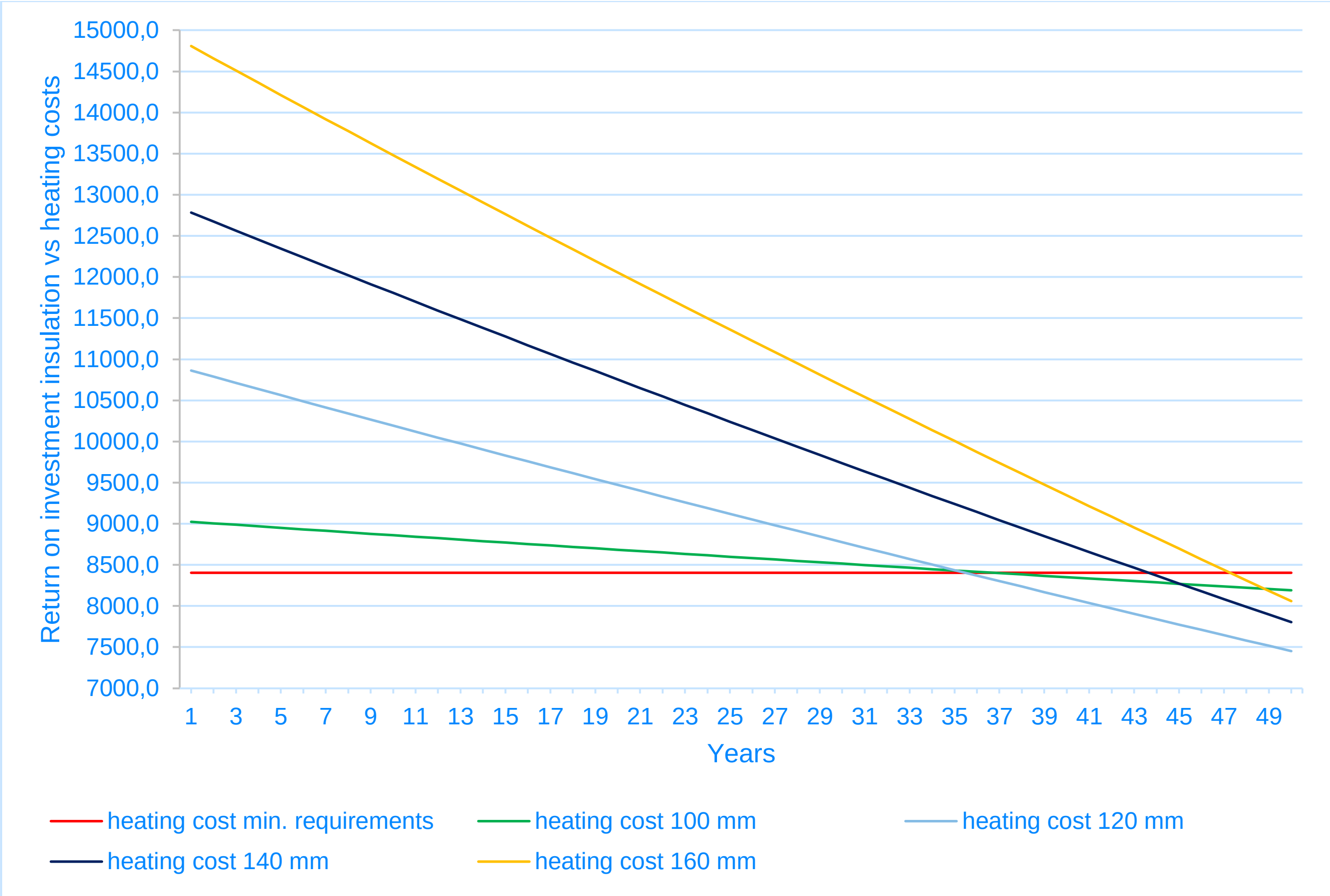
160 mm

Energy consumption heating	31384,83 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	4435,43
Floor	160	5259,53
Roof	160	5262,42
Total		***14957,37***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results
Minimum requirements	95	80	100	41 596,56	U ✓ · K 31 · E 42 · Et - · NE 66 · V ✓ · O 1.357, · HE ✓
100 mm	100	100	100	40 337,68	U ✓ · K 30 · E 41 · Et - · NE 64 · V ✓ · O 1.409, · HE ✓
120 mm	120	120	120	36 435,77	U ✓ · K 27 · E 37 · Et - · NE 58 · V ✓ · O 1.599, · HE ✓
140 mm	140	140	140	34 059,6	U ✓ · K 25 · E 35 · Et - · NE 54 · V ✓ · O 1.740, · HE ✓
160 mm	160	160	160	31 384,83	U ✓ · K 23 · E 33 · Et - · NE 50 · V ✓ · O 1.926, · HE ✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results
Minimum requirements	X	X	6	U ✓ · K 31 · E 29 · Et - · NE 64 · V ✓ · O 1.357, · HE ✓
100 mm	X	X	5	U ✓ · K 30 · E 30 · Et - · NE 62 · V ✓ · O 1.409, · HE ✓
120 mm	X		3	U ✓ · K 27 · E 30 · Et - · NE 58 · V ✓ · O 1.599, · HE ✓
140 mm	X		2	U ✓ · K 25 · E 30 · Et - · NE 54 · V ✓ · O 1.740, · HE ✓
160 mm	X		1	U ✓ · K 23 · E 29 · Et - · NE 50 · V ✓ · O 1.926, · HE ✓


Return on investment insulation vs heating costs
15000,0
14500,0
14000,0
13500,0
13000,0
12500,0
12000,0
11500,0
11000,0
10500,0
10000,0
9500,0
9000,0
8500,0
8000,0
7500,0
7000,0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49
Years
heating cost min. requirements
heating cost 100 mm
heating cost 120 mm
heating cost 140 mm
heating cost 160 mm

- EPB Belgian style various thickness PUR-PUR boards 2018

Minimum requirements

Energy consumption heating	37033,51 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	100	3133,87
Roof	120	3923,76
Total		***10249,59***

120 mm

Energy consumption heating	36120,53 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	120	3822,82
Roof	120	3923,76
Total		***10938,54***

140 mm

Energy consumption heating	33286,93 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	140	4435,43
Floor	140	4536,97
Roof	140	4673,41
Total		***13645,81***

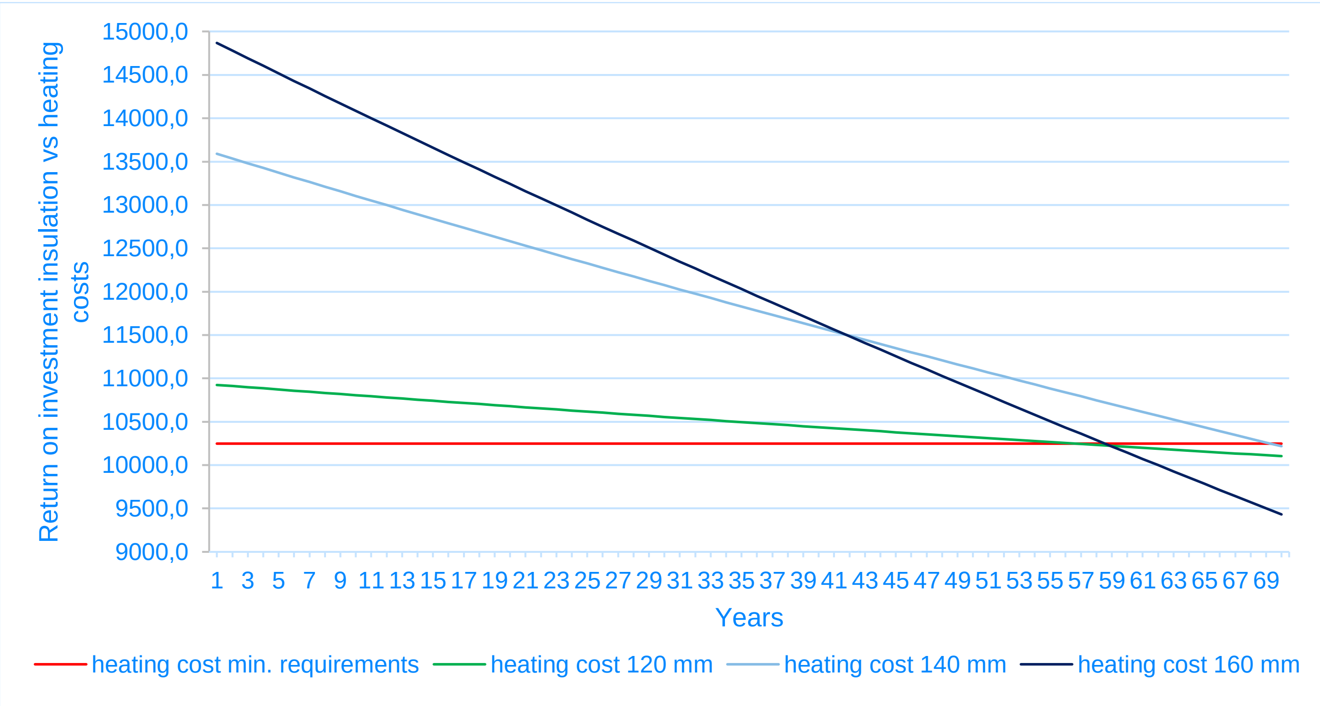
160 mm

Energy consumption heating	30996,67 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	4435,43
Floor	160	5259,53
Roof	160	5262,42
Total		***14957,37***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results								
					U	K	S	E	Et	NE	V	O	HE
Minimum requirements	120	100	120	37 0333,51	✓	-	31	37	-	-	✓	1.550	✓
120 mm	120	120	120	36 120,53	✓	-	30	37	-	-	✓	1.599	✓
140 mm	140	140	140	33 996,67	✓	-	28	34	-	-	✓	1.771	✓
160 mm	160	160	160	30 996,67	✓	-	26	32	-	-	✓	1.935	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results								
				U	K	S	E	Et	NE	V	O	HE
Minimum requirements	X		3	✓	-	31	30	-	-	✓	1.550	✓
120 mm	X		3	✓	-	30	29	-	-	✓	1.599	✓
140 mm	X		1	✓	-	28	30	-	-	✓	1.771	✓
160 mm	X		0	✓	-	26	30	-	-	✓	1.935	✓



- EPB Belgian style various thickness mineral wool-sprayed PUR 2017

Minimum requirements

Energy consumption heating	42287,27 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Isolatiekosten		
Construction component	Thickness (mm)	Price (€)
Muur	140	966,81
Vloer	80	3500,75
Dak	180	875,19
Total		***5342,75***

160 mm

Energy consumption heating	38437,93 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Isolatiekosten		
Construction component	Thickness (mm)	Price (€)
Muur	160	1115,55
Vloer	160	8401,80
Dak	180	875,19
Total		***10392,54***

180 mm

Energy consumption heating	37361,42 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Isolatiekosten		
Construction component	Thickness (mm)	Price (€)
Muur	180	1264,29
Vloer	180	8576,84
Dak	180	875,19
Total		***10716,32***

200 mm

Energy consumption heating	35688,63 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Isolatiekosten		
Construction component	Thickness (mm)	Price (€)
Muur	200	1366,92
Vloer	200	8751,88
Dak	200	1013,82
Total		***11132,61***

220 mm

Energy consumption heating	34288,05 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220	1505,25
Floor	220	8926,91
Roof	220	1138,44
Total		***11570,61***

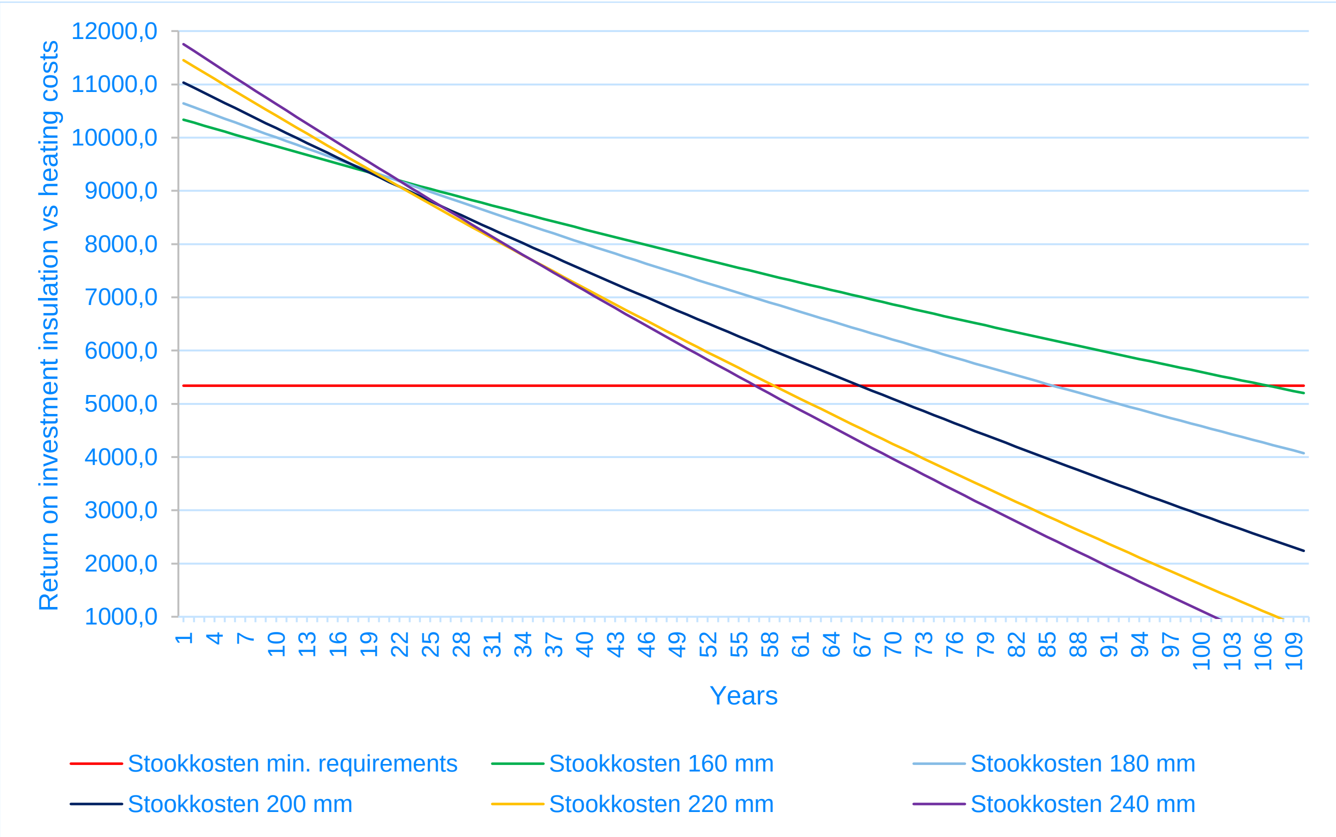
240 mm

Energy consumption heating	33642,99 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240	1640,60
Floor	240	9101,95
Roof	220	1138,44
Total		***11881,00***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results							
					U	K	E	Et	NE	V	O	HE
Minimum requirements	140	80	180	42 287,27	✓	31	42	-	67	✓	1.329,	✓
160 mm	160	160	180	38 437,93	✓	28	39	-	61	✓	1.497,	✓
180 mm	180	180	180	37 361,42	✓	28	38	-	59	✓	1.550,	✓
200 mm	200	200	200	35 688,63	✓	26	37	-	56	✓	1.641,	✓
220 mm	220	220	220	34 288,05	✓	25	35	-	54	✓	1.725,	✓
240 mm	240	240	220	33 642,99	✓	25	35	-	53	✓	1.767,	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results							
				U	K	E	Et	NE	V	O	HE
Minimum requirements	X	X	7	✓	31	28	-	65	✓	1.329,	✓
160 mm	X	X	5	✓	28	28	-	59	✓	1.497,	✓
180 mm	X		5	✓	28	28	-	59	✓	1.550,	✓
200 mm	X		3	✓	26	30	-	56	✓	1.641,	✓
220 mm	X		2	✓	25	30	-	54	✓	1.725,	✓
240 mm	X		2	✓	25	30	-	53	✓	1.767,	✓



- EPB Belgian style various thickness mineral wool-sprayed PUR 2018

Minimum requirements

Energy consumption heating	37608,68 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	1115,55
Floor	120	4200,90
Roof	200	1013,82
Total		***6330,27***

160 mm

Energy consumption heating	37317,43 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	1115,55
Floor	160	8401,80
Roof	200	1013,82
Total		***10531,17***

180 mm

Energy consumption heating	36253,3 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180	1264,29
Floor	180	8576,84
Roof	200	1013,82
Total		***10854,94***

200 mm

Energy consumption heating	35379,86 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200	1366,92
Floor	200	8751,88
Roof	200	1013,82
Total		***11132,61***

220 mm

Energy consumption heating	33991,4 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220	1505,25
Floor	220	8926,91
Roof	220	1138,44
Total		***11570,61***

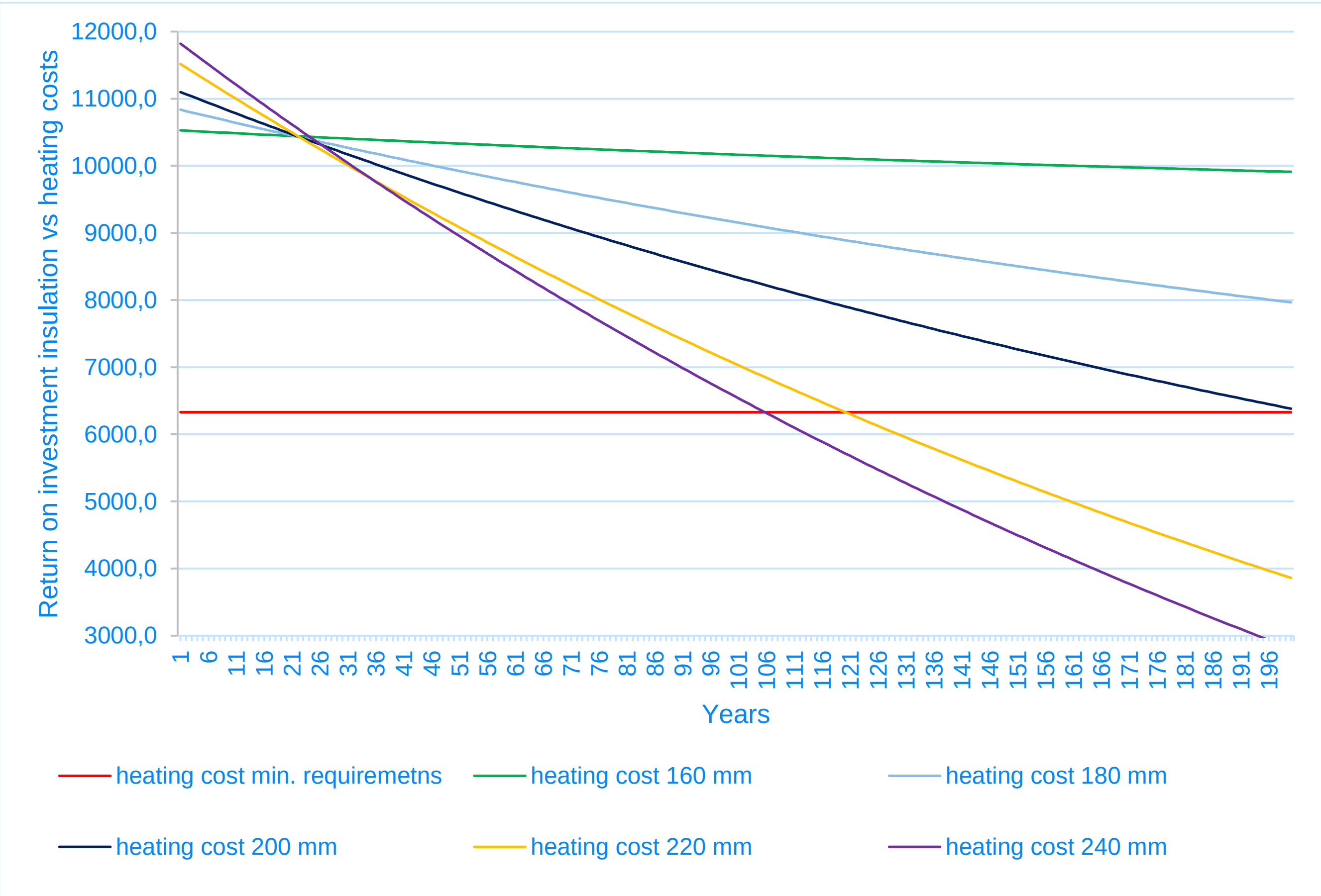
240 mm

Energy consumption heating	33351,91 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price naturla gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240	1640,60
Floor	240	9101,95
Roof	220	1138,44
Total		***11881,00***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results								
					U	K	S	E	Et	NE	V	O	HE
Minimum requirements	160	120	200	37 608,68	✓	-	31	38	-	-	✓	1.521	✓
160 mm	160	160	200	37 317,43	✓	-	31	38	-	-	✓	1.536	✓
180 mm	180	180	200	36 253,3	✓	-	30	37	-	-	✓	1.592	✓
200 mm	200	200	200	35 379,86	✓	-	29	36	-	-	✓	1.641	✓
220 mm	220	220	220	33 991,4	✓	-	28	35	-	-	✓	1.725	✓
240 mm	240	240	220	33 351,91	✓	-	28	34	-	-	✓	1.767	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results								
				U	K	S	E	Et	NE	V	O	HE
Minimum requirements	X		4	✓	-	31	29	-	-	✓	1.521	✓
160 mm	X		4	✓	-	31	29	-	-	✓	1.536	✓
180 mm	X		3	✓	-	30	29	-	-	✓	1.592	✓
200 mm	X		3	✓	-	29	29	-	-	✓	1.641	✓
220 mm	X		2	✓	-	28	29	-	-	✓	1.725	✓
240 mm	X		1	✓	-	28	30	-	-	✓	1.767	✓



- EPB Belgian style various thickness mineral wool-PUR boards 2017

Minimum requirements

Energy consumption heating	41079,62 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Isolatiekosten		
Construction component	Thickness (mm)	Price (€)
Muur	140	966,81
Vloer	80	2629,76
Dak	180	875,19
Total		***4471,76***

160 mm

Energy consumption heating	36836,45 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Isolatiekosten		
Construction component	Thickness (mm)	Price (€)
Muur	160	1115,55
Vloer	160	5259,53
Dak	180	875,19
Total		***7250,26***

180 mm

Energy consumption heating	35078,39 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Isolatiekosten		
Construction component	Thickness (mm)	Price (€)
Muur	180	1264,29
Vloer	180	5763,63
Dak	180	875,19
Total		***7903,11***

200 mm

Energy consumption heating	33169,18 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Isolatiekosten		
Construction component	Thickness (mm)	Price (€)
Muur	200	1366,92
Vloer	200	6267,74
Dak	200	1013,82
Total		***8648,48***

220 mm

Energy consumption heating	31587,14 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220	1505,25
Floor	220	6956,69
Roof	220	1138,44
Total		*9600,38*

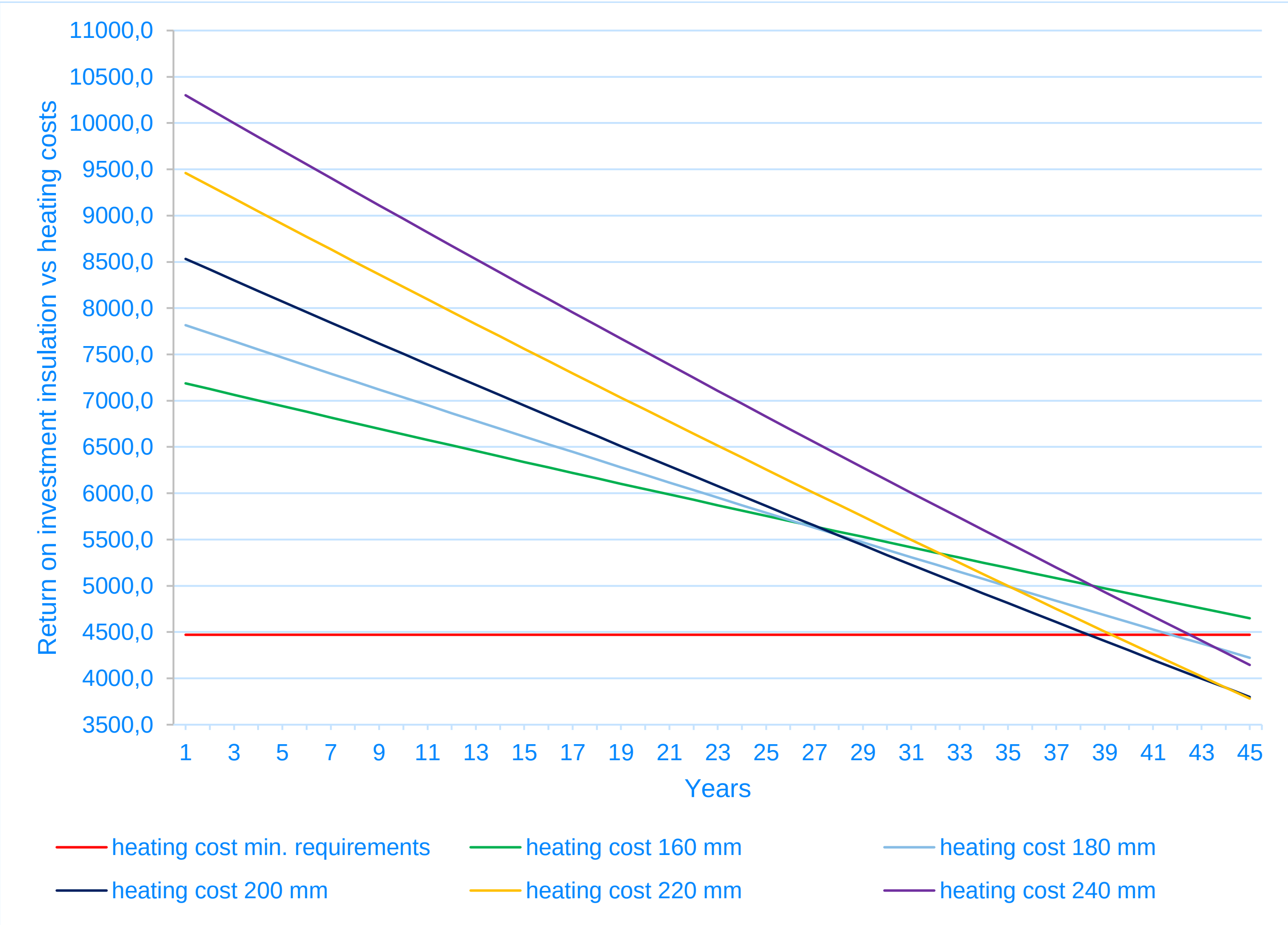
240 mm

Energy consumption heating	30798,88 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240	1640,60
Floor	240	7670,84
Roof	220	1138,44
Total		*10449,89*

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results							
					U	K	E	Et	NE	V	O	HE
Minimum requirements	140	80	180	41 079,62	✓	30	41	-	65	✓	1.378,	✓
160 mm	160	160	180	36 836,45	✓	27	38	-	58	✓	1.578,	✓
180 mm	180	180	180	35 078,39	✓	26	36	-	55	✓	1.677,	✓
200 mm	200	200	200	33 169,18	✓	24	34	-	52	✓	1.798,	✓
220 mm	220	220	220	30 798.88	✓	23	33	-	50	✓	1.911,	✓
240 mm	240	240	220	30 798,88	✓	23	30	-	49	✓	1.951,	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results							
				U	K	E	Et	NE	V	O	HE
Minimum requirements	X	X	5	✓	30	30	-	63	✓	1.378,	✓
160 mm	X		4	✓	27	29	-	58	✓	1.578,	✓
180 mm	X		3	✓	26	29	-	55	✓	1.677,	✓
200 mm	X		2	✓	24	29	-	52	✓	1.798,	✓
220 mm	X		1	✓	23	29	-	50	✓	1.911,	✓



- EPB Belgian style various thickness mineral wool-PUR boards 2018

Minimum requirements

Energy consumption heating	37537,67 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Isolatiekosten		
Construction component	Thickness (mm)	Price (€)
Muur	160	1115,55
Vloer	100	3133,87
Dak	200	1013,82
Total		***5263,24***

160 mm

Energy consumption heating	35351,76 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Isolatiekosten		
Construction component	Thickness (mm)	Price (€)
Muur	160	1115,55
Vloer	160	5259,53
Dak	200	1013,82
Total		***7388,89***

180 mm

Energy consumption heating	34303,43 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Isolatiekosten		
Construction component	Thickness (mm)	Price (€)
Muur	180	1264,29
Vloer	180	5763,63
Dak	200	1013,82
Total		***8041,74***

200 mm

Energy consumption heating	32882,2 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Isolatiekosten		
Construction component	Thickness (mm)	Price (€)
Muur	200	1366,92
Vloer	200	6267,74
Dak	200	1013,82
Total		***8648,48***

220 mm

Energy consumption heating	31473,53 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220	1505,25
Floor	220	6956,69
Roof	220	1138,44
Total		***9600,38***

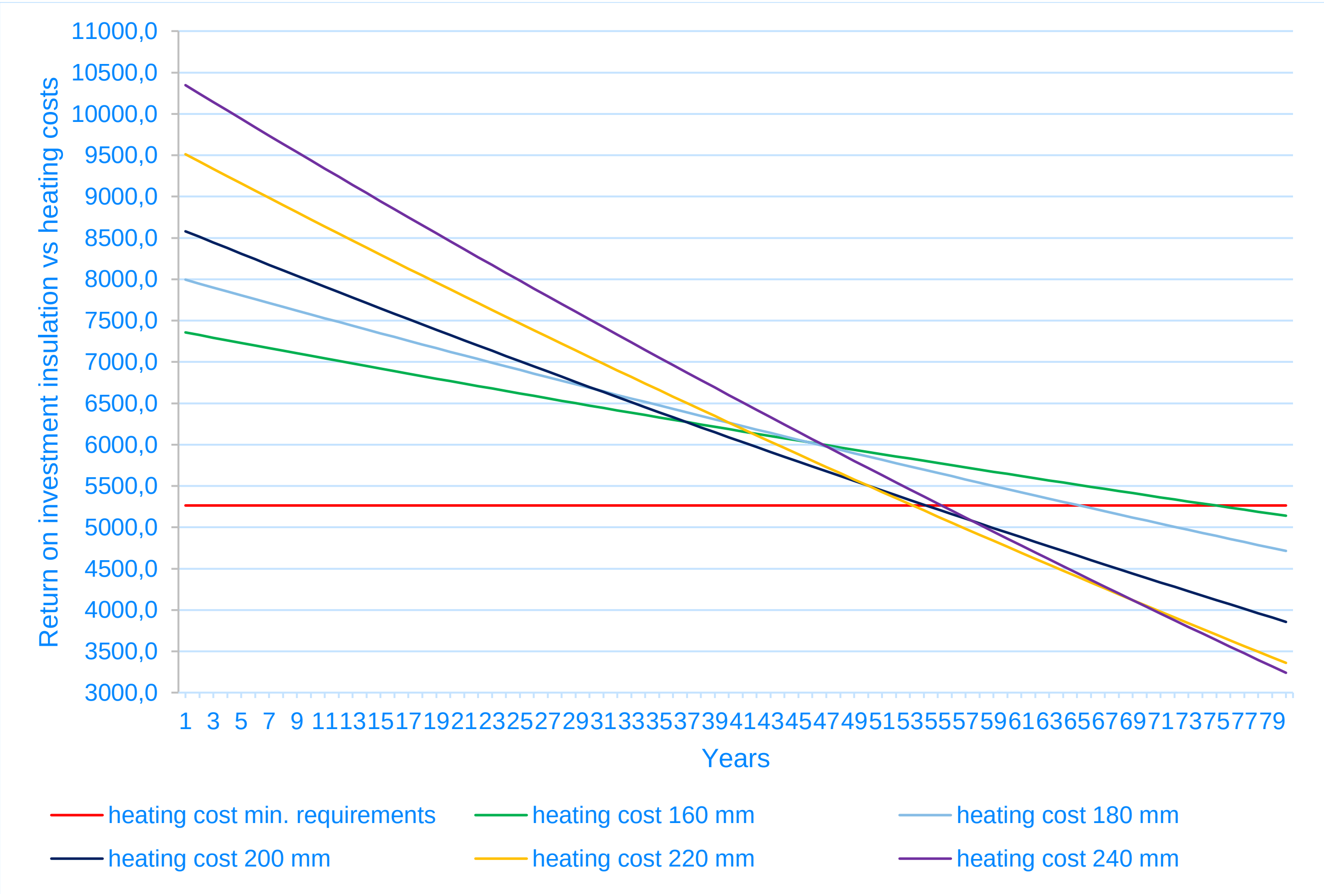
240 mm

Energy consumption heating	30532,41 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240	1640,60
Floor	240	7670,84
Roof	220	1138,44
Total		***10449,89***

File name	**Wall (mm)**	**Floor (mm)**	**Roof (mm)**	**Primary energy consumption (MJ)**	**EPB results**								
					U	K	S	E	Et	NE	V	O	HE
Minimum requirements	160	100	200	37 537,67	✓	-	31	38	-	-	✓	1.525	✓
160 mm	160	160	200	35 351,76	✓	-	29	36	-	-	✓	1.643	✓
180 mm	180	180	200	34 303,43	✓	-	28	35	-	-	✓	1.706	✓
200 mm	200	200	200	32 882,2	✓	-	27	34	-	-	✓	1.798	✓
220 mm	220	220	220	31 473,53	✓	-	26	32	-	-	✓	1.899	✓
240 mm	240	240	220	30 532,41	✓	-	25	32	-	-	✓	1.972	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results
Minimum requirements	X		4	U ✓ · K - · S 31 · E 29 · Et - · NE - · V ✓ · O 1.525 · HE ✓
160 mm	X		2	U ✓ · K - · S 29 · E 30 · Et - · NE - · V ✓ · O 1.643 · HE ✓
180 mm	X		2	U ✓ · K - · S 28 · E 29 · Et - · NE - · V ✓ · O 1.706 · HE ✓
200 mm	X		1	U ✓ · K - · S 27 · E 30 · Et - · NE - · V ✓ · O 1.798 · HE ✓
220 mm	X		0	U ✓ · K - · S 26 · E 30 · Et - · NE - · V ✓ · O 1.899 · HE ✓
240 mm	X		0	U ✓ · K - · S 25 · E 29 · Et - · NE - · V ✓ · O 1.972 · HE ✓



- EPB Belgian style continuous thickness PUR-sprayed PUR 2017

Minimum requirements

Energy consumption heating	43255,83 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	95	2570,23
Floor	80	3500,75
Roof	100	3203,86
Total		***9274,84***

100 mm

Energy consumption heating	40409,61 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	100	2704,09
Floor	120	4200,90
Roof	100	3203,86
Total		***10108,85***

120 mm

Energy consumption heating	37428,14 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	120	4200,90
Roof	120	3923,76
Total		***11316,62***

140 mm

Energy consumption heating	35269,89 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	140	4435,43
Floor	120	4200,90
Roof	140	4673,41
Total		***13309,74***

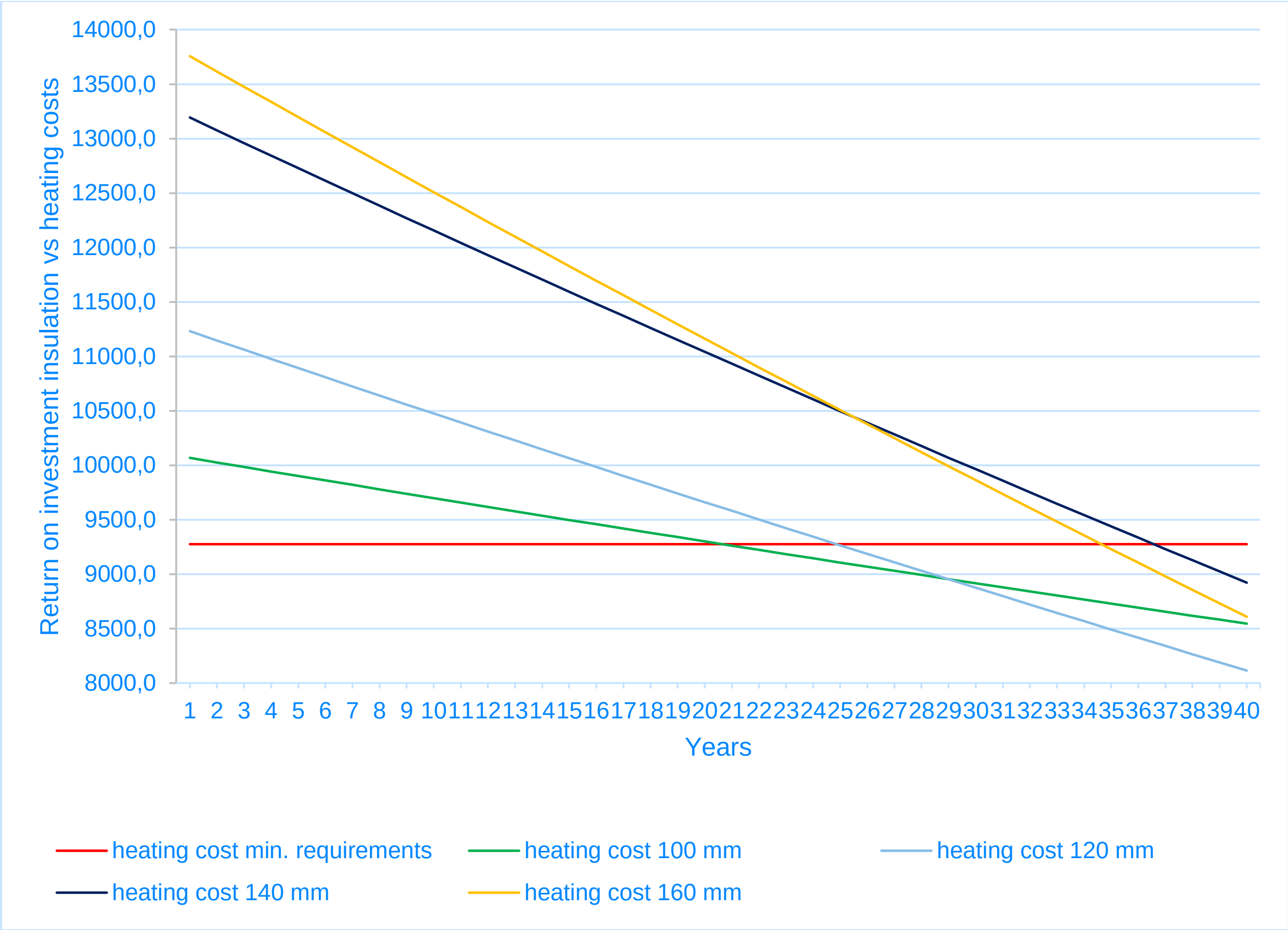
160 mm

Energy consumption heating	33626,77 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	4435,43
Floor	120	4200,90
Roof	160	5262,42
Total		***13898,75***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results							
					U	K	E	Et	NE	V	O	HE
Minimum requirements	95	80	100	43 255,83	✓	32	43	-	68	✓	1.292,	✓
100 mm	*100*	*120*	*100*	*40 409,61*	✓	30	41	-	64	✓	1.406,	✓
120 mm	*120*	*120*	*120*	*37 428,14*	✓	28	38	-	59	✓	1.546,	✓
140 mm	140	120	140	35 269,89	✓	26	36	-	56	✓	1.666,	✓
160 mm	160	120	160	33 626,77	✓	25	35	-	53	✓	1.768,	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results							
				U	K	E	Et	NE	V	O	HE
Minimum requirements	X	X	7	✓	32	29	-	66	✓	1.292,	✓
100 mm	X	X	5	✓	30	30	-	62	✓	1.406,	✓
120 mm	X		4	✓	28	30	-	59	✓	1.546,	✓
140 mm	X		3	✓	26	29	-	56	✓	1.666,	✓
160 mm	X		2	✓	25	30	-	53	✓	1.768,	✓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13000,0
12500,0
12000,0
11500,0
11000,0
10500,0
10000,0
9500,0
9000,0
8500,0
8000,0
Return on investment insulation vs heating costs
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Years
heating cost min. requirements
heating cost 100 mm
heating cost 120 mm
heating cost 140 mm
heating cost 160 mm

- EPB Belgian style continuous thickness PUR-sprayed PUR 2018

Minimum requirements

Energy consumption heating	38131,03 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	100	3850,83
Roof	120	3923,76
Total		***10966,55***

120 mm

Energy consumption heating	37104,31 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	120	4200,90
Roof	120	3923,76
Total		***11316,62***

140 mm

Energy consumption heating	34964,74 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	140	4435,43
Floor	120	4200,90
Roof	140	4673,41
Total		***13309,74***

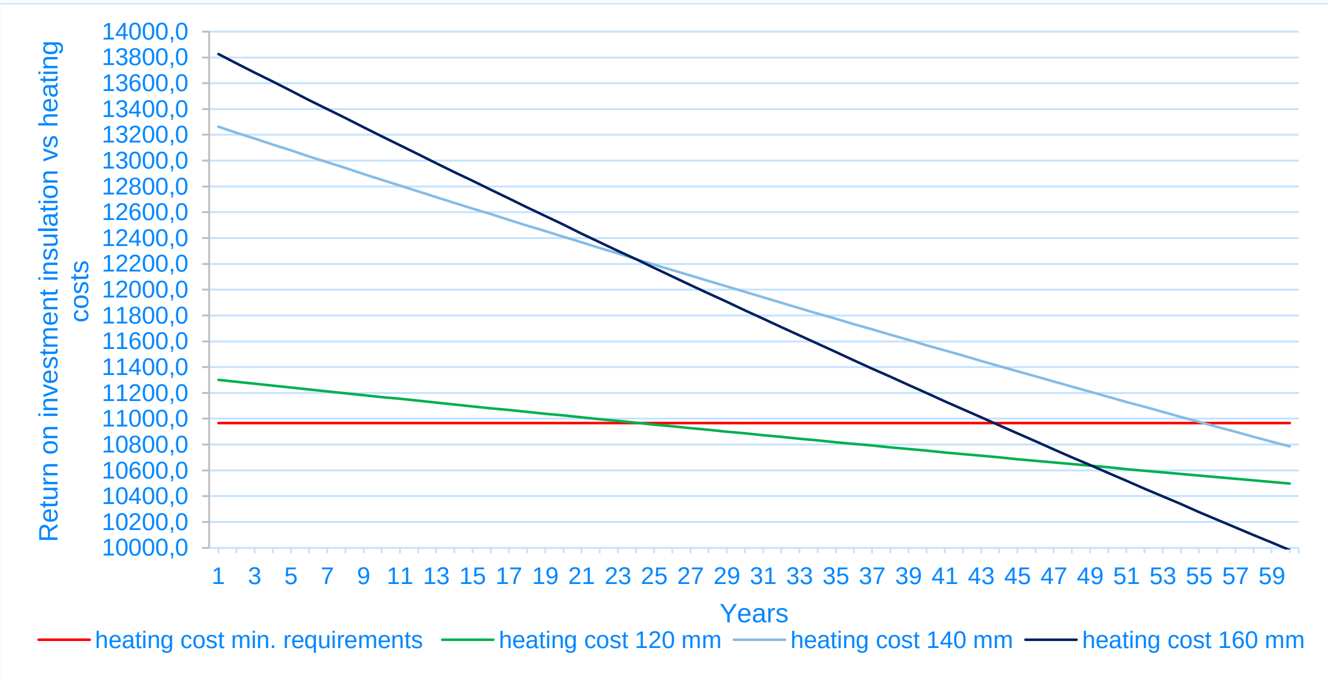
160 mm

Energy consumption heating	33218,65 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	4435,43
Floor	120	4200,90
Roof	160	5262,42
Total		***13898,75***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results
Minimum requirements	120	100	120	38 131,03	U ✓ · K - · S 31 · E 38 · Et - · NE - · V ✓ · O 1.496 · HE ✓
120 mm	*120*	*120*	*120*	*37 104,31*	U ✓ · K - · S 31 · E 37 · Et - · NE - · V ✓ · O 1.546 · HE ✓
140 mm	140	120	140	34 964,74	U ✓ · K - · S 29 · E 36 · Et - · NE - · V ✓ · O 1.666 · HE ✓
160 mm	160	160	160	33 218,65	U ✓ · K - · S 27 · E 34 · Et - · NE - · V ✓ · O 1.776 · HE ✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results
Minimum requirements	X		4	U ✓ · K - · S 31 · E 29 · Et - · NE - · V ✓ · O 1.496 · HE ✓
120 mm	X		3	U ✓ · K - · S 31 · E 30 · Et - · NE - · V ✓ · O 1.546 · HE ✓
140 mm	X		2	U ✓ · K - · S 29 · E 30 · Et - · NE - · V ✓ · O 1.666 · HE ✓
160 mm	X		1	U ✓ · K - · S 27 · E 30 · Et - · NE - · V ✓ · O 1.776 · HE ✓



- EPB Belgian style continuous thickness PUR-PUR boards 2017

Minimum requirements

Energy consumption heating	41596,56 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	95	2570,23
Floor	80	2629,76
Roof	100	3203,86
Total		***8403,85***

100 mm

Energy consumption heating	40337,68 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	100	2704,09
Floor	100	3133,87
Roof	100	3203,86
Total		***9041,82***

120 mm

Energy consumption heating	36435,77 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	120	3822,82
Roof	120	3923,76
Total		***10938,54***

140 mm

Energy consumption heating	34738,23 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	140	3684,29
Floor	120	3822,82
Roof	140	4673,41
Total		***12180,52***

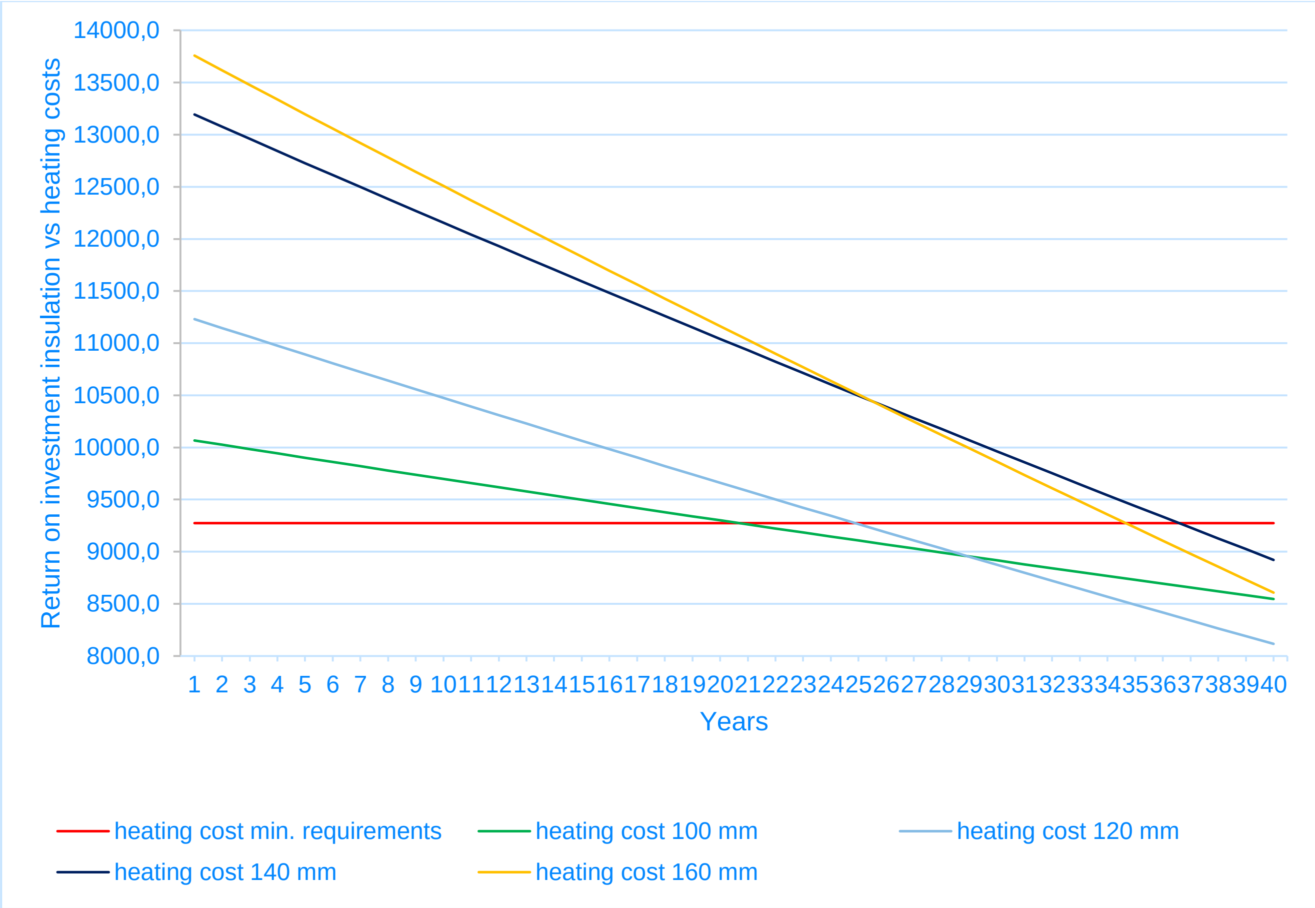
160 mm

Energy consumption heating	33447,36 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	4435,43
Floor	120	3822,82
Roof	160	5262,42
Total		*13520,67*

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results							
					U	K	E	Et	NE	V	O	HE
Minimum requirements	95	80	100	43 255,83	✓	32	43	-	68	✓	1.292,	✓
100 mm	*100*	*120*	*100*	*40 409,61*	✓	30	41	-	64	✓	1.406,	✓
120 mm	*120*	*120*	*120*	*37 428,14*	✓	28	38	-	59	✓	1.546,	✓
140 mm	140	120	140	35 269,89	✓	26	36	-	56	✓	1.666,	✓
160 mm	160	120	160	33 626,77	✓	25	35	-	53	✓	1.768,	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results							
				U	K	E	Et	NE	V	O	HE
Minimum requirements	X	X	7	✓	32	29	-	66	✓	1.292,	✓
100 mm	X	X	5	✓	30	30	-	62	✓	1.406,	✓
120 mm	X		4	✓	28	30	-	59	✓	1.546,	✓
140 mm	X		3	✓	26	29	-	56	✓	1.666,	✓
160 mm	X		2	✓	25	30	-	53	✓	1.768,	✓



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13500,0
13000,0
12500,0
12000,0
11500,0
11000,0
10500,0
10000,0
9500,0
9000,0
8500,0
8000,0
Return on investment insulation vs heating costs
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Years
heating cost min. requirements
heating cost 100 mm
heating cost 120 mm
heating cost 140 mm
heating cost 160 mm

- EPB Belgian style continuous thickness PUR-PUR boards 2018

Minimum requirements

Energy consumption heating	37033,51 MJ	Results from EPB-software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	100	3133,87
Roof	120	3923,76
Total		***10249,59***

120 mm

Energy consumption heating	36120,53 MJ	Results from EPB-software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	120	3822,82
Roof	120	3923,76
Total		***10938,54***

140 mm

Energy consumption heating	33984,68 MJ	Results from EPB-software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	140	4435,43
Floor	120	3822,82
Roof	140	4673,41
Total		***12931,66***

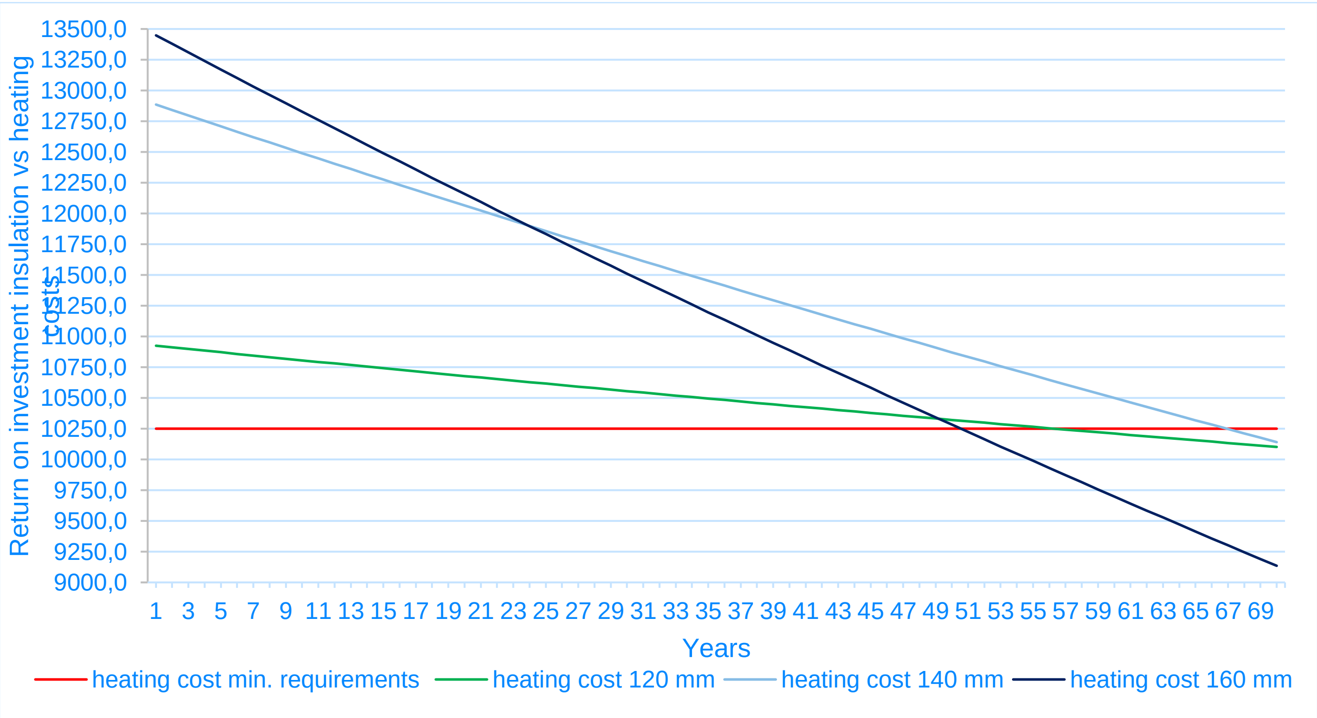
160 mm

Energy consumption heating	32242 MJ	Results from EPB-software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	4435,43
Floor	120	3822,82
Roof	160	5262,42
Total		***13520,67***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results
Minimum requirements	120	100	120	37 033,51	U ✓, K -, S 31, E 37, Et -, NE -, V ✓, O 1.550, HE ✓
120 mm	120	120	120	36 120,53	U ✓, K -, S 30, E 37, Et -, NE -, V ✓, O 1.599, HE ✓
140 mm	140	120	140	33 984,68	U ✓, K -, S 28, E 35, Et -, NE -, V ✓, O 1.726, HE ✓
160 mm	160	120	160	32 242	U ✓, K -, S 27, E 33, Et -, NE -, V ✓, O 1.843, HE ✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results
Minimum requirements	X		3	U ✓, K -, S 31, E 30, Et -, NE -, V ✓, O 1.550, HE ✓
120 mm	X		3	U ✓, K -, S 30, E 29, Et -, NE -, V ✓, O 1.599, HE ✓
140 mm	X		2	U ✓, K -, S 28, E 29, Et -, NE -, V ✓, O 1.726, HE ✓
160 mm	X		1	U ✓, K -, S 27, E 29, Et -, NE -, V ✓, O 1.843, HE ✓



- EPB Belgian style continuous thickness mineral wool-sprayed PUR 2017

Minimum requirements

Energy consumption heating	42287,27 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price
Wall	140	966,81
Floor	80	3500,75
Roof	180	875,19
Total		***5342,75***

160 mm

Energy consumption heating	38732,14 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	1115,55
Floor	120	4200,90
Roof	180	875,19
Total		***6191,64***

180 mm

Energy consumption heating	37808,27 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180	1264,29
Floor	120	4200,90
Roof	180	875,19
Total		***6340,38***

200 mm

Energy consumption heating	36250,06 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200	1366,92
Floor	120	4200,90
Roof	200	1013,82
Total		***6581,64***

220 mm

Energy consumption heating	34974,95 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220	1505,25
Floor	120	4200,90
Roof	220	1138,44
Total		***6844,59***

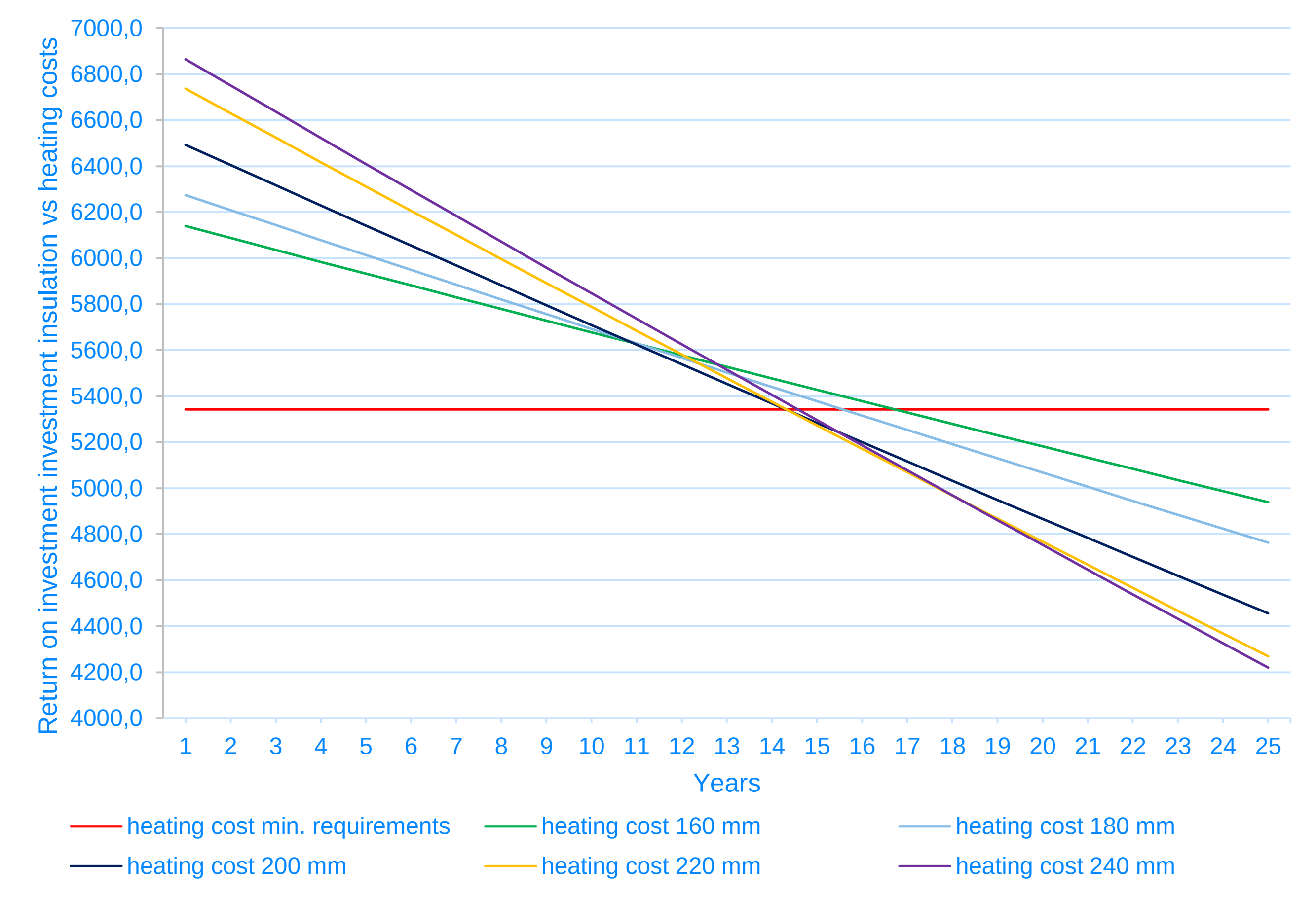
240 mm

Energy consumption heating	34450,19 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240	1640,60
Floor	120	4200,90
Roof	220	1138,44
Total		***6979,95***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results							
					U	K	E	Et	NE	V	O	HE
Minimum requirements	140	80	180	42 2287,27	✓	31	42	-	67	✓	1.329,	✓
160 mm	*160*	*120*	*180*	*38 732,14*	✓	29	39	-	61	✓	1.483,	✓
180 mm	*180*	*120*	*180*	*37 808,27*	✓	28	39	-	60	✓	1.528,	✓
200 mm	*200*	*120*	*200*	*36 250,06*	✓	26	37	-	56	✓	1.641,	✓
220 mm	*220*	*120*	*220*	*34 974,95*	✓	26	36	-	55	✓	1.683,	✓
240 mm	*240*	*120*	*220*	*34 450,19*	✓	25	36	-	55	✓	1.715,	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results
Minimum requirements	X	X	7	U ✓ / K 31 / E 28 / Et - / NE 65 / V ✓ / O 1.329, / HE ✓
160 mm	X	X	4	U ✓ / K 29 / E 30 / Et - / NE 59 / V ✓ / O 1.483, / HE ✓
180 mm	X		4	U ✓ / K 28 / E 30 / Et - / NE 60 / V ✓ / O 1.528, / HE ✓
200 mm	X		4	U ✓ / K 27 / E 29 / Et - / NE 57 / V ✓ / O 1.610, / HE ✓
220 mm	X		3	U ✓ / K 26 / E 29 / Et - / NE 55 / V ✓ / O 1.683, / HE ✓
240 mm	X		2	U ✓ / K 25 / E 30 / Et - / NE 55 / V ✓ / O 1.715, / HE ✓



- EPB Belgian style continuous thickness mineral wool-sprayed PUR 2018

Minimum requirements

Energy consumption heating	37608,68 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	1115,55
Floor	120	4200,90
Roof	200	1013,82
Total		***6330,27***

160 mm

Energy consumption heating	37608,68 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	1115,55
Floor	120	4200,90
Roof	200	1013,82
Total		***6330,27***

180 mm

Energy consumption heating	36679,75 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180	1264,29
Floor	120	4200,90
Roof	200	1013,82
Total		***6479,01***

200 mm

Energy consumption heating	35936,43 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200	1366,92
Floor	200	4200,90
Roof	200	1013,82
Total		***6581,64***

220 mm

Energy consumption heating	34671,95 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220	1505,25
Floor	120	4200,90
Roof	220	1138,44
Total		***6844,59***

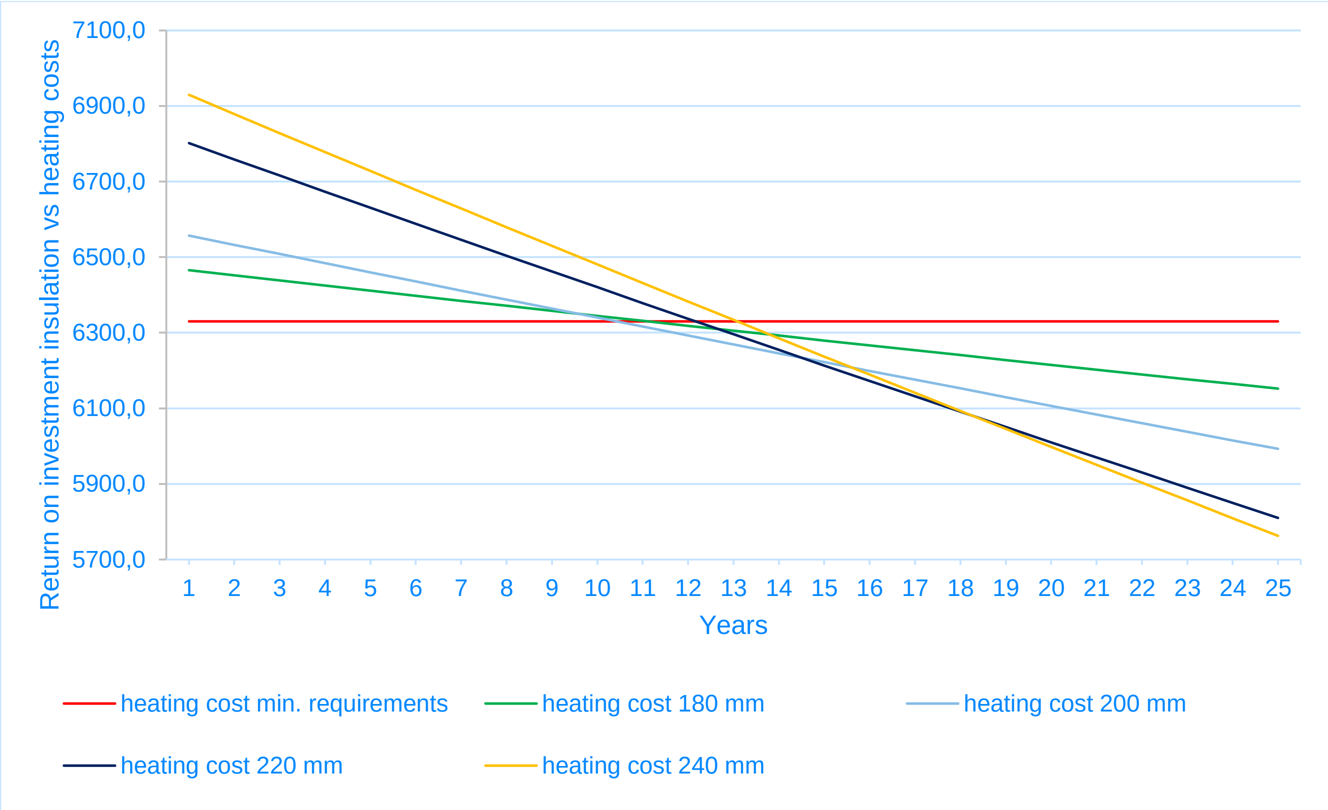
240 mm

Energy consumption heating	34152,13 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240	1640,60
Floor	120	4200,90
Roof	220	1138,44
Total		***6979,95***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results								
					U	K	S	E	Et	NE	V	O	HE
Minimum requirements	160	120	200	37 608,68	✓	-	31	38	-	-	✓	1.521	✓
180 mm	*180*	*120*	*200*	*36 679,75*	✓	-	30	37	-	-	✓	1.569	✓
200 mm	*200*	*120*	*200*	*35 936,43*	✓	-	30	36	-	-	✓	1.610	✓
220 mm	*220*	*120*	*220*	*34 671,95*	✓	-	29	35	-	-	✓	1.683	✓
240 mm	*240*	*120*	*220*	*34 152,13*	✓	-	28	35	-	-	✓	1.715	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results
Minimum requirements	X		4	U: ✓; K: -; S: 31; E: 29; Et: -; NE: -; V: ✓; O: 1.525; HE: ✓
180 mm	X		3	U: ✓; K: -; S: 30; E: 30; Et: -; NE: -; V: ✓; O: 1.569; HE: ✓
200 mm	X		3	U: ✓; K: -; S: 30; E: 29; Et: -; NE: -; V: ✓; O: 1.610; HE: ✓
220 mm	X		2	U: ✓; K: -; S: 29; E: 30; Et: -; NE: -; V: ✓; O: 1.683; HE: ✓
240 mm	X		2	U: ✓; K: -; S: 28; E: 29; Et: -; NE: -; V: ✓; O: 1.715; HE: ✓



- EPB Belgian style continuous thickness mineral wool-PUR boards 2017

Minimum requirements

Energy consumption heating	41079,62 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	140	966,81
Floor	80	2629,76
Roof	180	875,19
Total		***4471,76***

160 mm

Energy consumption heating	38196,17 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	1115,55
Floor	120	3822,82
Roof	180	875,19
Total		***5813,56***

180 mm

Energy consumption heating	36799,18 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180	1264,29
Floor	120	3822,82
Roof	180	875,19
Total		***5962,30***

200 mm

Energy consumption heating	35259,69 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200	1366,92
Floor	120	3822,82
Roof	200	1013,82
Total		***6203,56***

220 mm

Energy consumption heating	33986,49 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220	1505,25
Floor	120	3822,82
Roof	220	1138,44
Total		*6466,51*

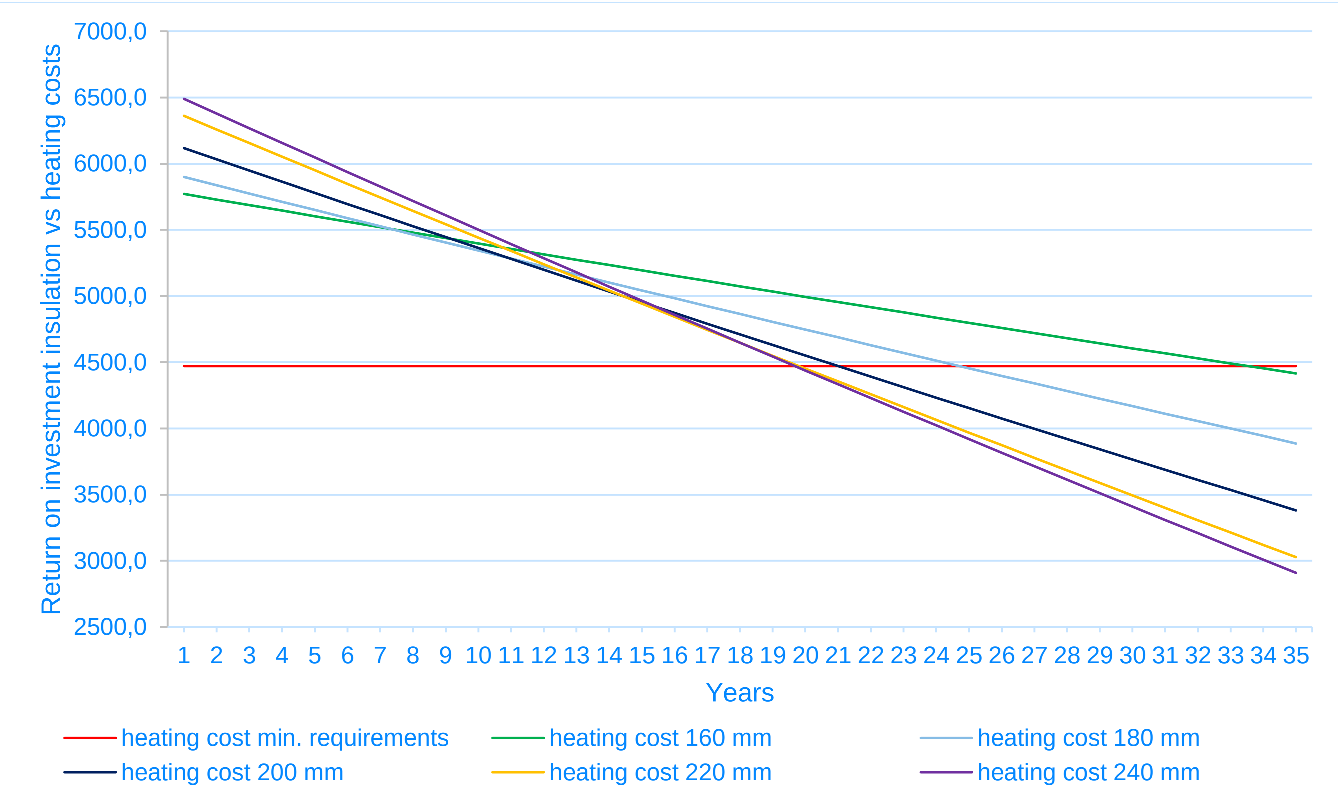
240 mm

Energy consumption heating	33463,13 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240	1640,60
Floor	120	3822,82
Roof	220	1138,44
Total		*6601,87*

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results							
					U	K	E	Et	NE	V	O	HE
Minimum requirements	140	80	180	41 079,62	✓	30	41	-	65	✓	1.378,	✓
160 mm	160	120	180	38 196,17	✓	28	39	-	60	✓	1.509,	✓
180 mm	*180*	*120*	*180*	*36 799,18*	✓	27	38	-	58	✓	1.580,	✓
200 mm	*200*	*120*	*200*	*35 529,69*	✓	26	36	-	56	✓	1.666,	✓
220 mm	*220*	*120*	*220*	*33 986,49*	✓	25	35	-	54	✓	1.744,	✓
240 mm	*240*	*120*	*220*	*33 463,13*	✓	25	35	-	53	✓	1.779,	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results U	K	E	Et	NE	V	O	HE
Minimum requirements	X		5	✓	30	30	-	63	✓	1.378,	✓
160 mm	X		4	✓	28	30	-	60	✓	1.509,	✓
180 mm	X		4	✓	27	29	-	58	✓	1.580,	✓
200 mm	X		3	✓	26	29	-	56	✓	1.666,	✓
220 mm	X		2	✓	25	30	-	54	✓	1.744,	✓
240 mm	X		2	✓	25	29	-	53	✓	1.779,	✓



- EPB Belgian style continuous thickness mineral wool-PUR boards 2018

Minimum requirements

Energy consumption heating	37537,67 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	1115,55
Floor	100	3133,87
Roof	200	1013,82
Total		***5263,24***

160 mm

Energy consumption heating	36607,85 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	1115,55
Floor	120	3822,82
Roof	200	1013,82
Total		***5952,19***

180 mm

Energy consumption heating	36151,09 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180	1264,29
Floor	120	3822,82
Roof	200	1013,82
Total		***6100,93***

200 mm

Energy consumption heating	34954,62 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200	1366,92
Floor	120	3822,82
Roof	200	1013,82
Total		***6203,56***

220 mm

Energy consumption heating	34145,18 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220	1505,25
Floor	120	3822,82
Roof	220	1138,44
Total		***6466,51***

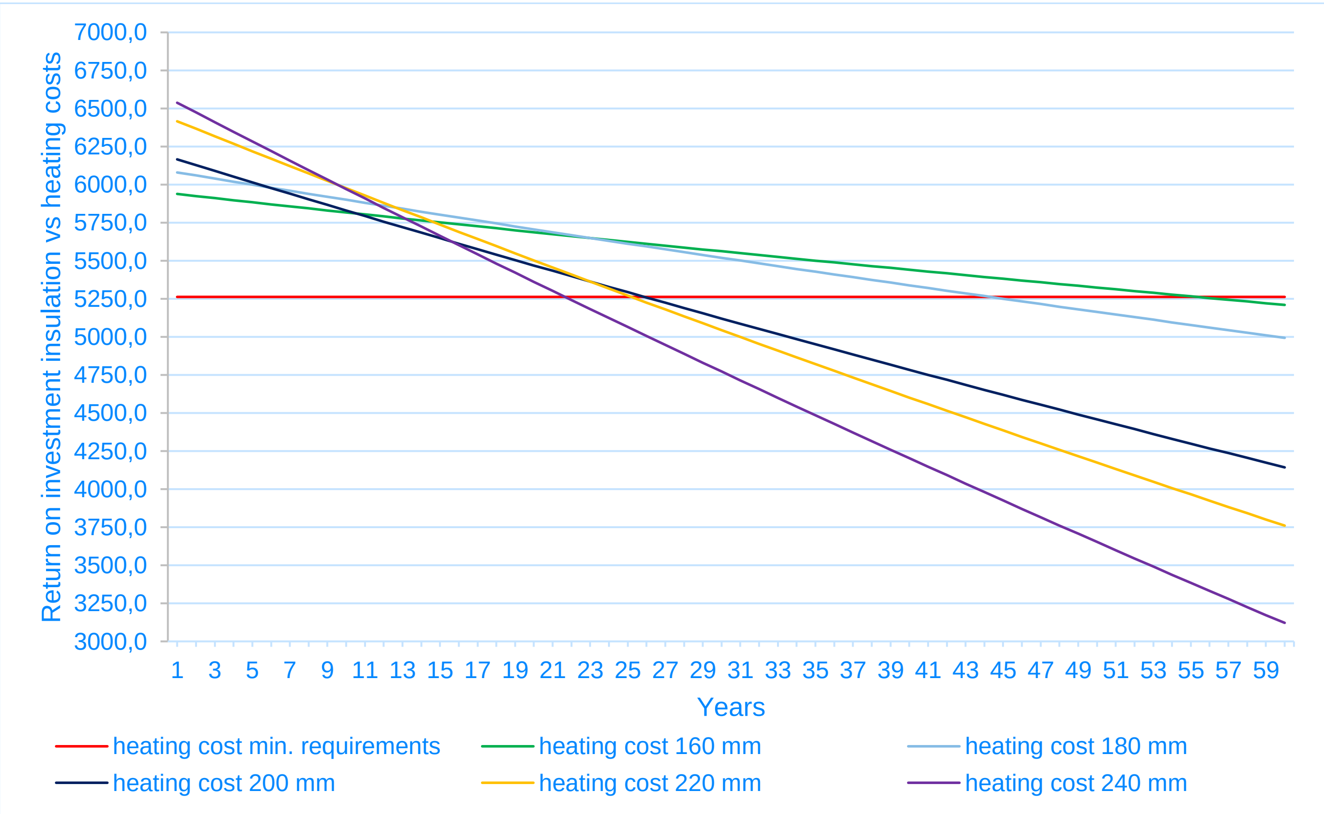
240 mm

Energy consumption heating	33173,61 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240	1640,60
Floor	120	3822,82
Roof	220	1138,44
Total		***6601,87***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results								
					U	K	S	E	Et	NE	V	O	HE
Minimum requirements	160	100	200	37 537,67	✓	-	31	38	-	-	✓	1.525	✓
160 mm	160	120	200	36 607,85	✓	-	30	37	-	-	✓	1.573	✓
180 mm	180	120	200	36 151,09	✓	-	30	37	-	-	✓	1.598	✓
200 mm	200	200	200	34 954,62	✓	-	29	36	-	-	✓	1.666	✓
220 mm	220	220	220	34 145,18	✓	-	28	35	-	-	✓	1.716	✓
240 mm	*240*	*240*	*220*	*33 173,61*	✓	-	27	34	-	-	✓	1.779	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results								
				U	K	S	E	Et	NE	V	O	HE
Minimum requirements	X		4	✓	-	31	29	-	-	✓	1.525	✓
160 mm	X		3	✓	-	30	30	-	-	✓	1.573	✓
180 mm	X		3	✓	-	30	29	-	-	✓	1.598	✓
200 mm	X		2	✓	-	29	30	-	-	✓	1.666	✓
220 mm	X		2	✓	-	28	29	-	-	✓	1.716	✓
240 mm	X		1	✓	-	27	30	-	-	✓	1.779	✓



- EPB Finnish style various thickness CLT structure-sprayed PUR 2017

Minimum requirements

Energy consumption heating	41925,27 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	160+60	1643,58
Floor	80	3500,75
Roof	180	875,19
Total		***6019,51***

160 mm

Energy consumption heating	39238,34 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	160+60	1643,58
Floor	160	8401,80
Roof	180	875,19
Total		***10920,56***

180 mm

Energy consumption heating	38428,74 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	180	8576,84
Roof	180	875,19
Total		***11244,34***

200 mm

Energy consumption heating	37824,69 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	200+60	1894,95
Floor	200	8751,88
Roof	200	1013,82
Total		***11660,64***

220 mm

Energy consumption heating	35608,91 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	220+60	2033,28
Floor	220	8926,91
Roof	220	1138,44
Total		***12098,63***

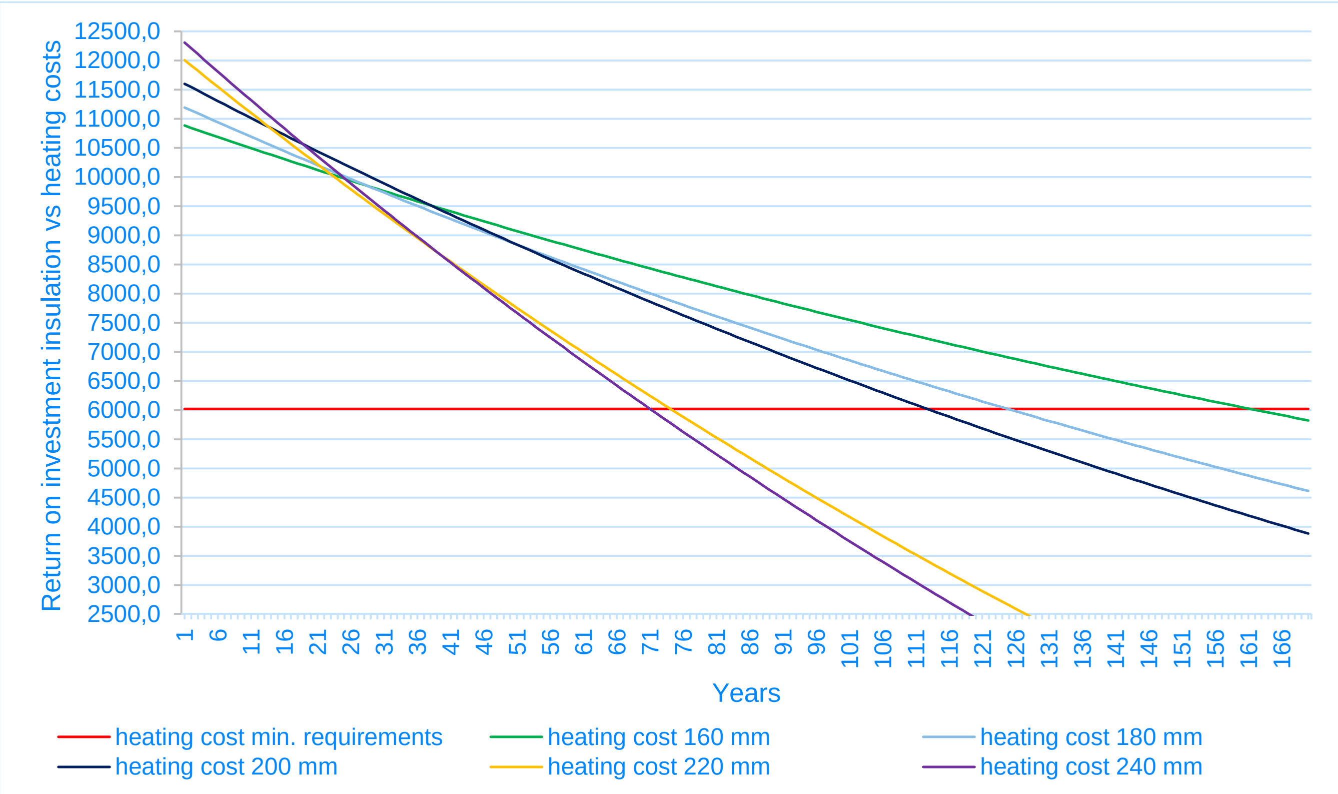
240 mm

Energy consumption heating	35032,82 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	240+60	2168,63
Floor	240	9101,95
Roof	220	1138,44
Total		***12409,02***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results							
					U	K	E	Et	NE	V	O	HE
Minimum requirements	180+60	80	200	41 925,27	✓	31	42	-	66	✓	1.343,	✓
160 mm	180+60	160	200	39 238,34	✓	29	40	-	62	✓	1.459,	✓
180 mm	180+60	180	200	38 428,74	✓	28	39	-	61	✓	1.497,	✓
200 mm	200+60	200	200	37 824,69	✓	28	39	-	60	✓	1.527,	✓
220 mm	220+60	220	220	35 608,91	✓	26	37	-	56	✓	1.646,	✓
240 mm	240+60	240	220	35 032,82	✓	26	36	-	55	✓	1.680,	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results							
				U	K	E	Et	NE	V	O	HE
Minimum requirements	X	X	6	✓	31	29	-	64	✓	1.343,	✓
160 mm	X	X	4	✓	29	30	-	60	✓	1.459,	✓
180 mm	X		5	✓	28	29	-	61	✓	1.497,	✓
200 mm	X		4	✓	28	30	-	60	✓	1.527,	✓
220 mm	X		3	✓	26	30	-	56	✓	1.646,	✓
240 mm	X		3	✓	26	29	-	55	✓	1.680,	✓



- EPB Finnish style various thickness CLT structure-sprayed PUR 2018

Minimum requirements

Energy consumption heating	37736,43 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	120	4200,90
Roof	200	1013,82
Total		***7007,03***

160 mm

Energy consumption heating	37445,11 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	160	8401,80
Roof	200	1013,82
Total		***11207,93***

180 mm

Energy consumption heating	37308,32 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	180	8576,84
Roof	200	1013,82
Total		***11382,97***

200 mm

Energy consumption heating	36583,43 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	200+60	1894,95
Floor	200	8751,88
Roof	200	1013,82
Total		***11660,64***

220 mm

Energy consumption heating	35300,82 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	220+60	2033,28
Floor	220	8926,91
Roof	220	1138,44
Total		*12098,63*

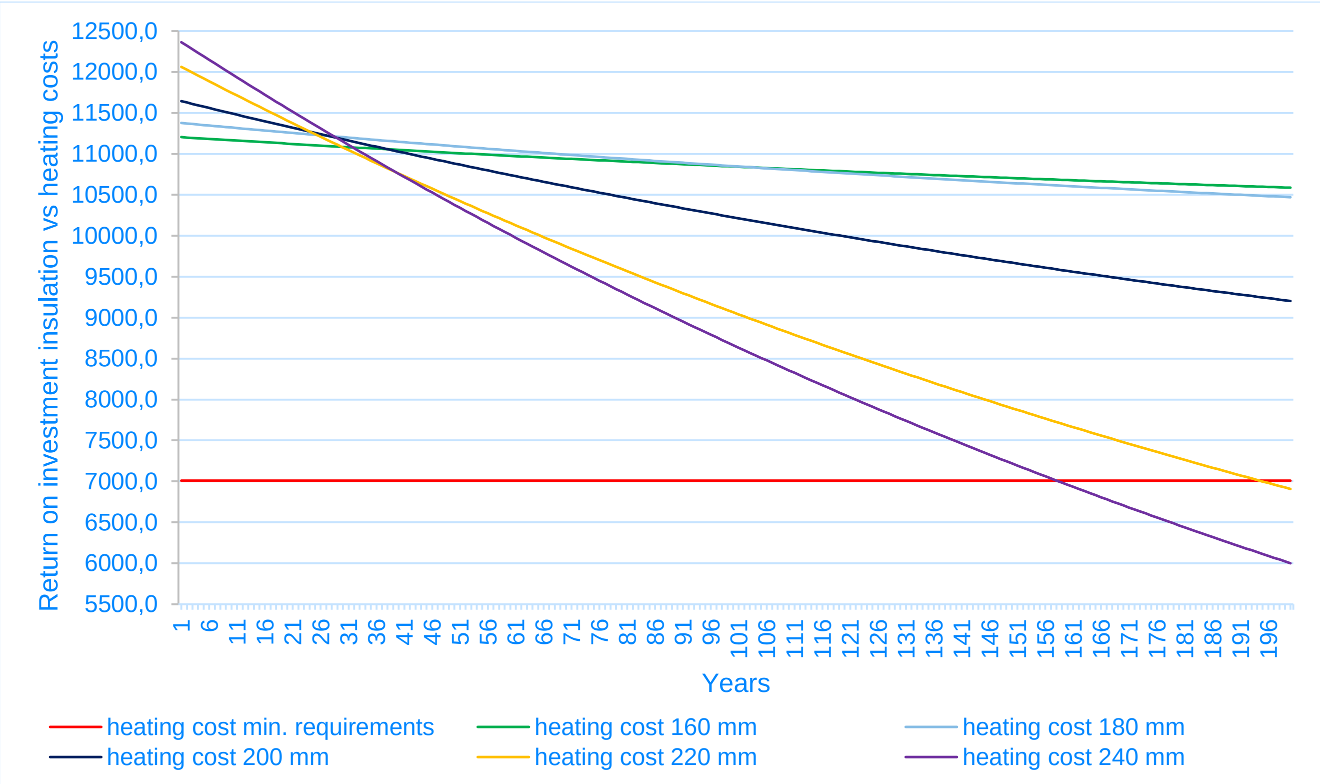
240 mm

Energy consumption heating	34729,72 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	240+60	2168,63
Floor	240	9101,95
Roof	220	1138,44
Total		*12409,02*

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results: U	K	S	E	Et	NE	V	O	HE
Minimum requirements	180+60	120	200	37 736,43	✓	-	31	38	-	-	✓	1.515	✓
160 mm	180+60	160	200	37 445,11	✓	-	31	38	-	-	✓	1.530	✓
180 mm	180+60	180	200	37 308,32	✓	-	31	38	-	-	✓	1.537	✓
200 mm	200+60	200	200	36 583,43	✓	-	30	37	-	-	✓	1.574	✓
220 mm	220+60	220	220	35 300,82	✓	-	29	36	-	-	✓	1.646	✓
240 mm	240+60	240	220	34 729,72	✓	-	29	35	-	-	✓	1.680	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results								
				U	K	S	E	Et	NE	V	O	HE
Minimum requirements	X		4	✓	-	31	29	-	-	✓	1.515	✓
160 mm	X		4	✓	-	31	29	-	-	✓	1.530	✓
180 mm	X		3	✓	-	31	30	-	-	✓	1.537	✓
200 mm	X		3	✓	-	30	30	-	-	✓	1.574	✓
220 mm	X		3	✓	-	29	29	-	-	✓	1.646	✓
240 mm	X		2	✓	-	29	30	-	-	✓	1.680	✓



- EPB Finnish style various thickness CLT structure-PUR boards 2017

Minimum requirements

Energy consumption heating	40718,27 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	160+60	1643,58
Floor	80	2629,76
Roof	180	875,19
Total		***5148,53***

160 mm

Energy consumption heating	37246,82 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	160+60	1643,58
Floor	160	5259,53
Roof	180	875,19
Total		***7778,29***

180 mm

Energy consumption heating	36124,21 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	180	5763,63
Roof	180	875,19
Total		***8431,14***

200 mm

Energy consumption heating	34307,61 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	200+60	1894,95
Floor	200	6267,74
Roof	200	1013,82
Total		***9176,51***

220 mm

Energy consumption heating	32900,83 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	220+60	2033,28
Floor	220	6956,69
Roof	220	1138,44
Total		***10128,41***

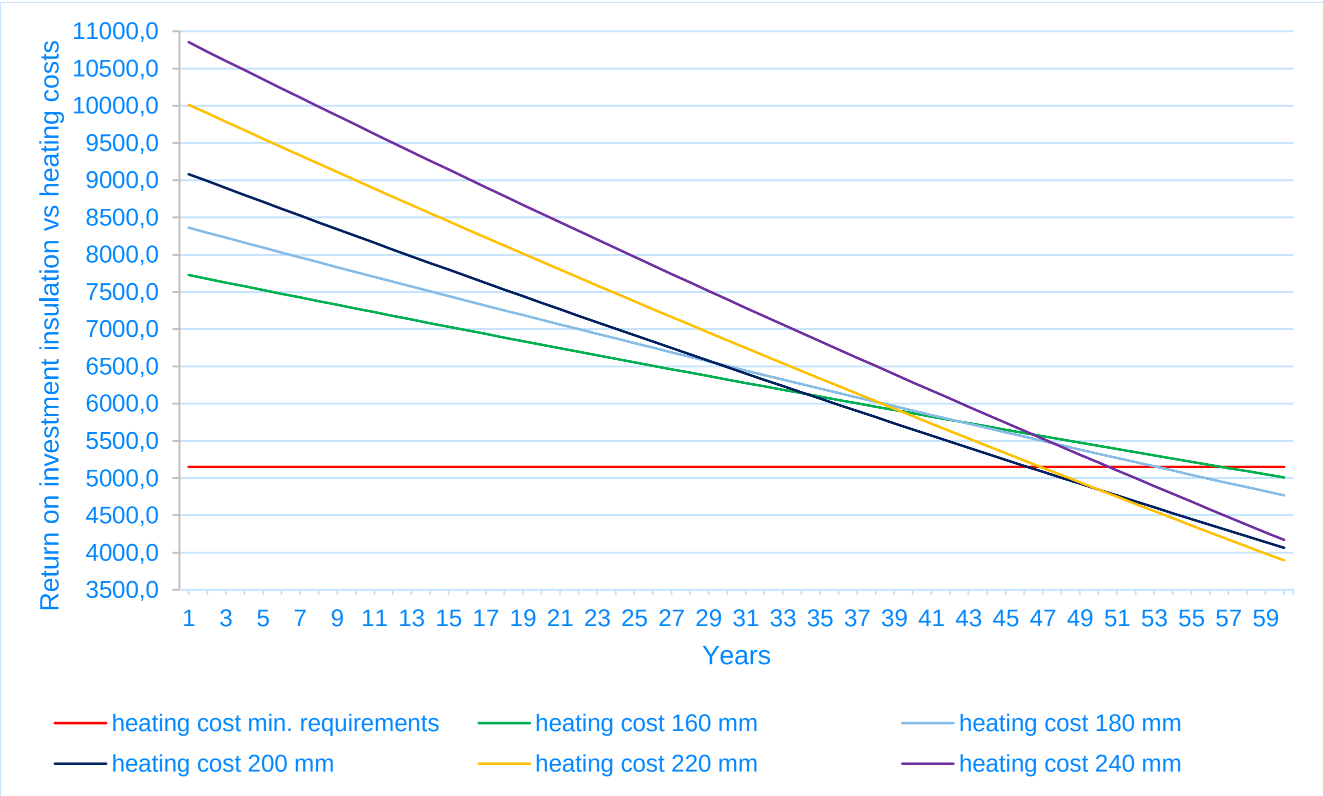
240 mm

Energy consumption heating	32180,43 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	240+60	2168,63
Floor	240	7670,84
Roof	220	1138,44
Total		***10977,92***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results							
					U	K	E	Et	NE	V	O	HE
Minimum requirements	160+80	80	180	40 718,27	✓	30	41	-	64	✓	1.393,	✓
160 mm	160+80	160	180	37 246,82	✓	27	38	-	59	✓	1.556,	✓
180 mm	180+80	180	180	36 124,21	✓	27	37	-	57	✓	1.617,	✓
200 mm	200+80	200	200	34 307,61	✓	25	36	-	54	✓	1.720,	✓
220 mm	220+80	220	220	32 900,83	✓	24	34	-	52	✓	1.817,	✓
240 mm	240+80	240	220	32 180,43	✓	24	34	-	51	✓	1.867,	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results U	K	E	Et	NE	V	O	HE
Minimum requirements	X	X	5	✓	30	30	-	62	✓	1.393,	✓
160 mm	X		4	✓	27	30	-	59	✓	1.556,	✓
180 mm	X		3	✓	27	30	-	57	✓	1.617,	✓
200 mm	X		2	✓	25	30	-	54	✓	1.720,	✓
220 mm	X		2	✓	24	29	-	52	✓	1.817,	✓
240 mm	X		1	✓	24	30	-	51	✓	1.867,	✓



- EPB Finnish style various thickness CLT structure-PUR boards 2018

Minimum requirements

Energy consumption heating	37665,4 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	100	3133,87
Roof	200	1013,82
Total		***5940,01***

160 mm

Energy consumption heating	35478,74 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	160	5259,53
Roof	200	1013,82
Total		***8065,66***

180 mm

Energy consumption heating	35028,45 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	180	5763,63
Roof	200	1013,82
Total		***8569,77***

200 mm

Energy consumption heating	34080,18 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	200+60	1894,95
Floor	200	6267,74
Roof	200	1013,82
Total		***9176,51***

220 mm

Energy consumption heating	32616,17 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	220+60	2033,28
Floor	220	6956,69
Roof	220	1138,44
Total		***10128,41***

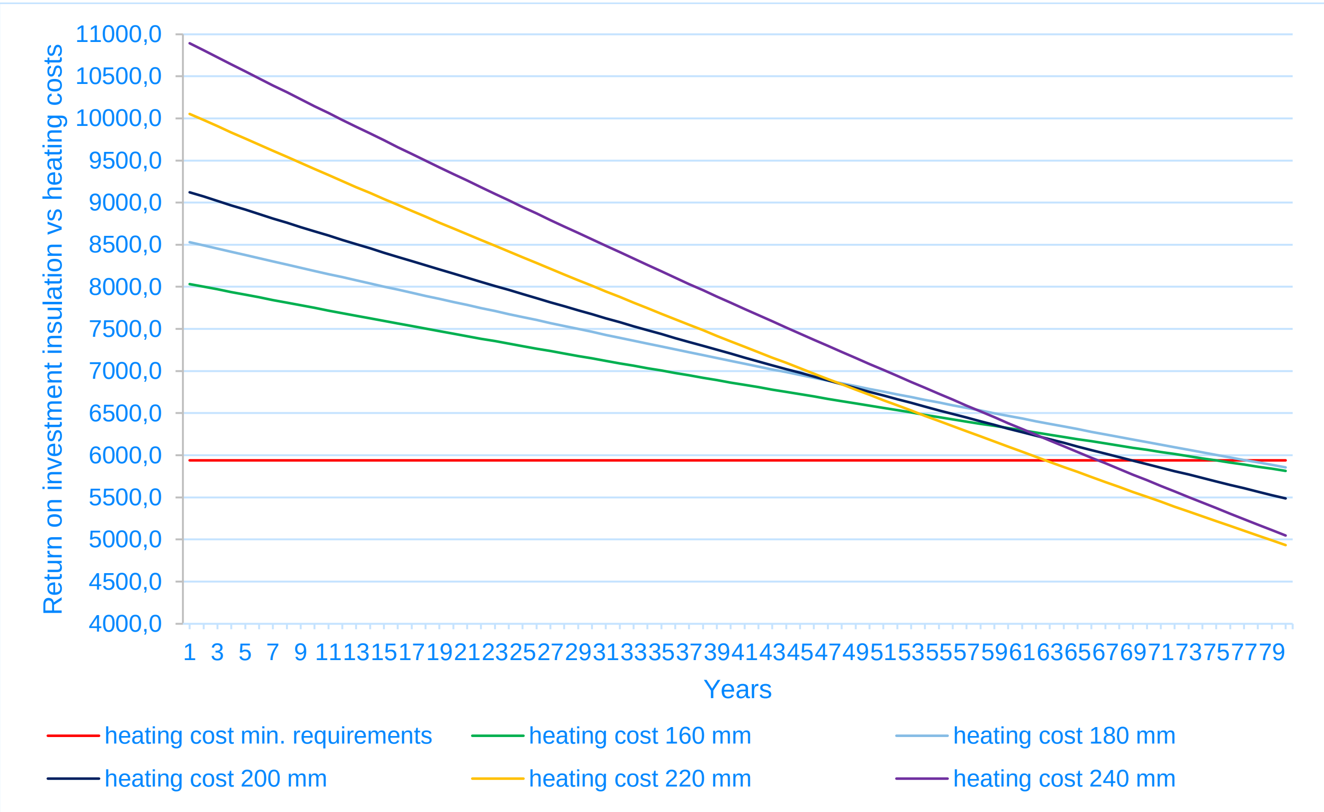
240 mm

Energy consumption heating	31902,01 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulations cost		
Construction component	Thickness (mm)	Price (€)
Wall	240+60	2168,63
Floor	240	7670,84
Roof	220	1138,44
Total		***10977,92***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results								
					U	K	S	E	Et	NE	V	O	HE
Minimum requirements	180+60	100	200	37 665,4	✓	-	31	38	-	-	✓	1.519	✓
160 mm	180+60	160	200	35 478,74	✓	-	29	36	-	-	✓	1.636	✓
180 mm	180+60	180	200	35 028,45	✓	-	29	36	-	-	✓	1.662	✓
200 mm	200+60	200	200	34 080,18	✓	-	28	35	-	-	✓	1.720	✓
220 mm	220+60	220	220	32 902,17	✓	-	27	33	-	-	✓	1.817	✓
240 mm	240+60	240	220	31 902,01	✓	-	26	33	-	-	✓	1.867	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results								
				U	K	S	E	Et	NE	V	O	HE
Minimum requirements	X		4	✓	-	31	29	-	-	✓	1.519	✓
160 mm	X		2	✓	-	29	30	-	-	✓	1.636	✓
180 mm	X		2	✓	-	29	30	-	-	✓	1.662	✓
200 mm	X		2	✓	-	28	29	-	-	✓	1.720	✓
220 mm	X		1	✓	-	27	30	-	-	✓	1.817	✓
240 mm	X		1	✓	-	26	29	-	-	✓	1.867	✓



- EPB Finnish style continuous thickness CLT structure-sprayed PUR 2017

Minimum requirements

Energy consumption heating	41925,27 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160+60	1643,58
Floor	80	3500,75
Roof	180	875,19
Total		***6019,51***

160 mm

Energy consumption heating	39532,94 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160+60	1643,58
Floor	120	4200,90
Roof	180	875,19
Total		***6719,66***

180 mm

Energy consumption heating	38861,18 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	120	4200,90
Roof	180	875,19
Total		***6868,40***

200 mm

Energy consumption heating	38389,34 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200+60	1894,95
Floor	120	4200,90
Roof	200	1013,82
Total		***7109,66***

220 mm

Energy consumption heating	36297,06 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220+60	2033,28
Floor	120	4200,90
Roof	220	1138,44
Total		*7372,62*

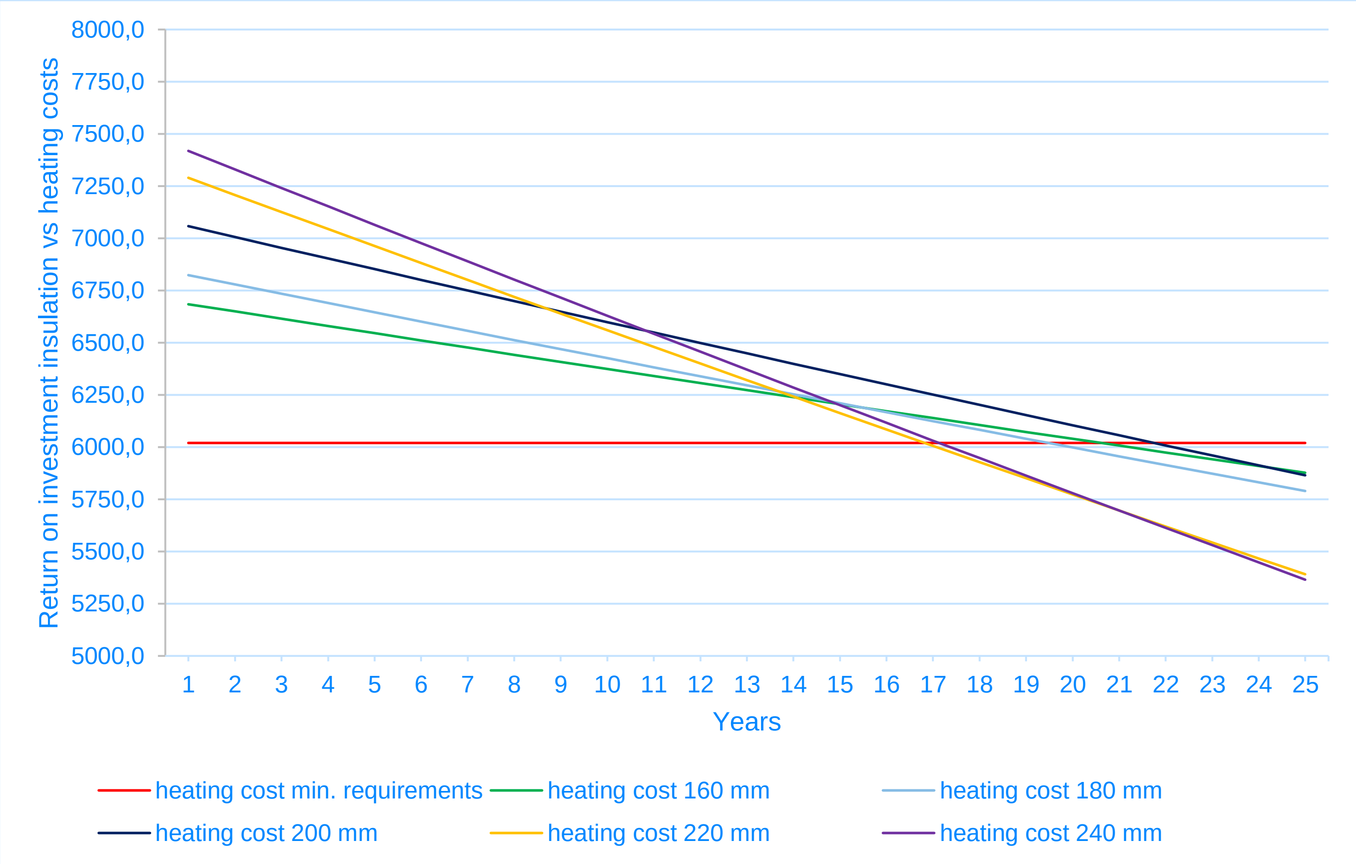
240 mm

Energy consumption heating	35842,13 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240+60	2168,63
Floor	120	4200,90
Roof	220	1138,44
Total		*7507,97*

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results							
					U	K	E	Et	NE	V	O	HE
Minimum requirements	160+60	80	180	41 925,27	✓	31	42	-	66	✓	1.343,	✓
160 mm	*160+60*	*120*	*180*	*39 532,94*	✓	29	40	-	63	✓	1.445,	✓
180 mm	*180+60*	*120*	*180*	*38 861,18*	✓	29	39	-	61	✓	1.476,	✓
200 mm	*200+60*	*120*	*200*	*38 389,34*	✓	28	39	-	61	✓	1.499,	✓
220 mm	*220+60*	*120*	*220*	*36 297,06*	✓	27	37	-	57	✓	1.607,	✓
240 mm	*240+60*	*120*	*220*	*35 842,13*	✓	26	37	-	57	✓	1.632,	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results
Minimum requirements	X	X	6	U ✓ · K 31 · E 29 · Et - · NE 64 · V ✓ · O 1.343, · HE ✓
160 mm	X		5	U ✓ · K 29 · E 30 · Et - · NE 63 · V ✓ · O 1.445, · HE ✓
180 mm	X		5	U ✓ · K 29 · E 29 · Et - · NE 61 · V ✓ · O 1.476, · HE ✓
200 mm	X		5	U ✓ · K 28 · E 29 · Et - · NE 61 · V ✓ · O 1.499, · HE ✓
220 mm	X		3	U ✓ · K 27 · E 30 · Et - · NE 57 · V ✓ · O 1.607, · HE ✓
240 mm	X		3	U ✓ · K 26 · E 30 · Et - · NE 57 · V ✓ · O 1.632, · HE ✓



- EPB Finnish style continuous thickness CLT structure-sprayed PUR 2018

Minimum requirements

Energy consumption heating	37736,43 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	120	4200,90
Roof	200	1013,82
Total		***7007,03***

180 mm

Energy consumption heating	37736,43 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	120	4200,90
Roof	200	1013,82
Total		***7007,03***

200 mm

Energy consumption heating	37141,14 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200+60	1894,95
Floor	120	4200,90
Roof	200	1013,82
Total		***7109,66***

240 mm

Energy consumption heating (MJ)	35532,03 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price
Wall	240+60	2168,63
Floor	120	4200,90
Roof	220	1138,44
Total		***7507,97***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results
Minimum requirements	180+60	120	200	37 736,43	U: ✓, K: -, S: 31, E: 38, Et: -, NE: -, V: ✓, O: 1.515, HE: ✓
200 mm	*200+60*	*120*	*200*	*37 141,14*	U: ✓, K: -, S: 31, E: 37, Et: -, NE: -, V: ✓, O: 1.545, HE: ✓
220 mm	*220+60*	*120*	*220*	*35 983,02*	U: ✓, K: -, S: 30, E: 29, Et: -, NE: -, V: ✓, O: 1.607, HE: ✓
240 mm	*240+60*	*120*	*220*	*35 532,03*	U: ✓, K: -, S: 29, E: 36, Et: -, NE: -, V: ✓, O: 1.632, HE: ✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results
Minimum requirements	X		4	U: ✓, K: -, S: 31, E: 29, Et: -, NE: -, V: ✓, O: 1.515, HE: ✓
200 mm	X		3	U: ✓, K: -, S: 31, E: 30, Et: -, NE: -, V: ✓, O: 1.545, HE: ✓
220 mm	X		3	U: ✓, K: -, S: 30, E: 29, Et: -, NE: -, V: ✓, O: 1.607, HE: ✓
240 mm	X		3	U: ✓, K: -, S: 29, E: 29, Et: -, NE: -, V: ✓, O: 1.632, HE: ✓


Return on investment insulation vs heating costs
7500,0
7450,0
7400,0
7350,0
7300,0
7250,0
7200,0
7150,0
7100,0
7050,0
7000,0
6950,0
6900,0
6850,0
6800,0
6750,0
6700,0
6650,0
6600,0
6550,0
6500,0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
Years
heating cost min. requirements
heating cost 200 mm
heating cost 220 mm
heating cost 240 mm

- EPB Finnish style continuous thickness CLT structure-PUR boards 2017

Minimum requirements

Energy consumption heating	40718,27 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160+60	1643,58
Floor	80	2629,76
Roof	180	875,19
Total		***5148,53***

160 mm

Energy consumption heating	38543,93 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160+60	1643,58
Floor	120	3822,82
Roof	180	875,19
Total		***6341,58***

180 mm

Energy consumption heating	37864,31 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	120	3822,82
Roof	180	875,19
Total		***6490,32***

200 mm

Energy consumption heating	36472,86 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200+60	1894,95
Floor	120	3822,82
Roof	200	1013,82
Total		***6731,58***

220 mm

Energy consumption heating	35306,6 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220+60	2033,28
Floor	120	3822,82
Roof	220	1138,44
Total		***6994,54***

240 mm

Energy consumption heating	34852,48 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240+60	2168,63
Floor	120	3822,82
Roof	220	1138,44
Total		***7129,89***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results: U	K	E	Et	NE	V	O	HE
Minimum requirements	160+60	80	180	40 718,27	✓	31	42	-	66	✓	1.343,	✓
160 mm	160+60	120	180	38 543,93	✓	28	39	-	61	✓	1.492,	✓
180 mm	180+60	120	180	37 864,31	✓	28	39	-	60	✓	1.525,	✓
200 mm	200+60	120	200	36 472,86	✓	27	37	-	58	✓	1.597,	✓
220 mm	*220+60*	*120*	*220*	*35 306,6*	✓	26	36	-	56	✓	1.663,	✓
240 mm	*240+60*	*120*	*220*	*34 852,48*	✓	26	36	-	55	✓	1.691,	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results: U	K	E	Et	NE	V	O	HE
Minimum requirements	X	X	5	✓	30	30	-	62	✓	1.393,	✓
160 mm	X		5	✓	28	29	-	61	✓	1.492,	✓
180 mm	X		4	✓	28	30	-	60	✓	1.525,	✓
200 mm	X		4	✓	27	29	-	58	✓	1.597,	✓
220 mm	X		3	✓	26	29	-	56	✓	1.663,	✓
240 mm	X		3	✓	26	29	-	55	✓	1.691,	✓

- EPB Finnish style continuous thickness CLT structure-PUR boards 2018

Minimum requirements

Energy consumption heating	37665,4 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	100	3133,87
Roof	200	1013,82
Total		***5940,01***

180 mm

Energy consumption heating	36735,11 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	120	3822,82
Roof	200	1013,82
Total		***6628,95***

200 mm

Energy consumption heating	36157,3 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200+60	1894,95
Floor	120	3822,82
Roof	200	1013,82
Total		***6731,58***

220 mm

Energy consumption heating	35001,13 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220+60	2033,28
Floor	120	3822,82
Roof	220	1138,44
Total		***6994,54***

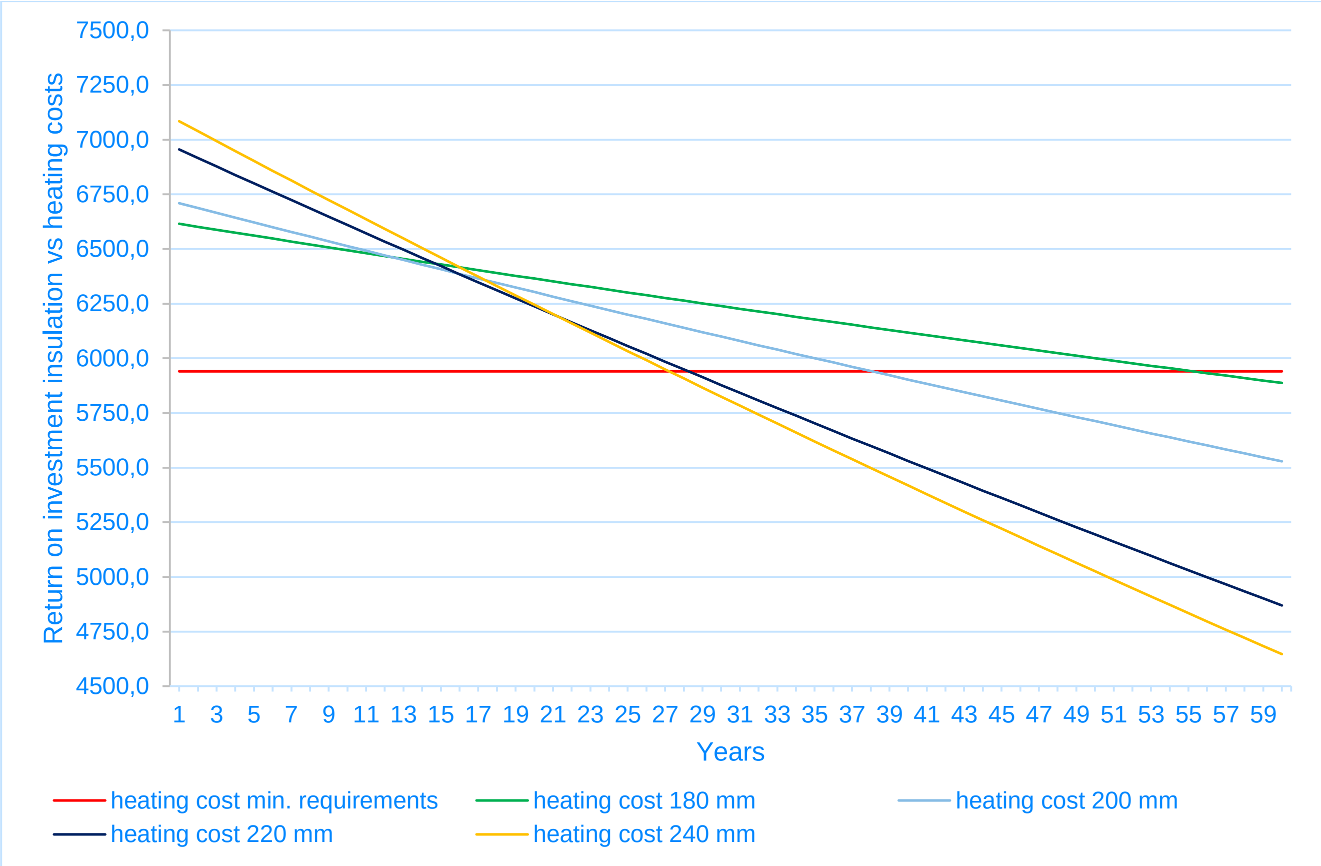
_240 mm_

Energy consumption heating	34550,94 MJ	Results from EPB software
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240+60	2168,63
Floor	120	3822,82
Roof	220	1138,44
Total		7129,89

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)	EPB results								
					U	K	S	E	Et	NE	V	O	HE
Minimum requirements	180+60	100	200	37 665,4	✓	-	31	38	-	-	✓	1.519	✓
180 mm	180+60	120	200	36 735,11	✓	-	30	37	-	-	✓	1.566	✓
200 mm	200+60	200	200	36 157,3	✓	-	30	37	-	-	✓	1.597	✓
220 mm	220+60	220	220	35 001,13	✓	-	29	36	-	-	✓	1.663	✓
240 mm	240+60	240	220	34 550,94	✓	-	29	35	-	-	✓	1.691	✓

File name	Energy efficiency class A+	thermal efficiency heat recovery of 85%	Number of extra solar panels	EPB results								
				U	K	S	E	Et	NE	V	O	HE
Minimum requirements	X		4	✓	-	31	29	-	-	✓	1.519	✓
180 mm	X		3	✓	-	30	30	-	-	✓	1.566	✓
200 mm	X		3	✓	-	30	29	-	-	✓	1.597	✓
220 mm	X		2	✓	-	29	30	-	-	✓	1.663	✓
240 mm	X		2	✓	-	29	30	-	-	✓	1.691	✓


Return on investment insulation vs heating costs
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6250,0
6000,0
5750,0
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5250,0
5000,0
4750,0
4500,0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59
Years
heating cost min. requirements
heating cost 180 mm
heating cost 200 mm
heating cost 220 mm
heating cost 240 mm

- ArchiCad Belgian style various thickness PUR

Minimum requirements

Energy consumption heating	10568 kWh	Results from Archicad
Energy consumption heating	38044,8 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	160	5259,53
Roof	280	9038,93
Total		***17490,42***

140 mm

Energy consumption heating	10375 kWh	Results from Archicad
Energy consumption heating	37350 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	140	3684,29
Floor	160	5259,53
Roof	280	9038,93
Total		***17982,75***

160 mm

Energy consumption heating	10224 kWh	Results from Archicad
Energy consumption heating	36806,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	4435,43
Floor	160	5259,53
Roof	280	9038,93
Total		***18733,88***

180 mm

Energy consumption heating	10027 kWh	Results from Archicad
Energy consumption heating	36097,2 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180	4923,29
Floor	180	5763,63
Roof	280	9038,93
Total		***19725,86***

200 mm

Energy consumption heating	9863 kWh	Results from Archicad
Energy consumption heating	35506,8 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200	5408,19
Floor	200	6267,74
Roof	280	9038,93
Total		***20714,86***

220 mm

Energy consumption heating	9724 kWh	Results from Archicad
Energy consumption heating	35006,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220	5896,05
Floor	220	6956,69
Roof	280	9038,93
Total		***21891,67***

240 mm

Energy consumption heating	9604 kWh	Results from Archicad
Energy consumption heating	34574,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

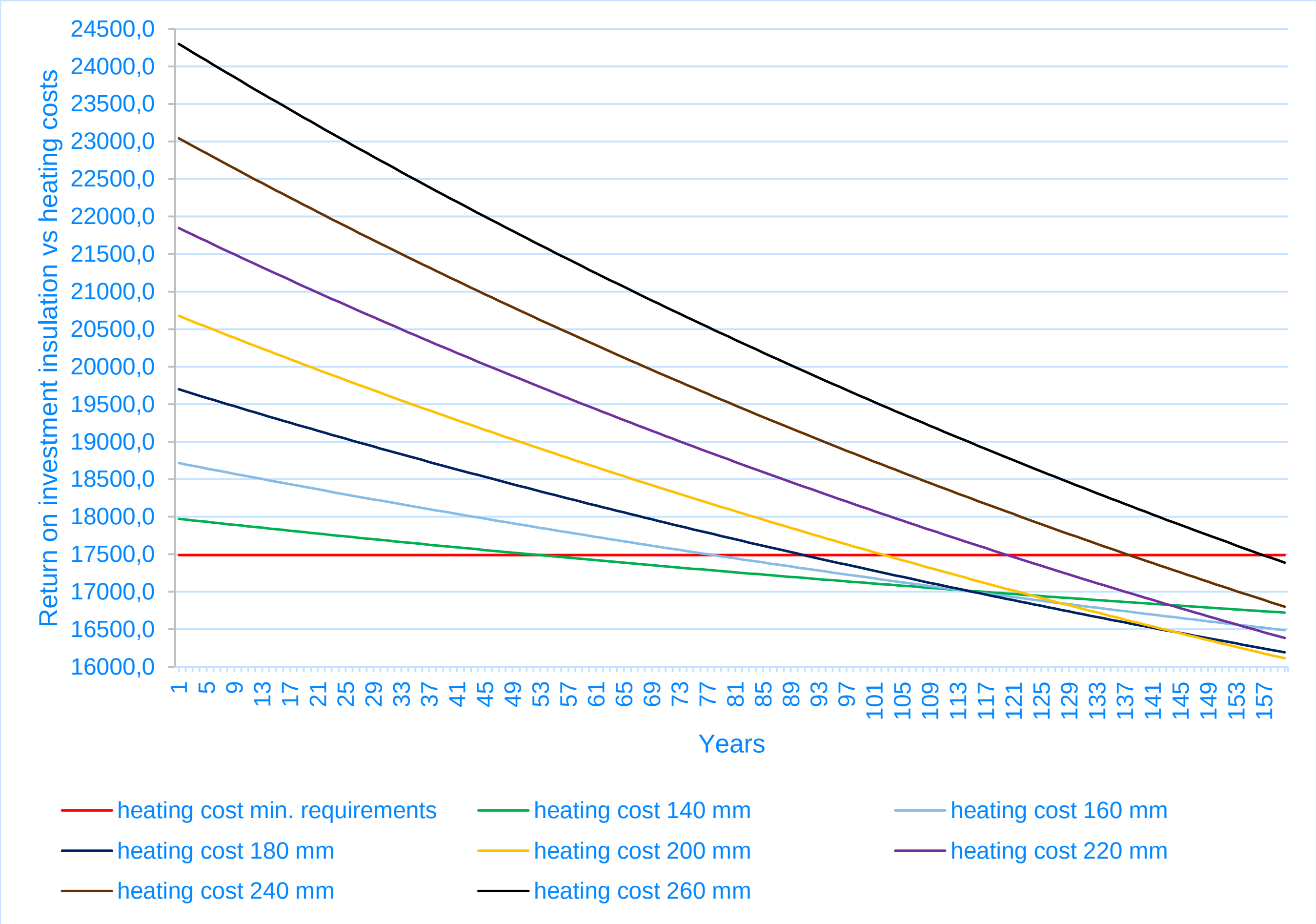
Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240	6383,92
Floor	240	7670,84
Roof	280	9038,93
Total		***23093,69***

260 mm

Energy consumption heating	9500 kWh	Results from Archicad
Energy consumption heating	34200 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	260	7139,52
Floor	260	8179,15
Roof	280	9038,93
Total		***24357,60***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)
Minimum requirements	120	160	280	38 044,8
140 mm	140	160	280	37 350
160 mm	160	160	280	36 806,4
180 mm	180	180	280	36 097,2
200 mm	200	200	280	35 506,8
220 mm	220	220	280	35 006,4
240 mm	240	240	280	34 574,4
260 mm	260	260	280	34 200



- ArchiCad Belgian style various thickness mineral wool

Minimum requirements

Energy consumption heating	10647 kWh	Results from Archicad
Energy consumption heating	38329,2 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180	1264,29
Floor	160	5259,53
Roof	440	2276,89
Total		***8800,70***

180 mm

Energy consumption heating	10572 kWh	Results from Archicad
Energy consumption heating	38059,2 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180	1264,29
Floor	180	5763,63
Roof	440	2276,89
Total		***9304,81***

200 mm

Energy consumption heating	10396 kWh	Results from Archicad
Energy consumption heating	37425,6 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200	1366,92
Floor	200	6267,74
Roof	440	2276,89
Total		***9911,55***

220 mm

Energy consumption heating	10196 kWh	Results from Archicad
Energy consumption heating	36705,6 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220	1505,25
Floor	220	6956,69
Roof	440	2276,89
Total		***10738,83***

240 mm

Energy consumption heating	10047 kWh	Results from Archicad
Energy consumption heating	36169,2 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240	1640,60
Floor	240	7670,84
Roof	440	2276,89
Total		***11588,33***

260 mm

Energy consumption heating	9916 kWh	Results from Archicad
Energy consumption heating	35697,6 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	260	1802,73
Floor	260	8179,15
Roof	440	2276,89
Total		***12258,77***

280 mm

Energy consumption heating	9840 kWh	Results from Archicad
Energy consumption heating	35424 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	280	1933,62
Floor	260	8179,15
Roof	440	2276,89
Total		***12389,66***

300 mm

Energy consumption heating	9722 kWh	Results from Archicad
Energy consumption heating	34999,2 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	300	2082,36
Floor	260	8179,15
Roof	440	2379,84
Total		***12641,35***

320 mm

Energy consumption heating	9712 kWh	Results from Archicad
Energy consumption heating	34963,2 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

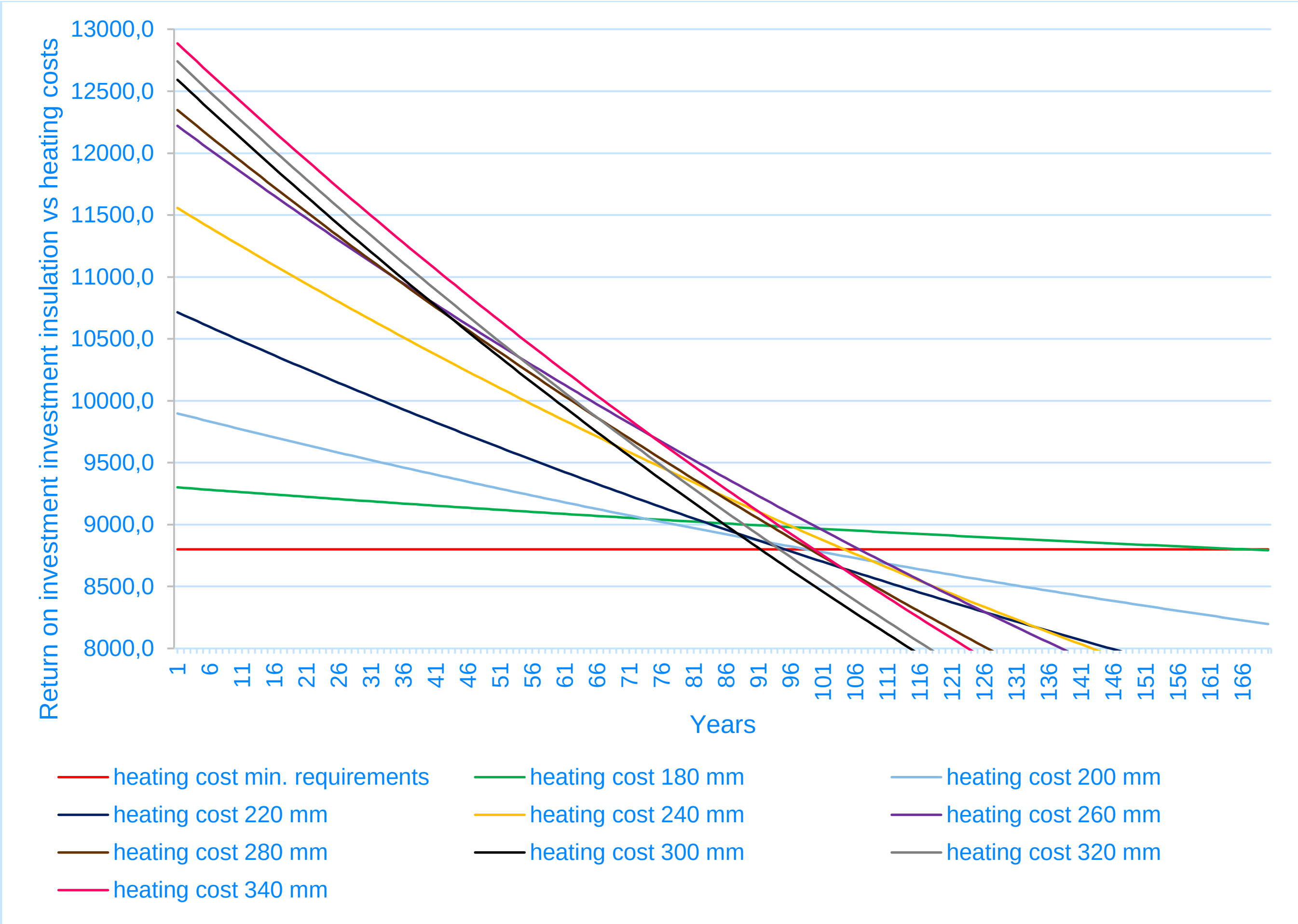
Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	320	2231,10
Floor	260	8179,15
Roof	440	2379,84
Total		***12790,09***

340 mm

Energy consumption heating	9658 kWh	Results from Archicad
Energy consumption heating	34768,8 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	340	2379,84
Floor	260	8179,15
Roof	440	2379,84
Total		***12938,83***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)
Minimum requirements	180	160	440	38 329,2
180 mm	180	180	440	38 059,2
200 mm	200	200	440	37 425,6
220 mm	220	220	440	36 705,6
240 mm	240	240	440	36 169,2
260 mm	260	260	440	35 697,6
280 mm	280	280	440	35 424
300 mm	300	300	440	34 999,2
320 mm	320	320	440	34 963,2
340 mm	340	340	440	34 768,8



Return on investment investment insulation vs heating costs
13000,0
12500,0
12000,0
11500,0
11000,0
10500,0
10000,0
9500,0
9000,0
8500,0
8000,0
1 6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96 101 106 111 116 121 126 131 136 141 146 151 156 161 166
Years
heating cost min. requirements
heating cost 180 mm
heating cost 200 mm
heating cost 220 mm
heating cost 240 mm
heating cost 260 mm
heating cost 280 mm
heating cost 300 mm
heating cost 320 mm
heating cost 340 mm

- ArchiCad Belgian style continuous thickness PUR

Minimum requirements

Energy consumption heating	10568 kWh	Results from Archicad
Energy consumption heating	38044,8 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120	3191,96
Floor	160	5259,53
Roof	280	9038,93
Total		***17490,42***

140 mm

Energy consumption heating	10375 kWh	Results from Archicad
Energy consumption heating	37350 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	140	3684,29
Floor	160	5259,53
Roof	280	9038,93
Total		***17982,75***

160 mm

Energy consumption heating	10224 kWh	Results from Archicad
Energy consumption heating	36806,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160	4435,43
Floor	160	5259,53
Roof	280	9038,93
Total		***18733,88***

180 mm

Energy consumption heating	10103 kWh	Results from Archicad
Energy consumption heating	36370,8 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180	4923,29
Floor	160	5259,53
Roof	280	9038,93
Total		***19221,75***

200 mm

Energy consumption heating	10003 kWh	Results from Archicad
Energy consumption heating	36010,8 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200	5408,19
Floor	160	5259,53
Roof	280	9038,93
Total		***19706,64***

220 mm

Energy consumption heating	9919 kWh	Results from Archicad
Energy consumption heating	35708,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220	5896,05
Floor	160	5259,53
Roof	280	9038,93
Total		***20194,51***

240 mm

Energy consumption heating	9848 kWh	Results from Archicad
Energy consumption heating	35452,8 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

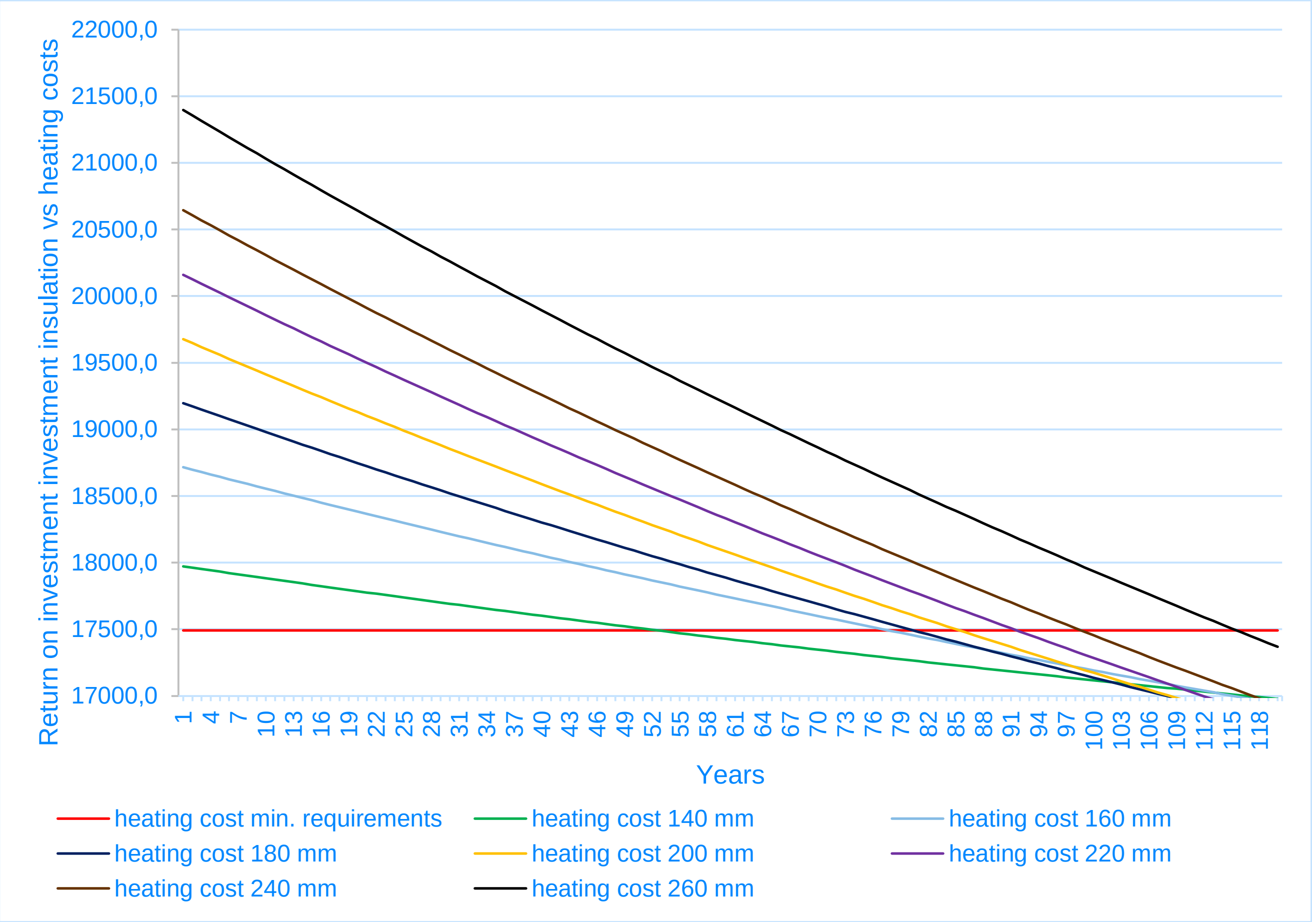
Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240	6383,92
Floor	160	5259,53
Roof	280	9038,93
Total		***20682,38***

260 mm

Energy consumption heating	9787 kWh	Results from Archicad
Energy consumption heating	35233,2 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	260	7139,52
Floor	160	5259,53
Roof	280	9038,93
Total		***21437,98***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)
Minimum requirements	120	160	280	38 044,8
140 mm	140	160	280	37 350
160 mm	160	160	280	36 806,4
180 mm	180	160	280	36 370,8
200 mm	200	160	280	36 010,8
220 mm	220	160	280	35 708,4
240 mm	240	160	280	35 452,8
260 mm	260	160	280	35 233,2



- ArchiCad Belgian style continuous thickness mineral wool

Minimum requirements

Energy consumption heating	10647 kWh	Results from Archicad
Energy consumption heating	38329,2 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180	1264,29
Floor	160	5259,53
Roof	440	2276,89
Total		***8800,70***

180 mm

Energy consumption heating	10647 kWh	Results from Archicad
Energy consumption heating	38329,2 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180	1264,29
Floor	160	5259,53
Roof	440	2276,89
Total		***8800,70***

200 mm

Energy consumption heating	10508 kWh	Results from Archicad
Energy consumption heating	37828,8 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200	1366,92
Floor	160	5259,53
Roof	440	2276,89
Total		***8903,34***

220 mm

Energy consumption heating	10390 kWh	Results from Archicad
Energy consumption heating	37404 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220	1505,25
Floor	160	5259,53
Roof	440	2276,89
Total		***9041,66***

240 mm

Energy consumption heating	10289 kWh	Results from Archicad
Energy consumption heating	37040,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240	1640,60
Floor	160	5259,53
Roof	440	2276,89
Total		***9177,02***

260 mm

Energy consumption heating	10201 kWh	Results from Archicad
Energy consumption heating	36723,6 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	260	1802,73
Floor	160	5259,53
Roof	440	2276,89
Total		***9339,14***

280 mm

Energy consumption heating	10125 kWh	Results from Archicad
Energy consumption heating	36450 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	280	1933,62
Floor	160	5259,53
Roof	440	2276,89
Total		***9470,03***

300 mm

Energy consumption heating	10057 kWh	Results from Archicad
Energy consumption heating	36205,2 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	300	2082,36
Floor	160	5259,53
Roof	440	2379,84
Total		***9721,73***

320 mm

Energy consumption heating	9997 kWh	Results from Archicad
Energy consumption heating	35989,2 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

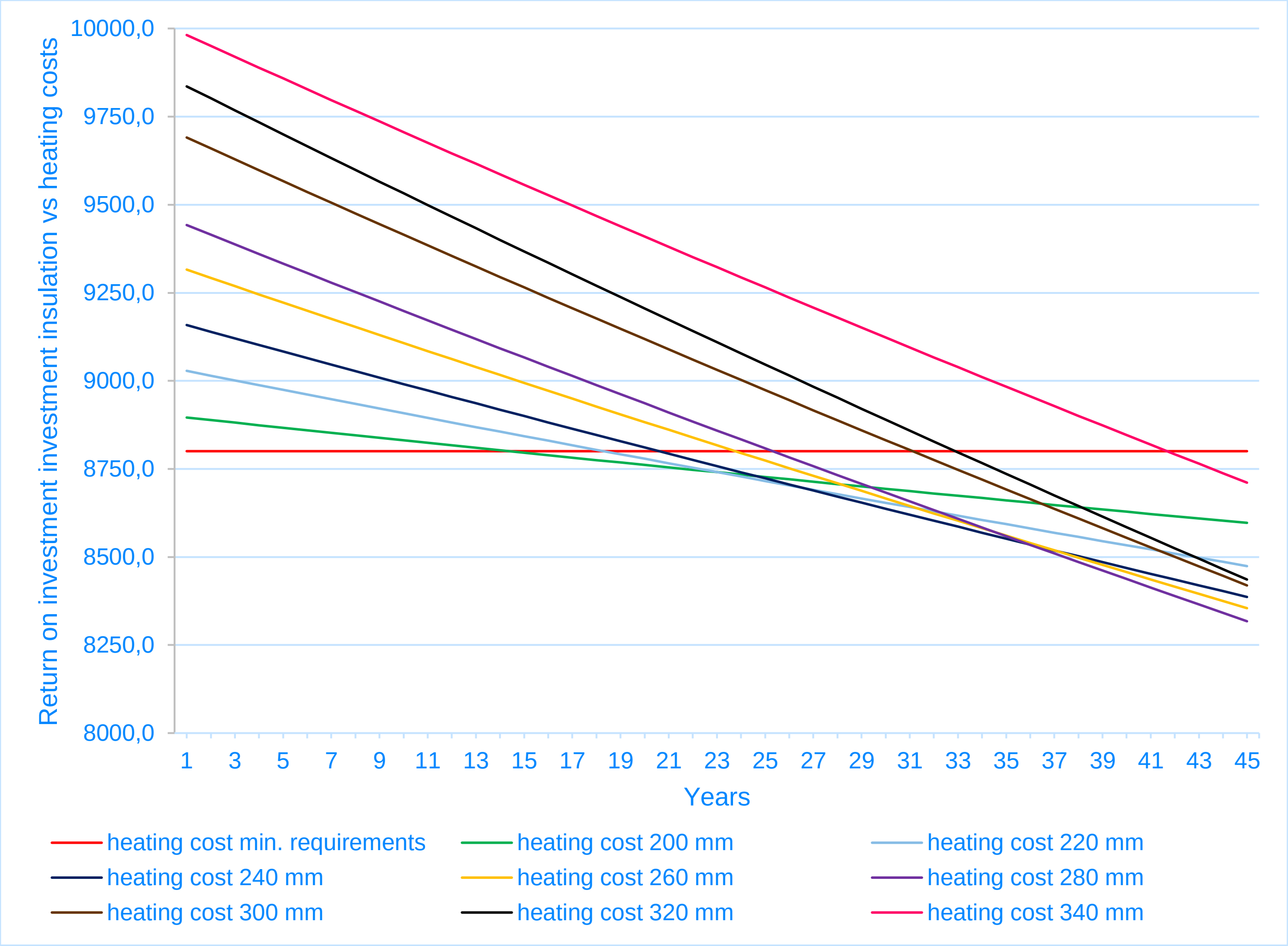
Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	320	2231,10
Floor	160	5259,53
Roof	440	2379,84
Total		***9870,47***

340 mm

Energy consumption heating	9944 kWh	Results from Archicad
Energy consumption heating	35798,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	340	2379,84
Floor	160	5259,53
Roof	440	2379,84
Total		***10019,21***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)
Minimum requirements	180	160	440	38 329,2
200 mm	*200*	*200*	*440*	37 828,8
220 mm	*220*	*220*	*440*	37 404
240 mm	*240*	*240*	*440*	37 040,4
260 mm	*260*	*260*	*440*	36 723,6
280 mm	280	280	440	36 450
300 mm	300	300	440	36 205,2
320 mm	320	320	440	35 989,2
340 mm	340	340	440	35 798,4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9500,0
9250,0
9000,0
8750,0
8500,0
8250,0
8000,0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45
Years
heating cost min. requirements
heating cost 200 mm
heating cost 220 mm
heating cost 240 mm
heating cost 260 mm
heating cost 280 mm
heating cost 300 mm
heating cost 320 mm
heating cost 340 mm

- ArchiCad Finnish style various thickness CLT structure

Minimum requirements

Energy consumption heating	10594 kWh	Results from Archicad
Energy consumption heating	38138,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120+60	1363,95
Floor	160	5259,53
Roof	440	2276,89
Total		***8900,36***

140 mm

Energy consumption heating	10460 kWh	Results from Archicad
Energy consumption heating	37656 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	140+60	1494,84
Floor	160	5259,53
Roof	440	2276,89
Total		***9031,25***

160 mm

Energy consumption heating	10346 kWh	Results from Archicad
Energy consumption heating	37245,6 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160+60	1643,58
Floor	160	5259,53
Roof	440	2276,89
Total		***9179,99***

180 mm

Energy consumption heating	10174 kWh	Results from Archicad
Energy consumption heating	36626,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	160	5259,53
Roof	440	2276,89
Total		***9328,73***

200 mm

Energy consumption heating	10025 kWh	Results from Archicad
Energy consumption heating	36090 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200+60	1894,95
Floor	160	5259,53
Roof	440	2276,89
Total		***9431,36***

220 mm

Energy consumption heating	9896 kWh	Results from Archicad
Energy consumption heating	35625,6 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220+60	2033,28
Floor	160	5259,53
Roof	440	2276,89
Total		***9569,69***

240 mm

Energy consumption heating	9782 kWh	Results from Archicad
Energy consumption heating	35215,2 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240+60	2168,63
Floor	160	5259,53
Roof	440	2276,89
Total		***9705,04***

260 mm

Energy consumption heating	9682 kWh	Results from Archicad
Energy consumption heating	34855,2 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

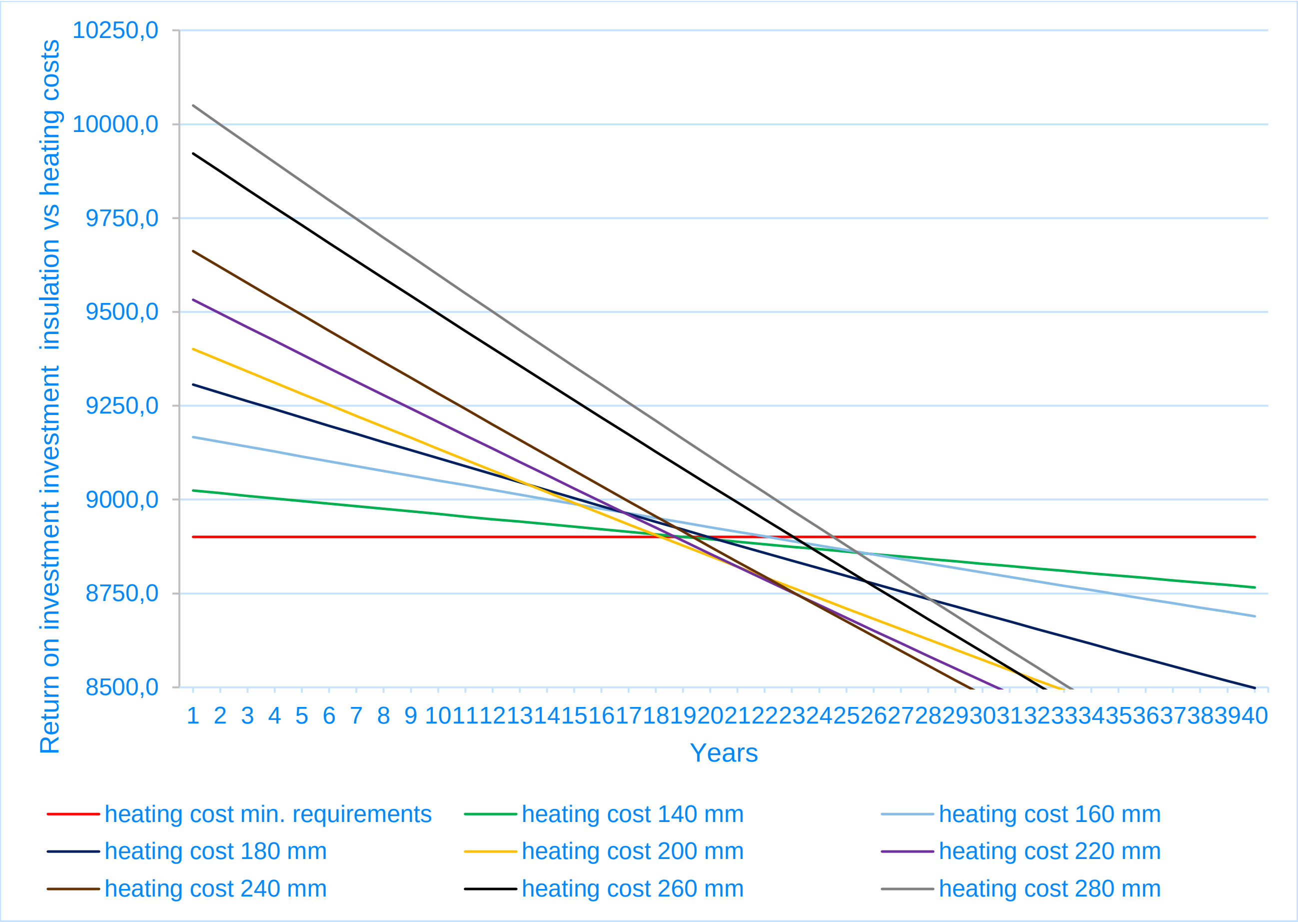
Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	260+60	2330,76
Floor	160	5259,53
Roof	440	2379,84
Total		***9970,12***

280 mm

Energy consumption heating	9629 kWh	
Energy consumption heating	34664,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	280+60	2461,65
Floor	160	5259,53
Roof	440	2379,84
Total		***10101,01***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)
Minimum requirements	120+60	160	440	38 138,4
140 mm	*140+60*	*160*	*440*	37 656
160 mm	*160+60*	*160*	*440*	37 245,6
180 mm	*180+60*	*180*	*440*	36 626,4
200 mm	*200+60*	*200*	*440*	36 090
220 mm	*220+60*	*220*	*440*	35 625,6
240 mm	*240+60*	*240*	*440*	35 215,2
260 mm	*260+60*	*260*	*440*	34 855,2
280 mm	280+60	280	440	34 664,4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9250,0
9000,0
8750,0
8500,0
Return on investment investment insulation vs heating costs
1 2 3 4 5 6 7 8 9 10111213141516171819202122232425262728293031323334353637383940
Years
heating cost min. requirements
heating cost 140 mm
heating cost 160 mm
heating cost 180 mm
heating cost 200 mm
heating cost 220 mm
heating cost 240 mm
heating cost 260 mm
heating cost 280 mm

- ArchiCad Finnish style continuous thickness CLT structure

Minimum requirements

Energy consumption heating	10594 kWh	Results from Archicad
Energy consumption heating	38138,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	120+60	1363,95
Floor	160	5259,53
Roof	440	2276,89
Total		***8900,36***

140 mm

Energy consumption heating	10460 kWh	Results from Archicad
Energy consumption heating	37656 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	140+60	1494,84
Floor	160	5259,53
Roof	440	2276,89
Total		***9031,25***

160 mm

Energy consumption heating	10346 kWh	Results from Archicad
Energy consumption heating	37245,6 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	160+60	1643,58
Floor	160	5259,53
Roof	440	2276,89
Total		***9179,99***

180 mm

Energy consumption heating	10249 kWh	Results from Archicad
Energy consumption heating	36896,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	180+60	1792,32
Floor	160	5259,53
Roof	440	2276,89
Total		***9328,73***

200 mm

Energy consumption heating	10164 kWh	Results from Archicad
Energy consumption heating	36590,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	200+60	1894,95
Floor	160	5259,53
Roof	440	2276,89
Total		***9431,36***

220 mm

Energy consumption heating	10089 kWh	Results from Archicad
Energy consumption heating	36320,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	220+60	2033,28
Floor	160	5259,53
Roof	440	2276,89
Total		***9569,69***

240 mm

Energy consumption heating	10024 kWh	Results from Archicad
Energy consumption heating	36086,4 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	240+60	2168,63
Floor	160	5259,53
Roof	440	2276,89
Total		***9705,04***

260 mm

Energy consumption heating	9965 kWh	Results from Archicad
Energy consumption heating	35874 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

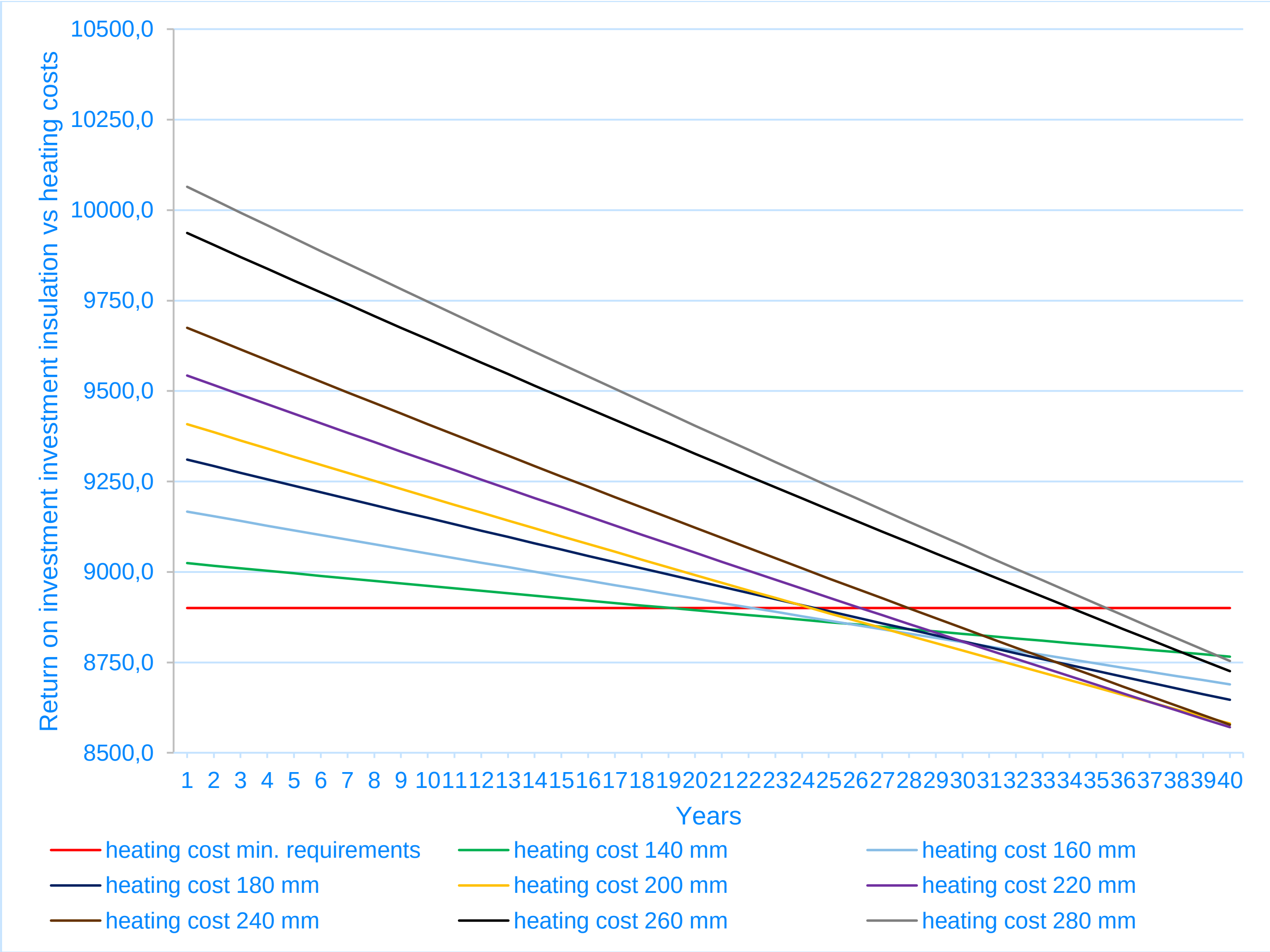
Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	260+60	2330,76
Floor	160	5259,53
Roof	440	2379,84
Total		***9970,12***

280 mm

Energy consumption heating	9913 kWh	Results from Archicad
Energy consumption heating	35686,8 MJ	
Change of investment	2,65%	Assumptions
Discount rate	3,00%	
Price natural gas	0,01472 €/MJ	

Insulation cost		
Construction component	Thickness (mm)	Price (€)
Wall	280+60	2461,65
Floor	160	5259,53
Roof	440	2379,84
Total		***10101,01***

File name	Wall (mm)	Floor (mm)	Roof (mm)	Primary energy consumption (MJ)
Minimum requirements	120+60	160	440	38 138,4
140 mm	*140+60*	*160*	*440*	37 656
160 mm	*160+60*	*160*	*440*	37 245,6
180 mm	*180+60*	*160*	*440*	36 896,4
200 mm	*200+60*	*160*	*440*	36 590,4
220 mm	220+60	160	440	36 320,4
240 mm	240+60	160	440	36 086,4
260 mm	260+60	160	440	35 874
280 mm	280+60	160	440	35 686,8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10250,0
10000,0
9750,0
9500,0
9250,0
9000,0
8750,0
8500,0
Return on investment investment insulation vs heating costs
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Years
heating cost min. requirements
heating cost 140 mm
heating cost 160 mm
heating cost 180 mm
heating cost 200 mm
heating cost 220 mm
heating cost 240 mm
heating cost 260 mm
heating cost 280 mm

ANNEX D ENERGY PERFORMANCE REPORT FROM ARCHICAD

- Performance report from the simulation Belgian building style, various thickness PUR, 160 mm

- Performance report from the simulation Belgian building style, various thickness PUR, 160 mm

Energy Performance Evaluation

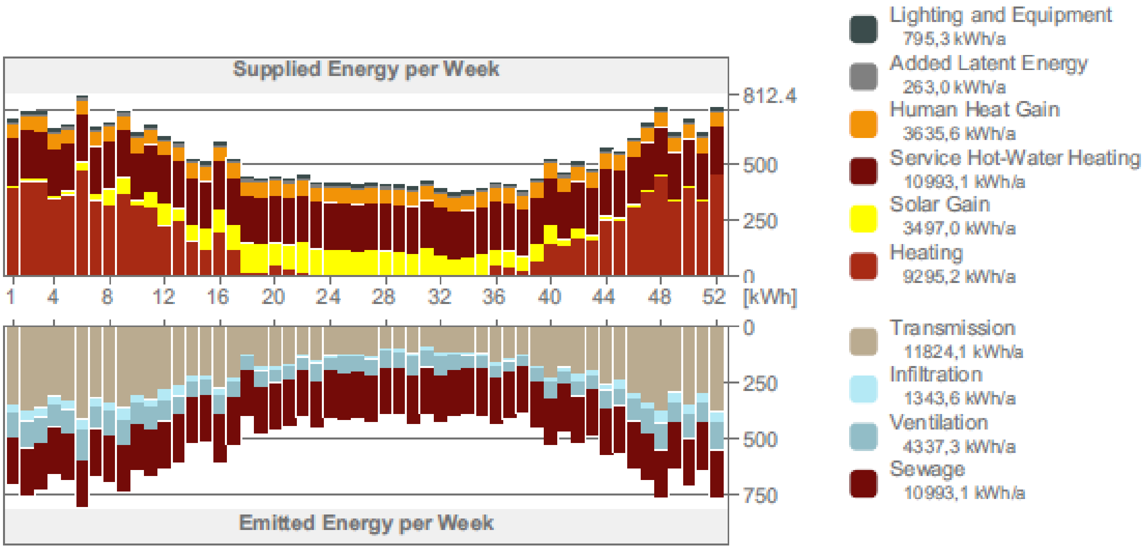
[Project Number] [Project Name]

Key Values

General Project Data		
Project Name:	bungalow_Belgium_PUR	
City Location:		
Latitude:	60° 10' 0" N	
Longitude:	24° 58' 0" E	
Altitude:	0,00	m
Climate Data Source:	FIN_Helsin...40_IWEC.epw	
Evaluation Date:	3.5.2018 16.20.01	
Building Geometry Data		
Gross Floor Area:	**127,51**	m²
Treated Floor Area:	**103,76**	m²
External Envelope Area:	**156,53**	m²
Ventilated Volume:	**280,14**	m³
Glazing Ratio:	**6**	%
Building Shell Performance Data		
Infiltration at 50Pa:	**2,51**	ACH

Heat Transfer Coefficients	U value	[W/m²K]
Building Shell Average:	**0,50**	
Floors:	**0,15 - 0,15**	
External:	**0,12 - 1,36**	
Underground:	**--**	
Openings:	**0,88 - 1,00**	
Specific Annual Values		
Net Heating Energy:	**89,59**	kWh/m²a
Net Cooling Energy:	**0,00**	kWh/m²a
Total Net Energy:	**89,59**	kWh/m²a
Energy Consumption:	**206,12**	kWh/m²a
Fuel Consumption:	**206,12**	kWh/m²a
Primary Energy:	**246,85**	kWh/m²a
Fuel Cost:	**--**	€/m²a
CO_2 Emission:	**44,52**	kg/m²a
Degree Days		
Heating (HDD):	**6842,95**	
Cooling (CDD):	**665,12**	

Project Energy Balance



Thermal Blocks

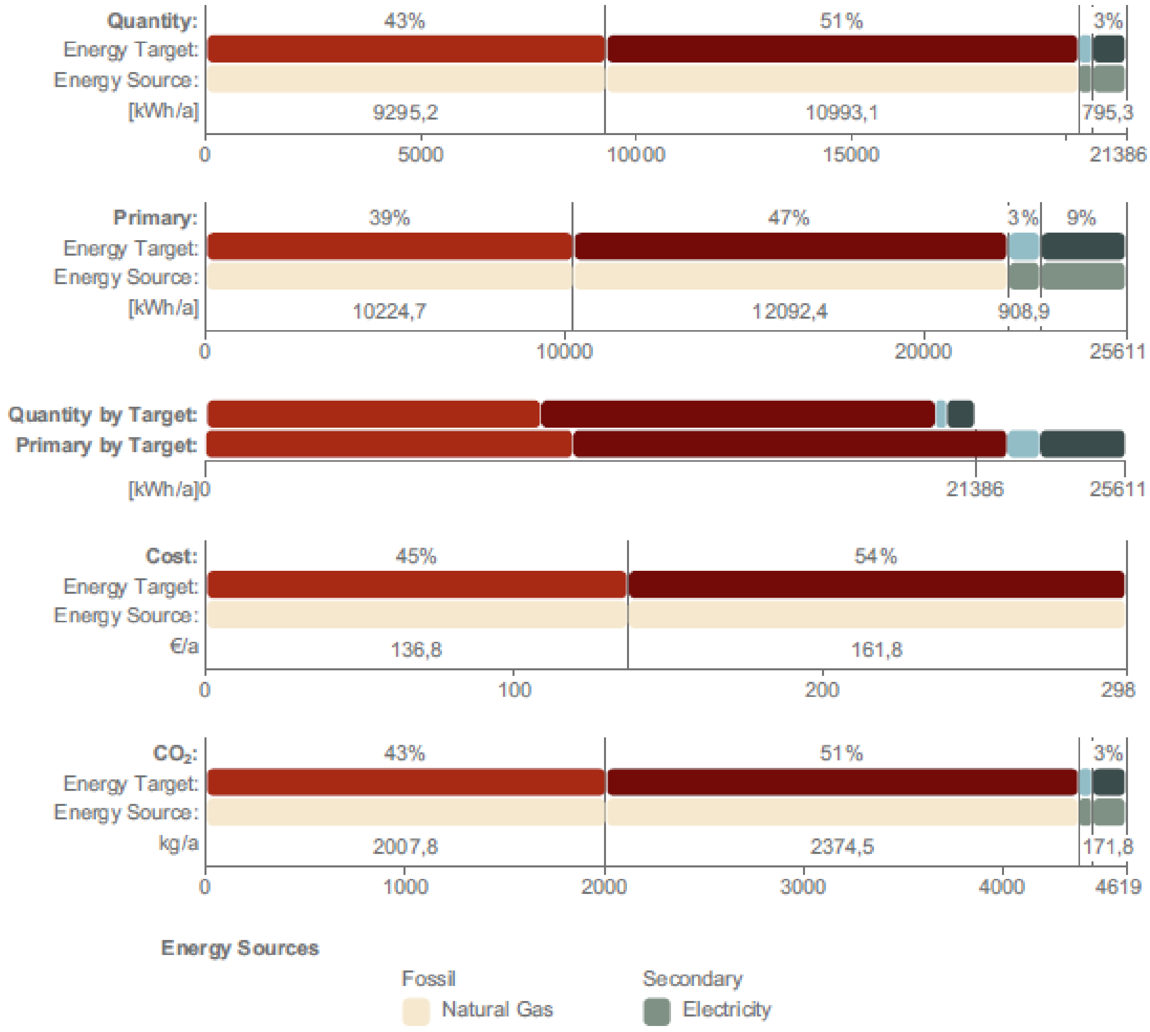
Thermal Block	Zones Assigned	Operation Profile	Gross Floor Area m²	Volume m³
001 Sample Thermal Block	9	Residential	127,51	280,14
Total:	**9**		**127,51**	**280,14**

Energy Performance Evaluation

[Project Number] [Project Name]

Energy Consumption by Targets

Target Name	Energy Quantity kWh/a	Energy Primary kWh/a	Energy Cost €/a	CO_2 Emission kg/a
Heating	9295	10224	136	2007
Cooling	0	0	0	0
Service Hot-Water	10993	12092	161	2374
Ventilation Fans	302	908	0	65
Lighting & Appliances	795	2385	0	171
Total:	**21386**	**25611**	**NA**	**4619**

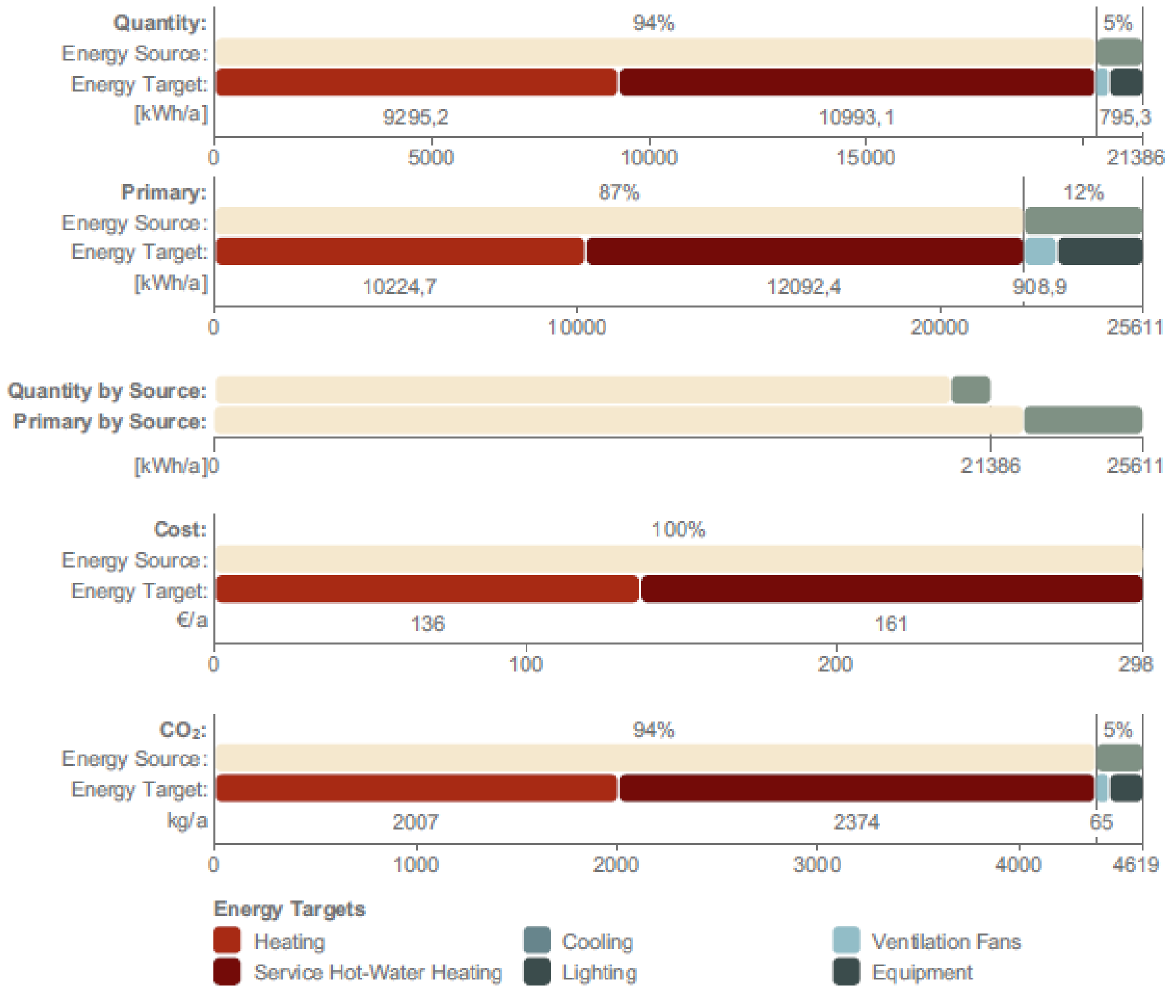


Energy Performance Evaluation

[Project Number] [Project Name]

Energy Consumption by Sources

Source Type		Energy				CO_2 Emission
	Source Name	Quantity	Primary	Cost		
		kWh/a	kWh/a	€/a		kg/a
Fossil	Natural Gas	20288	22317	298		4382
Secondary	Electricity	1098	3294	--		237
	Total:	21386	25611	Not Applicable		4619



Environmental Impact

Source Type	Source Name	Primary Energy kWh/a	CO_2 emission kg/a
Fossil	Natural Gas	22317	4382
Secondary	Electricity	3294	237
	Total:	25611	4619

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