NTNU – Trondheim
Norwegian University of
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NZEB Refurbishment- A Norwegian case

Energy use and analysis of embodied energy of different insulations technologies

Donato Greco

Master's Thesis
Submission date: May 2015
Supervisor: Marit Støre Valen, BAT
Co-supervisor: Marit Valen, BAT

Norwegian University of Science and Technology
Department of Civil and Transport Engineering

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Abstract

The energy use of the buildings is nowadays one of the most challenging problems that designer must deal with. This is due to the current climate changes that make the scientific research aware to analyse the factors that are not considered from the European energy code.

The European Union have implemented regulations and standards that introduce the concepts of Passive House, Low-Energy Building and Nearly Zero Energy Building. However, these standards have not been implemented considering all the important factors that influence the aim to reduce the energy used and consequently the CO_2 emissions in the atmosphere. Indeed, these standards consider most of the time the energy used by the building during its lifetime and do not consider the energy use to produce materials that are in need for the construction process. Having a building that consume less energy during the operational life, it is in need to use more materials. This means that in the global energy balance of the building if more energy is used during the production of the materials, less energy will be used by the building during the operational life. The difficulty in this case is to have a method that create a balance. All these considerations are originated by the current practise of built Zero Energy Buildings or low-energy Buildings that consider the use of thick layers of insulation in order to comply with the codes and regulations.

This work will deal with a Refurbishment of an existing building block, where the main consideration is that a renovation in general consume less energy than the demolition and construction of a new building. However, a refurbished building in the current practice do not achieve the same energy use level of the new NZEBs or Low-energy buildings. For this reason, the first aim for this work is to show that is possible and important to achieve this result also in extreme cold temperature, indeed this work deal with the energy retrofitting of an apartment building in Oslo, Norway.

In the first stage, this study will show the energy use during the operational life of the Building. It will be shown that the refurbishment with energy upgrade reaching the same energy use of new buildings is possible also in the extremely cold temperature. This stage will show the concept of the refurbishment fulfil the ZEB-O concept as defined from the currently studies in Norway.

In the second stage, the study will compare different insulation solutions that have the same effect on the energy used by the building during the operational life, but have different thermal features, different production process and consequently different embodied energy. The comparison will be done between different insulations type because the insulation is one of the most used material for an energy upgrading. The results will show that including or not the embodied energy in the calculation the energy balance of the building will be very different. And this will be also affected from the insulation type. Indeed some insulations give as result small embodied energy and some other require big embodied energy respect the energy used during the operational life by the building. This stage will show the concept of the refurbishment fulfil the ZEB-OM concept as defined from the currently studies in Norway.

The second stage will also include considerations about the PV panels' embodied energy that are in need to fulfil the ZEB-OM concept for the proposed insulation alternatives for the retrofit.

The main findings of this work show that the NZEB concept is extremely depended from the definition assumption and that the effort of the member states to define their NZEB concept could be useless if the embodied energy is not considered in the calculation. Indeed the embodied energy in some alternative will be comparable with the building energy use.

A development of this work starts from the limitations of this study, analysing the energy used during the lifetime of the building such as the energy used for the maintenance, construction process and end-of-life stage and the importance that the future reuse of the material can have on the energy use balance. Including these consideration we have a more complete overview that will be helpful to choose the right material when the aim is the refurbishment reaching the Zero Energy or the Nearly Zero Energy level. These last considerations and the helps of the future works can end with correlations that help the designers to identify the best solution to use depending on the different conditions of the projects.

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Dedication

Dedico questo lavoro di tesi ai miei genitori e a mia sorella, persone su cui potrò sempre contare.

Ai miei genitori pronti a darmi supporto morale ed economico. Li ringrazio per avermi dato la possibilità di vivere questa esperienza, vi voglio bene.

A mia sorella che si sta dimostrando sempre più donna e sempre più responsabile, ti voglio bene.

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1 INTRODUCTION

1.1 Background (Building and Sustainability)

The building industry plays an important role in the Climate change and the CO_2 emissions that could have different effect on the environmental impacts. Easy example of environmental impact caused by the high level of CO_2 emissions is the global warming that will lead to a rising in the sea level. Standing at European level it is fundamental being conscious that our building stock with the mix of historical and modern building gives significant opportunities and challenges.

In this general framework, the buildings are responsible for 40% of the energy consumption and for this reason they are responsible for the 36 % of the CO_2 emission of the EU total energy consumption and emission. To have an idea with another type of industry, the light-duty vehicles produce around 15 % of the EU's emissions of CO_2. So, it is possible to define that the construction industry has the highest level of emission in Europe. It is important to highlight also that the future trend of the global climate depends from the today energy use and CO_2 emission reduction [11].

Nowadays the construction industry has a worldwide importance regard the energy use and the CO_2 emissions. Indeed the construction industry support the 7 % of the jobs that are available in the world, consume the 17% of water of the total world water consume, use the 40% of the total world energy use, use the 50 % of the raw materials used in the world. The Figure 1. shows the previous data that are according to [12]

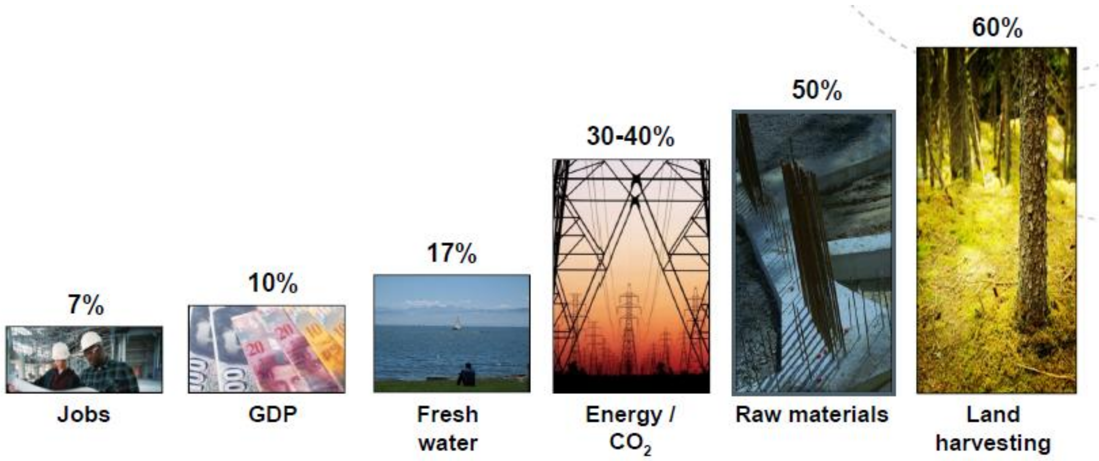


Figure 1. Importance of the construction industry in the world economy and in the environmental impact: SOURCE [4].

The Zero Energy Building (ZEB) concept is one of the solution for the mitigation of the CO_2 emission and the reduction of the energy use in the building sector. For this reason, The European Commission with the Directive 2010/31/EU of the Energy Performance of Buildings (EPBD- Recast) gives specific measures in the building sector after the introductions given by the Directive 2002/91/EC. The European objectives are to reach 20 % of reduction of the greenhouse gas emissions below the 1990 levels and 20 % of primary energy savings by 2020 [13]. Improving the energy performance of the buildings is a cost effective way of reduce the CO_2 emission and the energy use and so subsequently fighting against climate change.

After these considerations it became important the concept of Zero Energy Buildings (ZEBs) or the related concept of Nearly Zero Energy Buildings (NZEBs). The general ZEB topic has received increasing attention in recent years, until became part of the energy policy in several countries. In the recast of EU (EPBD) at the article 9 it is specified that by the end of 2020 all the new buildings shall be “nearly zero energy buildings”, but less consideration are present about the upgrade of the existing buildings. In fact, the directive says that the main aim of the major renovation is to meet minimum energy requirements.

1.2 Importance of energy upgrading of the building

The existing buildings play a fundamental role in the topic of energy saving, indeed according with Ecomidou [14] the residential buildings cover the 75% of the construction in Europe, and among the residential buildings the 36 % are Apartment blocks.

In general, the energy performance of our existing building is generally so poor that the level of energy consumed in buildings place the sector among the most significant CO_2 emissions sources in Europe. While new buildings can be constructed with high performance levels the older buildings, that represent the vast majority of the building stock, are characterized from low energy performance and in need of renovation work. Energy efficiency of the buildings can have an important role in a sustainable future with many social benefits. Speaking about building stocks and Refurbishment it is important to mention the Refurbishment Road map that is currently being developed from the EU. The Refurbishment Road map requires Member State to develop programs and standards about the refurbishment that describe the country’s vision on a long-term strategy to renovate their building stocks before the 2050. With these requirements by 2050 in Europe, the energy retrofit of residential buildings can potentially reduce the final energy demand in the building sector by 70% [15].

In Norway, a large portion of the building stock originates from the period 1955-1990, and the case of study shown in this work has been erected in the 70s [16].

The energy retrofit of residential buildings towards NZEB standards represents today the best practice to reduce significantly both energy demands and usage of fossil fuels. Nevertheless, several studies have confirmed that retrofit solutions based on eco-friendly materials are more sustainable than the practice that include the demolition and the rebuild. In fact, sometimes in some cases demolishing and rebuilding a house requires an amount of resources up to 8 times higher than in case of refurbishment.

With the previous considerations is possible to understand that the topic of Refurbishment with the aim to achieve the same energy level of new building is a challenge but at the same time is the right way to meet the requirements that will be given in the 2050 Refurbishment Road Map. These concept are important especially if is understandable that the Refurbishment works have less impact in terms of both energy consumption and

CO_2 emissions then the new construction. This means that in general retrofit an old building have less environmental impact than to build a new one.

1.3 Objective of the work

The first objective of this Thesis work is to define a methodology to upgrade an existing building Block towards the NZEB level. The case investigated is based in Norway in a city near Oslo and the challenge is to reach the NZEB level in extremely cold temperature. The state of art in Norway does not have any example like this study and an important part of this work will be to define a Norwegian NZEB definition to set the parameter that will be used for the refurbishment of the building. The difficulties to define a NZEB depends from a lack of data. Indeed, in Europe the NZEB definition is not completely defined and each Member State has its own definition that often changes from a country to another and moreover not all the Member States have an official NZEB definition. All the official Member State NZEB definition will be presented in this work to define how big is the difference between the definitions. Moreover, it will be possible to define the big definition difference between Member States in the same climate zone. After the definition is defined, the design of the refurbishment will be proposed using the most common technologies to retrofit the external envelope of the building. The material that will be used in the first part will be Mineral Wool insulation.

The secondary objective will be to show and define how important is the choice of the insulation material to reduce the environmental impact of the refurbishment (express in embodied energy). This part will regard the NZEB step that include in the energy balance of the building both the energy use during the operational phase and the embodied energy that the materials contain due to the production process.

1.4 General ZEB definitions

The general ZEB (Zero Energy Building) definition has been discussed highly in the last years and it is connected with the energy use in the operational phase of a building during a period of one year [13, 17]. Therefore, ZEB refers to the primary “energy” use of the building.

A “Zero Energy Building” in the most general definition is a building with high-energy performance and the primary energy used by the building in one year is equal at zero kWh/m^2. In the general definition, more than a unit can be used to evaluate the ‘zero’ balance both in the definition and in the calculation methodology. These can be for example the final end-use energy, primary energy use, CO2 equivalent emission, energy, the cost of the energy of other parameters that could be defined by the national energy policy and by the different interest of the specific Member State [10].

In this work, the attention will be focused on the energy use and trying to go deeper in the meaning of the energy use, we find the term “embodied energy”. The embodied energy of a product is the energy used for the material production and for the construction process and it includes transportation, production of the building product and the energy used for replacements during the lifetime.

For these motivations, there are four different ambitions inside the simple definition of ZEB as presented by Dokka et al. [18]:

2. ZEB-O-EQ: Emissions related to all energy use in operation (O) except energy use for equipment/appliances (EQ) shall be compensated with on-site renewable energy generation and these could use for example the wind energy or the sunlight energy;
3. ZEB-O: Emissions related to all operational energy (O) shall be compensated for with on-site renewable energy generation as well as energy use for equipment;
4. ZEB-OM: This step include the ZEB-O definition and add the embodied emission related with the materials used. Indeed it considers the emissions related to all operational energy (O) use and embodied emissions from the materials (M) and technical installations shall be compensated for with on-site renewable energy generation;
5. ZEB-COM: This step include the ZEB-OM definition, but also taking into account the emissions related to the construction (C) process of the building.

After these levels it is possible to reach the highest level (ZEB-COMPLETE) that needs to be based on an analysis that includes all the stage defined by EN 15978 [1]. The EN 15978 divides the life cycle stage in 4main stages, that are the followings:

- Product stage;

- Use stage;
- End-of-life stage;
- Benefits and loads beyond the system boundary.

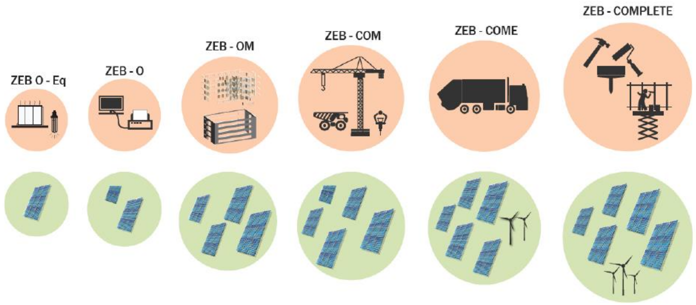


Figure 2. NZEB ambition levels with a schematic production of renewable energy on site. Red circle represent the different emission loads, Green circle represent the on-site renewable energy production that need to compensate.

Obviously, during the design stage is not easy to control both energy use and emissions related with the construction phases and the demolition phases, and this is the biggest challenge of this topic. Indeed in these phases is not everything predictable, and even if during the design it is possible to achieve the ‘zero balance’ in the real life could not be reached due to uncertainty of data during the construction phases (ZEB-COM) and the demolition phases (ZEB-COME and COMPLETE).

The Figure 2 show all the ZEB level, and include the aim of this work. Indeed the last aim will be to achieve the ZEB-OM level.

1.4.1 Nearly Zero Energy Buildings and Net Nearly Zero Energy Buildings

After the previous definitions that include in the ZEB term the interest on both emission of the building and energy usage of the building, other ZEB definition deal with the interaction between the building and the utility systems.

These ZEB definitions see the building not only as an energy-efficient building but also as a greed-connected building. To emphasize the balance concept, to define the boundaries and the connections of the building with different systems the term “Net” has been added, so that we can speak about “Net ZEB” and about the variant “nearly Net ZEB”. The difference between these definitions is that in the first one, the balance of primary energy is zero and in the second one, the balance of primary energy is nearly 0 kW/m^2. In particular a Net Zero Energy Building is a building with a total sum of zero energy transfer across the building-district boundary [10].

A building connected with the utility systems is also called on-grid ZEB or 'grid connected' or 'grid integrated' ZEB. This is a definition used for a building connected with the energy infrastructures; the advantage of this type of solution is that it is possible to abstain on-site electricity storages, that often have bad environmental impact.

However, when we speak about a grid-connected building it is necessary to define the boundaries system, that are physical boundaries and balance boundaries.

It is useful to identify the 'physical boundary' to understand if we are in the case of "on-site generation" or "off-site generation". To have an idea the typical on-site generation systems are PV and mico CHP, instead typical off-site option is a share in a wind energy turbine.

Moreover, it is useful to identify the balance boundary that define which energy service is included in the balance. For the standard EPBD definition, the balance boundary take into account the technical services for heating, cooling, ventilation and domestic hot water, thus are not included plugs loads and central services.

After the 'grid connected ZEB' also important is the term 'off-grid ZEB'. The "off-grid Zero Energy building" is not connected to any utility and it needs to use electricity storage. It is also called 'self-sufficient ZEB' or 'stand alone ZEB'. The buildings with these characteristics do not required connection to the grid and they have capacity to store energy for winter use and night use.

To define nearly Zero Energy Building, it is also important understand the meaning of the *Period of Balance.* The period of balance is the period of time over which the building calculation is performed, and this period can vary very much. It can be the full life cycle of the building, or the operating time of the building (e.g. 50 years) or commonly uses annual balance as defined from EPBD recast (Energy Performance of Buildings Directive –recast- 19/05/2010). For this reason it is very commonly used the annual balance or applied in special situations a seasonal or monthly balance [8, 10].

The directive 2010/31/EU of the European Parliament of 19 May 2010 on the energy performance of buildings (recast) define generally Nearly Zero Emission Building as a building with high-energy performance, where the energy performance of the building is expressed by using energy performance indicator of primary energy use. To be defined as Nearly Zero Emission Building, the methodology shall include the following characteristic [13]:

- Thermal characteristics as defined in the point a of the ANNEX 1 of the directive 2010/31/EU;
- Heating installation and hot water supply, including their insulation characteristics;
- Air-conditioning installations;
- Natural and mechanical ventilation;
- The design, positioning and orientation of the building, including outdoor climate;
- Passive solar systems and solar protection;
- Indoor climatic conditions, including the designed indoor climate;
- Internal load.

The directive use the NZEB concept in the article 9 by imposing at the Member States to ensure that by 31 December 2020 all new buildings are nearly zero-energy buildings and for the building owned or occupied by public authorities this will be valid after the 31 December 2018. According with the directive the unit used to calculate the balance of a Nearly ZEB is the primary energy and the energy balance of a building. The energy balance of the building can be calculated considering the building equipped with on-site and/or off-site renewable energy generation systems and/or interacting with the utility grid [13].

The directive does not give any other information about the NZEB concept and leave to the Member State the obligation to set a detailed NZEB definition that should be lead from the climatic condition or the climatic zone of the country. This is mainly due to the absence of standardized calculation methodology and specific value to use to set a national NZEB definition.

1.4.2 Nearly Zero Energy Buildings according to the Member States

From the previous NZEB definitions, it is possible to understand that the Energy Performance of Buildings Directive (recast EPBD, 2010) does not give a detailed definition of NZEB, but it set a general framework. The EPBD ask the Member states (MS) to elaborate their detailed definition and their national approaches.

In this section, a comparison between the Member State concepts of the Nearly Zero Energy Building are shown. The variety of these national approaches make impossible the aggregation of these definitions in only one NZEB definition, and the next pages are useful to understand how different are the approaches used by the Member States to define NZEB and how different is the NZEB concept in the different Member States regulations [19-21].

The member states according to the European laws have to elaborate national plans regarding the nearly Zero-Energy Buildings, where the targets must be differentiated regarding to the building category and regarding the climate zone. These plans must include the following parts:

- A definition of nearly Zero-Energy Building reflecting the local conditions and a numerical indicator of primary energy use;
- Intermediate target for improving the energy performance (e.g. a two-year period lists of target to achieve);
- Information on financial measures adopted for the promotion of nearly Zero-Energy Buildings;
- A leading example by developing measures for refurbishing public buildings towards nearly Zero-Energy Building.

The national plans than need to be evaluated from the European Commission that may request further information, and then after the evaluations the commission issue a recommendation.

Nowadays, only few of the MS have presented the officially national NZEB approach for 2020, and this are shown in the following pages:

BELGIUM

For Belgium, the implementation of the EPBD differs in the main regions: Brussels Region, Flemish Region and Walloon Region.

BRUSSELS REGION

The requirements are the following:

Residential Buildings

- Primary energy for heating, domestic hot water and auxiliary energy below or equal to 45 kWh/m^{2}y.

Office and Education buildings

- A primary energy consumption for heating, domestic hot water, lighting (only for Office) and auxiliary energy below or equal to 95-2.5 S/V kWh/m^{2}y where S/V is the compactness, calculated as the ratio between the volume and the area (max S/V is 4);

WALLON REGION

The requirement are the same for Residential and non-Residential buildings and they include:

- Primary energy use for heating, domestic hot water and auxiliary energy below or equal to 60 kWh/m^{2}y.
- At least 50 % of the energy has to be supplied from site renewable energy production (RES).

FLEMISH REGION

Residential Buildings

- Primary energy use for heating, cooling, ventilation, domestic hot water and auxiliary energy below or equal to 30 kWh/m^{2}y;
- At least 10 kWh/m^{2}y of energy has to be supplied from site renewable energy production (RES).

Office and Education buildings

- Primary energy use for heating, cooling, ventilation, domestic hot water and auxiliary energy below or equal to 40 kWh/m^{2}y;
- At least 10 kWh/m^{2}y of energy has to be supplied from site renewable energy production (RES).

CYPRUS

In the report of Cyprus (NZEB Action Plan), the nearly zero-energy buildings in Cyprus are defined as follow:

Residential Buildings

- Primary energy use for heating, cooling, hot water and lighting below or equal to 180 kWh/m^{2}y.
- At least 25 % of the primary energy has to be supplied from site renewable energy production (RES).

Non-Residential Buildings

- Primary energy use for heating, cooling, hot water and lighting below or equal to 210 kWh/m^{2}y.
- At least 25 % of the primary energy has to be supplied from site renewable energy production (RES).

In addition in the Cyprus regulations, for each building type are indicated specific requirements such as maximum U-values for building’s components, air permeability, natural ventilation and solar protection for windows.

SLOVAKIA

According with the Slovakian regulations, the limitations of Primary energy use are different for Residential and Non-Residential buildings. Moreover, for the Residential buildings there are different limitations for “apartment buildings” and “family houses” and for the Non-Residential buildings there are different value for “Office” and “Schools”.

Apartment Buildings

- Primary energy use for heating, hot water and auxiliary energy below or equal to 32 kWh/m^{2}y.

Family Houses

- Primary energy use for heating, hot water and auxiliary energy below or equal to 54 kWh/m^{2}y.

Office

- Primary energy use for heating, cooling, ventilation hot water and lighting below or equal to 60 kWh/m^{2}y.

Schools

- Primary energy use for heating, cooling, ventilation hot water and lighting below or equal to 34 kWh/m^{2}y.

For this country there are no requirements regarding the use of renewable energy production (RES) for the supply of part of primary energy.

FRANCE

For this country the requirement for NZEB are the following:

Residential Buildings

- Primary energy use for heating, cooling, ventilation hot water, lighting and auxiliary systems below or equal to 50 kWh/m^{2}y.

Non-Residential Buildings

- For the Office buildings non-air-conditioned the requirements of primary energy use for heating, cooling, ventilation, hot water, lighting and auxiliary systems must be below or equal to 70 kWh/m^{2}y;
- For the Office buildings air-conditioned, the requirement of primary energy use for heating, cooling, ventilation, hot water, lighting and auxiliary systems must be below or equal to 40 kWh/m^{2}y.

In France as for the Slovakia there are no requirements regarding the use of renewable energy production (RES) of primary energy.

IRELAND

For Ireland, the definition of NZEB is a bit different from the previous country analysed, and the Irish regulation presents difference regarding the indicator used. The previous countries use as indicator the primary energy use, instead Ireland use the energy loads by considering Energy Performance Coefficient (EPC) and Carbon Performance Coefficient (CPC).

The NZEB definition in Ireland is given for Residential Buildings, and the requirement to define the NZEB are the following:

- Primary energy use for heating, ventilation, hot water, lighting and auxiliary systems must be below or equal to 45 kWh/m^{2}y;
- EPC below or equal to 0.302;
- CPC below or equal to 0.305.

THE NETHERLANDS

Differently from Ireland and from the other countries in The Netherlands, only a non-dimensional number is used as an indicator of the buildings’ energy performance. This indicator is dependent on how the building is used, and is one of the indicator seen for Ireland: the Energy Performance Coefficient, EPC. This is an instrument used by Dutch government to reduce especially the CO2 emissions.

In this case, the EPC value is the same for Residential and Non-Residential buildings and it must be equal to zero. The energy uses included heating, cooling, ventilation, hot water and lighting. Moreover is necessary that part of the energy has to be supplied from RES production but now is not quantified any value.

DENMARK

Denmark is the first country that have set-up a national NZEB definition and the roadmap to 2020, where the minimum energy requirements will become gradually stricter starting from the previous standard (BR10) to a final target in 2020. The reason why Denmark was so fast to set-up the national NZEB definition are several:

- Send a signal to the players in the building industry;
- Give a positive assurance for the development of energy requirements;
- Create good basis for the sale of building materials, and the development of building technology consultancy.

The requirements for NZEB set-up by Denmark for the 2020 are different for Residential and Non-Residential buildings and the indicator to evaluate nZEB buildings is the primary energy consumption as most of the national definition seen until now.

Residential Buildings

- Primary energy use for heating, cooling, ventilation and domestic hot water below or equal to 20 kWh/m^{2}y.
- At least 51-56 % of the primary energy has to be supplied from site renewable energy production (RES).

Non-Residential Buildings

- Primary energy use for heating, cooling, ventilation, domestic hot water and lighting below or equal to 20 kWh/m^{2}y.
- At least 51-56 % of the primary energy has to be supplied from site renewable energy production (RES).

ESTONIA

For this country the requirement for NZEB are differentiated between the Residential Buildings and the Non-Residential Buildings. For the Residential there are two categories: “Detached houses” and “Apartment buildings”. For the Non-Residential Buildings there are seven categories: Office buildings, Hotels and Restaurants, Public buildings, Shopping malls, Schools, Day care centres, Hospitals.

Detached houses (Residential)

- Primary energy use for heating, cooling, ventilation hot water below or equal to 50 kWh/m^{2}y.

Apartment Buildings (Residential)

- Primary energy use for heating, cooling, ventilation hot water and lighting below or equal to 50 kWh/m^{2}y.

For the Non-Residential buildings will be shown only the requirements for Office Buildings and Hospital. In these two categories, there are the lowest and the highest allowed values of primary energy use.

Office Buildings (Non-Residential)

- Primary energy use for heating, cooling, ventilation, hot water, lighting and auxiliary appliances below or equal to 100 kWh/m^{2}y.

Hospitals (Non-Residential)

- Primary energy use for heating, cooling, ventilation, hot water, lighting and auxiliary appliances below or equal to 270 kWh/m^{2}y.

LITHUANIA

For Lithuania the nearly zero-energy buildings are those that respect the requirements of the buildings with class A++ energy performance, and most of the energy consumed is renewable (locally od nearby).

The indicator used to define Nearly Zero Energy Building is the Energy Performance Indicator (C), that must be equal or below 0.25, both for Residential Buildings and Non-Residential Buildings, and the primary energy production from site renewable energy must be at least 50% of the total amount of primary energy consumed.

LATVIA

In this country, the regulation for the Nearly Zero Energy Building does not present different requirements for Residential and Non-Residential buildings. In this case, the primary energy use allowed for a Nearly Zero Energy Building is 95 kWh/m^{2}y. Moreover, there are no reference regard to the part of energy that have to be supplied from Renewable source.

1.4.2.1 Summary

With the previous analysis of the available NZEB definitions in the different countries, we can see the differences in the Primary Energy values required and the differences in some countries to define the Nearly Zero Energy Buildings level, using different indicators from EP to set-up the minimum requirements for Nearly Zero Energy Buildings. The Table 1 shows the differences among the NZEB Member States definitions stated in the last pages.

These differences are also present between country in the same climate zone and for the same building type, and this is because different energy uses are included and different levels of ambition. These differences are due to the general definition given by EPBD. These general nZEB definitions do not give any level of ambition and consequently the possibility to compare the values among the different countries. What is missing is from the European general definition is a formal and consistent framework that considers all the important aspects characterizing the Nearly Zero Energy Buildings and allow each country to define a consistent definition and especially a uniform definition between the MS.

Other states such as Italy, Germany, Romania and Bulgaria have not an official NZEB definition, or better the governments are working with supports to have a definition of Nearly Zero-Energy Buildings.

A different case represent the UK because does not have a ‘nearly zero energy building’ definition, but the UK Government has a target for all new home to be ‘zero carbon’ from 2016. We can easily understand that the approach to achieve the ‘zero carbon’ level will conduct at the achievement of ‘zero energy buildings’.

ZONE	COUNTRY	NZEB definition						
		Energy Performance						RES
		EP value	Unit	Metric	Boundary	Building type		
Zone 1-2	Cyprus	180	kWh/m^{2}y	Primary Energy	heating, cooling, DHW, lighting		Residential	25%
		210	kWh/m^{2}y	Primary Energy			Non-Residential	25%
Zone 3	Slovakia	32	kWh/m^{2}y	Primary Energy	heating, DHW	Apartment buildings	Residential	50%
		54	kWh/m^{2}y	Primary Energy		Family houses		50%
		60	kWh/m^{2}y	Primary Energy	heating, cooling, ventilation, DHW, lighting	Office	Non-Residential	50%
		34	kWh/m^{2}y	Primary Energy		Schools		50%
Zone 4	Belgium BXL	45	kWh/m^{2}y	Primary Energy	heating, DHW, appliances	Individual dwellings	Residential	-
		95-2,5*(v/s)	kWh/m^{2}y	Primary Energy	heating, cooling, DHW, lighting, appliances	Office Buildings	Non-Residential	-
		95-2,5*(v/s)	kWh/m^{2}y	Primary Energy	heating, cooling, DHW, appliances	Schools		-
	Belgium Wallon	60	kWh/m^{2}y	Primary Energy	heating, DHW, appliances	Residentialbuildings, schools, office and service buildings	Residential/ Non-Residential	50%
	Belgium Flemish	30	kWh/m^{2}y	Primary Energy	heating, cooling, ventilation, DHW, auxilary systems		Residential	>10 kWh/m^{2}y
		40	kWh/m^{2}y	Primary Energy		Office buildings, schools	Non-Residential	>10 kWh/m^{2}y
	France	50	kWh/m^{2}y	Primary Energy	heating, cooling, ventilation, DHW, lighting, auxiliary systems		Residential	-
		70	kWh/m^{2}y	Primary Energy		Office buildings non-air-cond.	Non-Residential	-
		110	kWh/m^{2}y	Primary Energy		Office buildings air-cond.		-
	Ireland	45	kWh/m^{2}y	Energy load	heating, ventilation, DHW, lighting		Residential	-
	Netherlands	0		Energy performance coefficient (EPC)	heating, cooling, ventilation, DHW, lighting		Residential/ Non-Residential	not quantified (necessary)
Zone 5	Denmark	20	kWh/m^{2}y	Primary Energy	heating, cooling, ventilation, DHW		Residential	51% - 56%
		25	kWh/m^{2}y	Primary Energy	heating, cooling, ventilation, DHW, lighting		Non-Residential	51% - 56%
	Estonia	50	kWh/m^{2}y	Primary Energy	heating, cooling, ventilation, DHW, lighting, HVAC auxiliary, appliances	Detached houses	Residential	-
		100	kWh/m^{2}y	Primary Energy		Apartment buildings		-
		100	kWh/m^{2}y	Primary Energy		Office buildings	Non-Residential	-
		130	kWh/m^{2}y	Primary Energy		Hotels and restaurants		-
		120	kWh/m^{2}y	Primary Energy		Public buildings		-
		130	kWh/m^{2}y	Primary Energy		Shopping malls		-
		90	kWh/m^{2}y	Primary Energy		Schools		-
		100	kWh/m^{2}y	Primary Energy		Day care centres		-
		270	kWh/m^{2}y	Primary Energy		Hospital		-
	Latvia	95	kWh/m^{2}y	Primary Energy	heating,cooling,ventilation, DHW, lighting		Residential/ Non-Residential	
	Lithuania	< 0,25	-	Energy performance indicator C	heating		Residential/ Non-Residential	50%

Table 1. Summary of the NZEB definitions currently present in Europe.

1.5 A Norwegian NZEB Norwegian definition

The recast Energy Performance of Buildings Directive (2010) has not been implemented in Norway, but it is in the planning of future regulations. The Norwegian government affirmed that all new buildings should be Nearly Zero Energy Building by 2020. Thus, it does not exist an official NZEB definition considering the energy use, but there are proposal definitions the CO_2 emissions. These last definitions give the possibility to define ZEB as Zero Emissions Building, where the metric is not the Primary Energy use of the buildings, but the CO_2 emissions.

To be able to set a detailed NZEB definition for this work the next paths have been followed: the scientific papers that in Norway are focused in Zero Energy Building and the current Norwegian standard and regulations. The current regulations presents in Norway are regarding the Passive Houses and Low-Energy Buildings. These regulations are NS3700 for Residential buildings and NS 3701 for non-Residential buildings, these could be useful to set some parameters for this work, but then it is necessary to set other parameters and indicators that are useful to define a Nearly Zero Energy Building and to find out this parameter was followed [8, 10]. It is recognised that in accordance with the country's political targets different definitions are possible. Indeed the different Member States adapt the Nearly Zero Energy Definition to the specific conditions establishing specific requirements on energy efficiency or prioritizing certain supply technologies.

To have a definition of Nearly Zero Energy Building for this work it has been chosen to take as reference the Passive Houses requirements following the NS3700 [22]. This approach is in line with the NZEB definition proposed by Cyprus and Lithuania as stated above. Indeed, these two countries set a maximum Primary energy use allowed for Residential NZEB Buildings and they indicate specific requirements for the building components (e.g. envelope requirements of U-Value). As shown previously Cyprus indicates for each building type maximum U-values for Building's components (envelope components) and other parameters to respect, instead for Lithuania's laws a building to be considered NZEB need to meet the requirements defined for a class A++ Building.

The Building components requirements are taken from the indication given by NS 3700:2013 "Criteria for passive houses and low energy buildings – Residential buildings". This standard gives maximum values for different points allowed for Passive Houses and Low Energy Building and the following point are considered:

- Thermal insulation;
- Air Permeability;
- Ventilation requirements;
- Boiler system efficiency;
- Thermal Bridges;
- Ventilation Fan Power;
- Heat Recovery.

The following tables are taken from the NS3700 [22] and show the previous requirements. Looking at the Table 2, are interesting the values presented under the voice Passive House for this work.

Propriety	**Passive house**	**Low energy Buildings**	
		Class1	Class2
U-Value for windows and doors	< 0,8 W m^{-2}K^{-1}	< 0,8 W m^{-2}K^{-1}	< 0,8 W m^{-2}K^{-1}
Normalized Thermal Bridge	< 0,03 W m^{-2}K^{-1}	< 0,05 W m^{-2}K^{-2}	-
Annual average temperature efficiency of the heat recovery	< 80%	< 70%	-
SFP factor ventilation equipment	< 1,5 kW s m^{-3}	< 2,0 kW s m^{-3}	-

Table 2 Minimum Building Parts requirements, components and leakage figures (NS 3700[22])

Building components	**Passive house**	**Low energy Buildings**
	W m^{-2} K^{-1}	W m^{-2} K^{-1}
External wall	0,10 - 0,12	0,15 - 0,16
Ceiling	0,08 - 0,09	0,10 - 0,12
Floors	0,08	0,10 - 0,12

Table 3 U-Value to use to reach the Passive House or Low energy Building level (NS 3700)

After these requirements, the second important step is to think about the aim to achieve the NZEB level, and as we have seen in the previous pages, it is necessary to define the system boundary, the metric that is used and the time of reference. To have a proper definition, it has been followed the definition given by I. Sartori, A. Napolitano and K.

Voss [8]. They defined the general Net ZEB definition framework through the following criteria and sub-criteria:

- 1 Building system boundary
    - 1.1 Physical boundary
    - 1.2 Balance boundary
    - 1.3 Boundary conditions
- 2 Weighting system
    - 2.1 Metrics
    - 2.2 Symmetry
    - 2.3 Time dependent accounting
- 3 Net ZEB balance
    - 3.1 Balancing period
    - 3.2 Type of balance
    - 3.3 Energy efficiency
    - 3.4 Energy supply
- 4 Temporal energy match characteristics
    - 4.1 Load matching
    - 4.2 Grid interaction
- 5 Measurement and verification

Not all of the previous points are considered in this work for the Nearly Zero Energy Buildings definition. The next lines will explain the parameters used to obtain a NZEB definition for this work, and the Table 4 summarize the decision taken for this work.

PHYSICAL BOUNDARY

The physical boundary will be in this work ‘on-site’ generation system; it means that part of the required energy should be covered by renewable sources produced ‘on-site’ or ‘nearby’. Furthermore, the physical boundary defines that we can consider a single building or a cluster of buildings: in this work the physical boundary, it has been considered as a single building. The Figure 3 explains the different options of renewable supply that are available in the NZEB definition. This case of study is set to be in the second circle from the centre that is explained as “On-site generation from off-site renewables”.

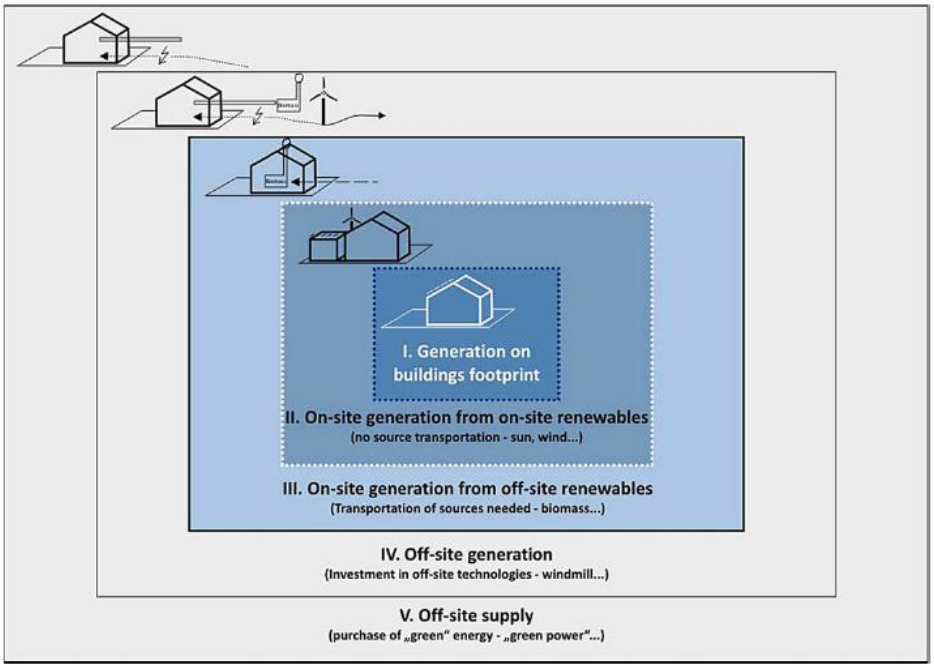


Figure 3. Overview of possible renewable supply options. Source [8, 10].

BALANCE BOUNDARY

The Balance boundary defines which energy uses are considered for the NZEB balance. As we have seen from the official Member States definitions, each country considers different combination of energy uses included for the calculation of the energy demand and this means that each Member State considers different Balance Boundary. Indeed, for each zero energy building definition it would be necessary specify which energy flows are included in the definition and which not. According to EPBD (recast) the energy flows to take into account in the NZEB definition is the energy use for heating, cooling, ventilation, hot water and lighting as shown from the Figure 4.

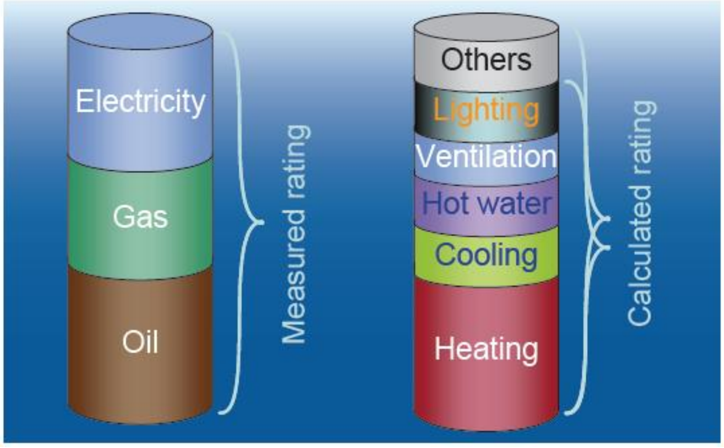


Figure 4.Measured energy flows and calculated energy ratings usually included in the ZEB concept. In the measured ratings usually all energy flows are included. In the calculated energy ratings, electricity for households and "others" may or may not be included.

In the definition set for this work the energy flows included will be heating, domestic hot water, cooling and ventilation as defined from the Danish requirements. Indeed, as stated above the requirements from the Denmark regulations are taken as reference in this work.

The Figure 5 gives an idea about the Boundary conditions that can be set to define a Nearly Zero Energy Building. Where is highlighted the possibility to have different weighting system and the importance of the building's connections with the energy grids, even if the building has on-site generation from on-site renewable supply.

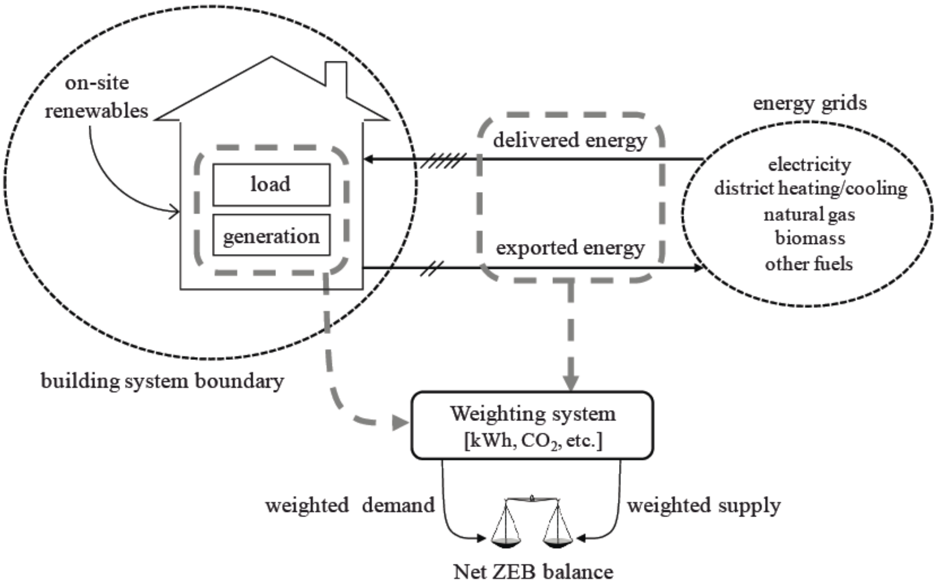


Figure 5. The sketch explain the connection between buildings and energy grids. The relevant definitions are shown and the weighting system considered in this work is kWh as metric to balance the difference between the energy demand and the energy supply. Source [8]

BOUNDARY CONDITIONS

To define the Boundary conditions it is necessary to define functionality, space effectiveness, climate and comfort of the building studied. The functionality describe which kind of building we are dealing with, and in this work, we are concerning with an apartment Building (Block). The space effectiveness can be expressed in energy use per person. The climate will depends from the outdoor climate of the climatic zone where the building is located and the comfort condition will be set according to the table A.3 of the NS3031:2004 [23] that gives set point temperature for heating or for cooling to achieve an inside comfortable temperature. Obviously different temperature settings cause different energy demands.

METRICS

The four types of metrics proposed by Sartori [8] are: site energy, source energy, energy cost and carbon emissions related to energy use. The different choice of Metric's type would affect the required PV installed capacity. In this work, the metric chosen is the site energy used. Moreover, the weighting system is defined throughout the energy demand and the energy production stated in kWh or kWh/m^2.

BALANCING PERIOD

For the balancing period that is also called time of reference, it is possible to follow directly the NZEB definition given by the article 9 of the EPBD (recast). This suggest to include an indicator of primary energy use expressed in KWh/m^2 and this indicator should be based on a national yearly average values. Indeed, from the European definitions comparison (chapter 1.4.2) it is possible to see that each country gives a yearly value, however not all the countries use the primary energy use as indicator. This proposed Balancing Period is also according with the Sartori definition framework that implicitly assume a yearly time span to set the balance. In this work as told before the reference definition is the definition set from Denmark and the value of Primary Energy use from non-Renewable energy must be below or equal to 20 kWh/m^{2}y.

TYPE OF BALANCE

For the type of balance is possible to consider an *import/export* balance or a *load/generation balance*. The import/export balance estimates the delivered and exported energy available in the design phase. The load/generation balance consider the weighted generation and load. The type of balance chosen for this work is the load/generation balance, despite the import/export balance gives the most complete information, the load/generation balance is the most suitable in the exiting building code that are oriented at calculating the loads.

Important is also defining that the Norwegian government utilizes both regulations and standards as instruments to reduce the energy demands of the buildings. The energy requirements for the new buildings are present in TEK 10 (Regulation on technical requirements for buildings). The current legislation requires that minimum 40% of the net energy demand shall be covered from renewable energy sources. In this study both the requirement that at least 40% of the energy demand need to be covered from renewable energy sources and the value of Primary Energy use from non-Renewable energy must be below or equal to 20 kWh/m^{2}y are respected.

The table below shows a summary of the previous concepts that are the basis of the NZEB concept of this thesis work.

Propriety	Parameter/value	
Physical Boundary	On-site energy supplement	
	Single Building	
Balance Boundary	Heating	
	Cooling	
	DHW	
	Ventilation	
Boundary condition	Functionality:	Building-Block
	Effectiveness:	Energy/Person
	Climate:	Oslo Wheater data
Metrics	Site Energy	
	kWh m^{-2} y^{-1}	
Balancing Period	year	
Type of Balance	Load/Generation	
Maximum primary energy use	20 kWh m^{-2} y^{-1}	
Minimum percentage of renewable energy compared to the energy demand	40%	

Table 4- Summary of the element that define a Nearly Zero Energy Building for this study

1.6 The embodied energy considerations

The term “embodied energy” refers to all the primary energy resources used to manufacture the product, from the ‘cradle’ that means from mining or harvesting the materials to finishing the product. There are different points of view in the international debate about including in the term “embodied energy” the energy that goes into the production of the material and the energy used into the construction process of the building. The last definitions also include the raw materials extraction and the energy use for packaging [24].

Other definitions of the “embodied energy” include also the energy used into the construction process itself. These definitions therefore include the energy that is used for the initial raw material extraction, transport and production of the building materials, the energy used for the construction process and the energy that goes into the materials used for replacements during the lifetime of the building.

Regarding the concept of the embodied energy is not possible to state a better definition, but it is useful to set the definition depending on the main aim that is in need to achieve.

Therefore, the proper definition of embodied energy changes with the aims of the case that is take under consideration.

Regarding the energy used by a NZEB or low-energy buildings, generally have the feature that consume less energy during the lifetime than a normal building. However, several studies show that when the energy use of the building during the operational life is reduced because of a well-insulated building envelope and highly efficient energy system, the embodied energy of the materials increases, because the well-insulated building uses more materials. To achieve a low-energy and sustainable designs, the aim is to balance the ratio between the energy used during the lifetime of the building and the energy used to produce the materials necessary for the construction.

Several studies show that the embodied energy of a building that follow the Norwegian Building code of the 1990s is between 10% and 15% of the buildings' total energy use instead for super insulated buildings these value varies between 30% and 60% of the total energy use. This means that in the normal-insulated buildings, the greater contribution of the energy is due to the use of the energy during the operational phase; instead for the low-energy buildings the choice of the envelope and structures materials is more important, because these will have a greater influence in the final energy balance. This is due to a lower energy in need during the building service life and a greater amount of energy to produce the insulation materials. The Figure 6 shows the different energy use trends of different building types, it is possible to notice that the buildings that satisfy the requirements imposed from TEK 10 have smaller embodied energy but big energy use during the lifetime with a positive slope. The passive houses have a bigger initial embodied energy use, but even if the trend is still positive (increase of energy), the final energy balance is globally smaller than the previous one. Instead, using and designing Active Houses or Zero Energy Building the slope become negative, with the final aim to have a total balance that is equal to zero. The time t_1 represent the time when refurbishment work are in need to upgrade the building after some years.

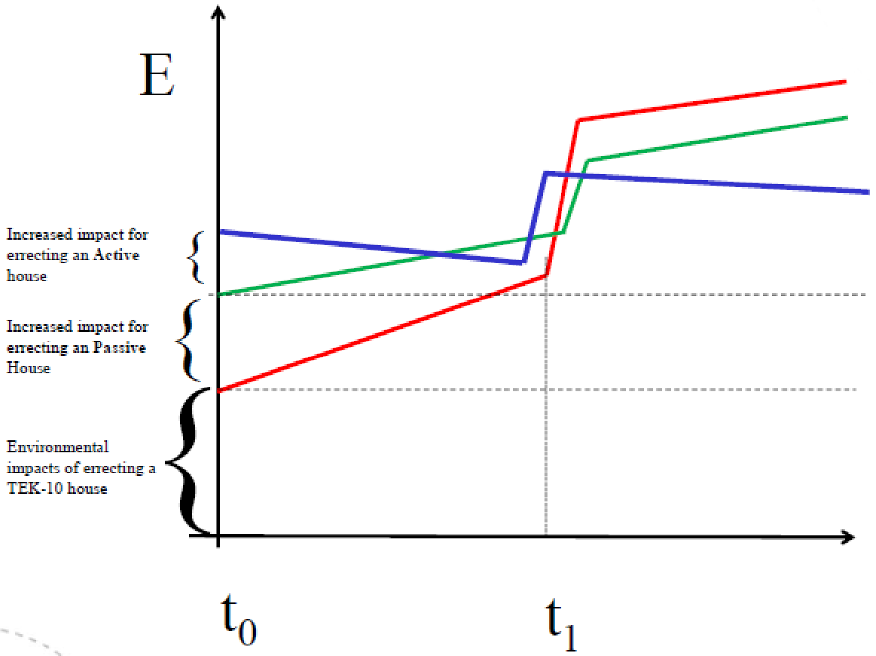


Figure 6. Sketch regarding the different behaviour of different building type. The graph define the Energy use during the lifetime of the different type of buildings and the embodied energy (initial energy). Source [4]

Both the service lifetime of the building and the lifetime of the single components are related with the energy use and the embodied energy calculation. Moreover, the service lifetime of the buildings, buildings components and materials are dependent from different factors. Indeed speaking about the service life there are several service lifetime that can be considered depending from the different points of view, these are the followings:

- The whole building;
- Building materials and construction parts;
- Technical equipment;
- Service lifetime of building after comprehensive refurbishment.

Regarding the Refurbishment achieving the nZEB standard level, it is important understand the issues related with it. One of the greater issue is if the embodied energy should be calculated or not for the old building construction. The recommendation from [18] is to avoid the calculation for the reused material and consequently to avoid new emissions. In this way it is possible to have less quantity of embodied energy as many building parts as possible should be reused. The service lifetime for a building after a complete refurbishment should be set to 40 years from the restoration date. In this case the building after the refurbishment is treat almost as a new building, and for this reason the service lifetime of the building is set to 50 years, whereas the lifetime of the new components is set according to the producer information. Moreover it is also important define that different type of buildings need different types of refurbishment and maintenance, and also have different operational life.

The main goal of these calculations is to estimate which of the materials used have the bigger contribute of embodied carbon dioxide emissions towards the principals of environmental assessment, or to decide between different materials that could have same features but different use of embodied energy.

With the previous lines that are according to [18, 24, 25], it is clear that have a consistent reduction of the energy use is a complex issue. This issue involves more factors than the energy use for the building operation and as defined from the EPDB Recast it is necessary to consider the energy flows and the emission balance during the operational life of the building.

1.7 Research questions

The aim of this work is to understand if it is possible to reach the Nearly Zero Energy level after a retrofit work. The main aim is not reaching the normal standard of buildings that are retrofitted with the goal to increase the energy efficiency, but understand if with a retrofit work it is possible to meet the same energy requirement that a new Nearly Zero Energy Building normally has. This could be difficult because facing with a refurbishment the designer does not have the same wide possibilities that he has when he is designing a new building. One easy example could be the orientation of the building. Indeed, in a new building the designer can design using the best building orientation to gain more energy from the sunlight, instead for a refurbishment the designer cannot control and modify this parameter but he needs to adapt his design concept to an existing building.

When a renovation is necessary, the evaluation of the possibility to achieve a Nearly Zero Energy Building after the renovation should also include several aspects that do not consider only the energy requirements during the operational life of the building. Indeed as stated in the previous subchapter the material choice has a big importance in the NZEB design.

The first research question for this work is *if it is possible to renovate a Building Block in Norway to achieve the Nearly Zero Energy Buildings levels.*

If the renovation as defined from the research question above is possible, the second question will deal with the issue to include also the embodied energy of the material that are essential for a retrofit with energy improvement, such as the insulation and the PV panels.

The second research question is: *how much the choice of the insulation is important in an energy upgrading of an existing building?*

The second research question is important to understand two important things:

- How important is to evaluate the embodied energy of the used material;
- How much the choice of the material induce the results.

Connected with the second research question there is a third question: *is it better to choose a thicker insulation panel with higher thermal conductivity or a thinner insulation panel with lower thermal conductivity?*

With this last research question, we will be able to understand which could be the best solution to use. However, the best solution will be good respect the variables that are important for this work, but in the same time the same solution could be the worst including other variables. So the complete aim of this work is not to define the global best solution or material to use, but define the material that uses less embodied energy, considering that in the last years the topic of the energy saving has gained more importance.

So that the variables that are analysed in this work will gain more importance in the next years.

2 NEARLY ZERO ENERGY BUILDING REFURBISHMENT: THE STATE OF ART

Many scientific researches deal with the problem to retrofit a building with the aim to improve the energy level as defined from the amendment of EPBD 2010. However, not many researches have studied the possibility to retrofit the buildings reaching the energy level of the new NZEB buildings.

The next pages are going to illustrate which is the state of art of the renovation toward the NZEB level in Europe and which are the studies conducted.

The cases that have been chosen to represent the state of art are the following:

- Blaue Heimat, Heidelberg (Germany);
- Apartment Building Rislerstrasse, Freiburg (Germany);
- Apartment building in Zurich (Switzerland).

It is also important to understand that there are no project in Norway with the goal to retrofit toward nearly zero energy levels. The most energy efficient renovations that have never been done in Norway used passive house elements or passive house technology.

Renovating an existing Building towards zero energy levels require that the thermal propriety of the building envelopment shall be improved, then it is necessary optimized the gains from solar energy. Other kind of energy use shall to be minimized to meet the NZEB standard level as energy use for ventilation, domestic hot water, lighting and electrical appliances, and at the end the renewable energy shall be produced preferably on site. When is not possible to reach the balance using on-site renewable energy alternative that take renewable energy from the grid shall be evaluate.

2.1 Some cases to define the State of the Art

2.1.1 Blaue Heimat, Heidelberg (Germany)

The Blaue Heimat complex according with [26] was built in 1951 and it consists in 155 apartments divided in four floors. The entire building has a basement with a solid concrete ceiling as ground floor slab, whereas the other floors are constructed of timber beams. Several modernization were carried out in the course of the time: the window were replaced, the ceiling slab was insulated, and a central heating system was installed. Despite these works of modernization, the poor thermal, the noise insulation, the outdated energy and hot water supply systems offered plenty of reasons to think about a complete renovation.

Figure 7. Blaue Heimat, Heidelberg - Germany. Before (left) and after (right) the renovation.

The original goal was to retrofit the existing building reaching the Zero Energy concept, but a complete equalised primary energy balance was not achieved because no wind power shares were available on the market. The renovation concept in this case also include giving the apartments a more attractive and contemporary design, and to achieve this goal, several apartments were combined and additional living spaces was created by using new staircases, and the attic space was added. Regarding the architectural upgrading new steel balconies were added, the goal in this case was to provide at almost all the apartments their balcony by adding economic value to each apartment. To improve the amount of the daylight inside the apartments and to increase passive solar gains larger areas of glazing was built. To reduce the heating energy demand, the solid external walls were insulated with a 20 cm thick thermal insulation system or 16 cm thick perimeter insulation with a lower U-Value.

The roof construction was completed with 18 cm of in filled mineral wool insulation and 10 cm on top, whereas the U-Value of the basement ceiling was improved by adding 16 mm of polystyrene (U-Value basement celling 0.17 W/m^{2}K; U-Value roof 0.13 W/m^{2}K). The new windows are triple-glazed with wood frames. The underground stores was upgraded by adding 7 cm of insulation. Importance was given at the thermal bridges and at the critical point. For instance, the bearing area between ground floor and the basement is insulated externally. The new balconies are detached from the thermal building envelope and were connected to the building only at selected points, this solution given the possibility to reduce the thermal bridge throughout continue or steel structure that should support the balcony.

To reduce ventilation losses, was paid attention to achieve an airtight building envelope, indeed the air tightness according to measurements was below 0.6 h^{-1}. The ventilations plans are located in the basement. To reduce the use of electricity as well as the thermal energy, the dishwasher and the washing machines was connected to the warm water system. The energy concept is based on the supply of heating from natural gas combined heat and power plant with 80 kW thermal capacity and 50 kW electrical capacity, which covers 95 % of the heating demand. The remaining 5 % are provided in very cold days and when large amount of water are required by two 92 kW peak load gas boiler. Before the renovation the requirements of heat capacity was 485 kW. The distribution of water in the building is by means of conventional radiator.

The annual heating energy consumption (around 19 kWh/m^2y) is almost 90 % below the value before the renovation. Despite the transfer of heat to the neighbouring buildings, it has not been possible to achieve a Zero Energy level. Even if the goal of Zero Energy buildings can not be achieved, however this project still indicate how the existing building can achieve very efficient building [26].

2.1.2 Apartment Building Rislerstrasse, Freiburg (Germany)

This apartment building was built in the 1961 and it is a typical example of and Nord European housing project from the 50s. The renovation was necessary because the thermal proprieties, the floor plans and the heating system were obsolete.

Figure 8. Apartment Building Rislerstrasse, Freiburg. Before (left) and after (right) the renovation.

External walls, attic floor and the addition of new windows were the envelope parts interested by renovation. To improve the thermal behaviour of the existing external wall made with clay brick (30 cm) and exterior plaster (2 cm), mineral wool insulation (18 cm) was added. It was possible by adding this insulation to reach a U-value equal to 0.15 W/m2K for the retrofitted wall. U-value of 0.14 W/m2K was achieved for the floor by adding at the existing reinforced concrete slab a 260 mm layer of mineral wool insulation, and a similar solution was adopted for the basement ceiling by adding a layer of 200 mm of mineral wood. The U-value reached for the basement is equal to 0.17W/m2K.

Other changes were done enlarging the balconies, and increasing the adaptability of the apartments; indeed the apartments have nowadays a good expandability of the kitchen and bathroom in case of new occupants.

Regarding the systems, the existing single stove in the building was replaced by central heating in the attic. Boiler with 60kW is used for heating and hot water, and the ventilation system is combined with heat recovery. Solar collector supports the heating system and connection to a future district heating system is planned. The building has also a 750-litre hot water storage tank. A reduction of primary use equal to 87 % for heating and production of hot water has been gained, indeed the primary energy use before the renovation was equal to 292 kWh/m2, instead the design primary energy use is equal to 39 kWh/m2 [27]. The difference between the last two data presented regard the different way to measure them, indeed the primary energy use before the renovation was measured on-site, whereas the primary energy use after the renovation was calculated.

2.1.3 Apartment building in Zurich (Switzerland)

This building has been built in 1954, and the building was in the original condition, indeed only small renovation have been done [28] before the ambitious renovation done in between 2009 and 2010. The building has both main façade and central wall that are the load bearing structure. The external walls were originally in bricks and not insulated.

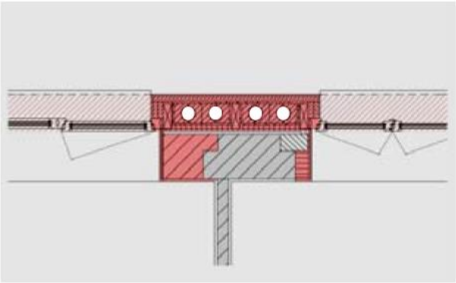
Figure 9. Apartment building in Zurich (Swiss). Before (left) and after (right) the renovation.

In the original building, the ceiling was of the reinforced concrete slab type, and the balconies had some damage due to corroded reinforcement. Radiators did the heat distribution and the hot water system not centralized worked with electric boiler.

For the renovation a new attic apartment and extension of the ground floor has was built. The façade was retrofitted using prefabricated element, but the difficult was that the new prefabricated element had to fit on the imprecise old wall, and for this motivation, cellulose insulation was used to fill all the gaps that occurred between the new prefabricated element and the existing wall. Several layer composes the prefabricated wall used: Tolerance/cellulose (20mm), Insulation/cellulose (180mm), wood fibreboard (40mm), exterior rendering (10mm). These panels was added at the existing brick wall.

The connection between the new windows and the old walls has been covered by plasterboard; the air-tightness of the renovated structure is excellent due also to the attention that was paid designing the details. For the roof, the most important solution is in the extension part, where the achieved U-value is 0.11 W/m2K.

For the ventilation ducts is used the new facades elements and the air inlets are positioned above each windows. The domestic hot water and the heating are supplied by a geothermal heat pump and by vacuum solar collectors, and the 75 % of the energy for the hot water are renewable energy from the sun. On the roof are also installed PV-system. The primary energy use for heating and for hot water is equal to 13,26 kWh/y, with a reduction of 87 % of primary energy use.



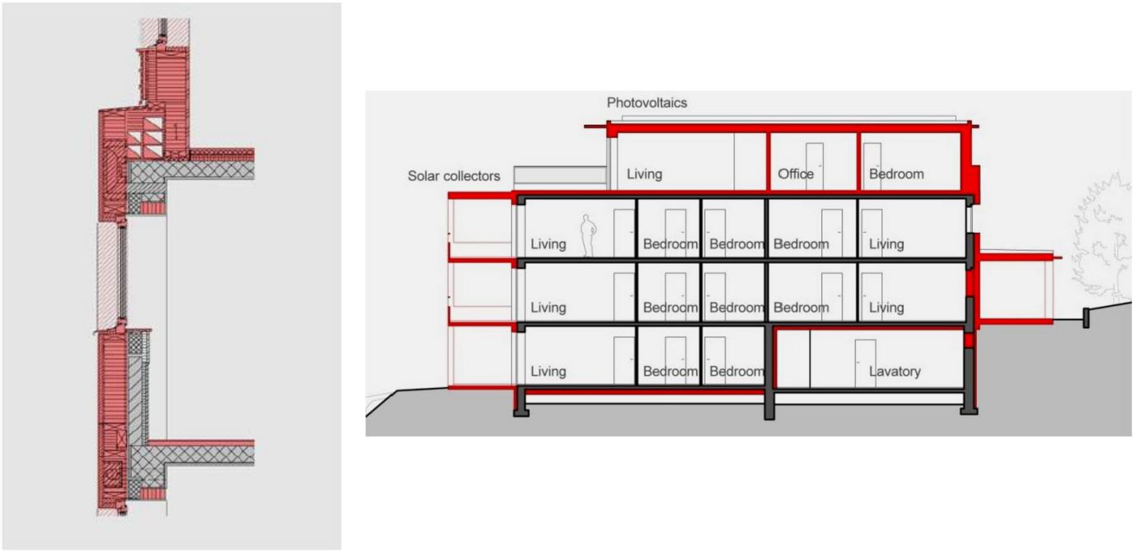


Figure 10. Section that shows the refurbishment works made in the Apartment in Zurich. The picture above shows the horizontal section of the façade with the integrated ventilation ducts. The picture below shows a vertical section of a window detail, with the horizontal ventilation distribution. A section of the complete building is shown, where the red parts are the new parts added after the refurbishment

2.2 Summary

It is easy to compare the previous examples to see that in the retrofit work with the goal to upgrade the energy efficiency, typical crucial elements are always included, works, or design decisions.

The first important element to retrofit indeed is the envelope that shall be with a U-value equal or below 0.15 W/m2K to be considered reasonable value for a retrofit work with the aim to upgrade the energy efficiency (this is the general value, but it might change the different countries). Each retrofit with energy upgrade need a new envelope technology and this can be observed from all the cases analysed above. The upgrading of the envelope could be done removing the external existing materials without removing non-damaged insulation layers or parts. Then on this structure, it is possible to add new material and a wind barrier that is essential to reduce the air infiltrations in the building.

A second fundamental design decision that in each case is present is the substitution of the windows with new windows that satisfy the low energy requirements. The state of art is place triple glazed windows filled in with argon. This aspect is also present in the cases of study shown above and this is considered as a part of the envelope upgrading. Both the external envelope (external wall, roof and floor) upgrade and the windows substitution are useful to reduce the heat loss and the air infiltrations, and consequently are the most important part to have a significant energy reduction.

It is also important the attention that in each project is given to avoid the thermal bridges and one of the most difficult thermal bridge to avoid is present when balconies are present. One visible example is shown in Blaue Heimat retrofit (chapter 2.1), where to avoid the thermal bridge between the balconies and the floor, the balconies are detached from the floor and connected to the building only in some selected point. Whit this solution the thermal bridge is smaller than the thermal bridges that could be present if there was a continue structure between these two elements.

Important, but not always used is to change the amount of glazing surface to increase the solar gain or to reduce the heat loss using the glazing elements, it is possible to see this solution used in the Blaue Heimat example. If the window-to wall ratio has been changed the study should be conducted carefully. Indeed, a big window-to-wall ratio induce bigger heat loss but at the same time bigger internal gains due to the sun energy. In reverse, a small window-to-wall ratio reduce the heat loss from the envelope but at the same time, it reduces also the internal gains.

Several ways to reduce the energy consumption using different installation are shown in the previous examples. Usually is used a heat pump that could be air-to air, air-to-water or geothermal heat pump (as shown in the example from Zurich). The main concept of the heat pumps is to move thermal energy opposite to the direction of spontaneous heat flow by absorbing heat from a cold space and releasing it to a warmer one. The heat pump is used for space heating or space cooling. In the previous example are shown two different heat pump solutions: the air source heat pump and the geothermal heat pump, where the first has a COP in the range 3 to 4, instead the second one has a COP in the range of 2.5 to 5.0. Generally, the best solution to adopt, in cases where the goal is to reach the NZEB level, is to use a geothermal heat pump or a water source heat pump, where a greater efficiency can be achieved connecting the water source heat pump with solar collectors, so that the water can be pre-heated before that goes into the heat pump.

All the examples that have been analysed present a ventilation and heat recovery system, and renewable energy system to gain energy and some of them have a connection with an external grid. As presented in the first part, the grid is important to take energy when the building is underproduction, or to leave the energy at the grid when the building produce more energy than the necessary. The design of a renewable system is also important to cover the quantity of energy that the building requires during its service life.

Advanced and unusual design choices have also shown in Blaue Heimat example, where the dishwasher and the washing machines were connected to the warm water system. This solution allows the dishwasher and the washing machines to use less electricity to warm the cold water before to launch the washing, indeed the goal is pre-heat the water before goes toward both dishwasher and washing machine.

From the previous examples, it is possible to see that the reduction of primary energy after the retrofit is always between the 75% and the 90 %, but these values are depending from the boundaries that was set to calculate the primary energy use. In fact, some of them include only the energy used to heat, whereas ssome other include the energy useful to produce Domestic Hot Water (DHW) and for the ventilation.

3 METHODOLOGY

3.1 Objective

The EPBD [13] does not set any specific requirements about deep renovations. Indeed the EPBD provides values to renovate with energy performance, but it does not give a proper NZEB definition that deal with the retrofit. For these reasons [29] and [30] set definitions about deep renovation, deep energy renovation, deep energy retrofit, deep energy reduction, zero carbon renovation and zero energy renovation but all of these are far away to be comparable with the requirements for the new NZEB as stated in the previous chapters. For this reason COHERENO (Collaboration for housing nearly zero-energy renovation) [31] elaborate a common criteria applicable in all the national contexts that is useful to define the concept of NZEB renovation, in order to increase the number of NZEB renovation on the market. For these evidences the [31] developed a 'NZEB radar' that is useful to track NZEB renovations. The NZEB radar needs to be accompanied by the already existing MS definition that are defined in the chapter 1.4.2. In this chapter the NZEB radar will be accompanied by the set Norwegian NZEB definition as stated in the chapter 1.5. but it lays down the application of the minimum requirements to energy performance of existing building. The main aim of the 'NZEB radar' is to define the ambition level of the renovation and needs to be compared with a NZEB definition, where the general rule applies is the closer to zero energy, the better. The different ambitious level are defined by the 4 circles shown in the Figure 11.

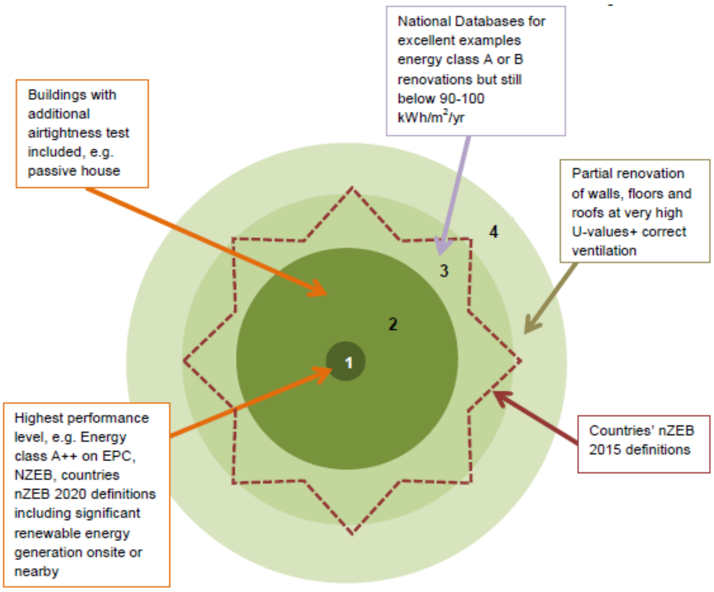


Figure 11. Example of nZEB target which was created to depict different methodologies and standard for defining nZEB buildings

Looking at the Figure 11 the circle 1 (very dark green) represents the highest performance level of the building renovation where the renovations meet at least the set requirements for a new NZEB following the national NZEB definition or concept. The circle 1 is the ambitious level of this work and as the national NZEB definition is not implemented in Norway, the ‘NZEB radar’ in this case will follow the NZEB definition as stated in the chapter 1.5.

Continuing to explain the circles that characterize the ‘NZEB radar’ the Circle 2 (dark green) includes renovations that achieve a specific energy consumption after the renovation at around 50-60 $kWhm^{-2}y^{-1}$. The Circle 3 (light green) includes cases with an higher primary energy consumption than in the previous circles. Indeed the specific primary energy consumption shall be below 90-100 $kWhm^{-2}y^{-1}$. The Circle 4 (light green) include the projects on a good way to NZEB renovation, with at least 3 measures such as in the following list:

- Deep envelope and roof insulation (U-value< 0.24 $Wm^{-2}K$)
- Triple glazed windows (U-value< 0.24 $Wm^{-2}K$)
- Update of an old heating system (boiler, pumps, etc.)
- Integration of RES (i.e. 50%)
- Correct ventilation for securing the air comfort inside the building

As stated above the goal of this work is achieve the condition to consider the refurbished building inside the Circle 1 (very dark green). This circle represents the highest performance level of the building renovation.

The ‘NZEB radar’ is important to create a connection between the set Norwegian nZEB definition that should be used for new buildings and the aim of this work that is the refurbishment of an existing building. To fulfil the requirements set through the Norwegian NZEB definition are important:

- Thermal proprieties of the envelope
- Update the old heating systems
- Ventilation and heat recovery systems
- Integration of RES, defining the building as net-building (PV systems)

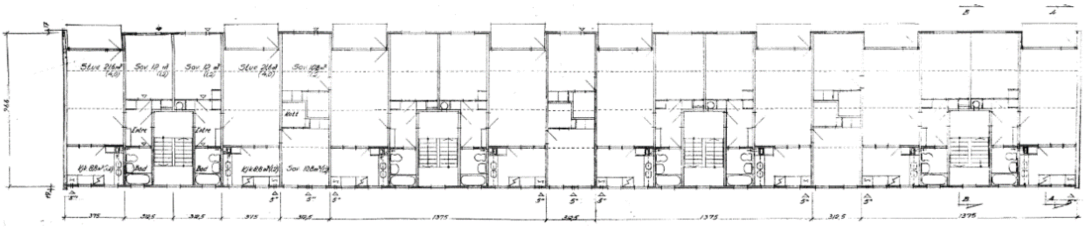
To increase the envelope thermal proprieties is necessary add insulation on the external leaf of the existing envelope and studying the solutions to remove thermal bridges, in this way it is possible reduce the heat loss during the cold season. To achieve this aim is extremely important to design the refurbishment of the envelope. And then there are other indispensable recommendations for the renovation, such as installation of the ventilation system to achieve a good indoor air quality and heat recovery systems.

3.2 The reference Building: Myhrerenga.

The building selected as reference Building is Myhrerenga [7], [32], [33] . It consists in seven similar blocks built between the 1960 and the 1970. These buildings are located in Skedsmokorset a village in the country of Akershus, and it is 15 Km North-East of Oslo.

Figure 12. Myhrerenga: seven similar blocks with west-facing and east-facing main facades.

The blocks present the same design and aspect, they are with three storeys and with 24 apartments in each block. Each block has a length of about 65 m a width of about 10 m. In each block, there are two type of apartments: 6 one-bedroom flats with a floor surface of 54 m^2 and 18 two-bedrooms flats with a floor surface of 68 m^2. The total number of the flats in Myhrerenga is 168. The Figure 13 shows the internal arrangement of both the inhabited floors and the basement.



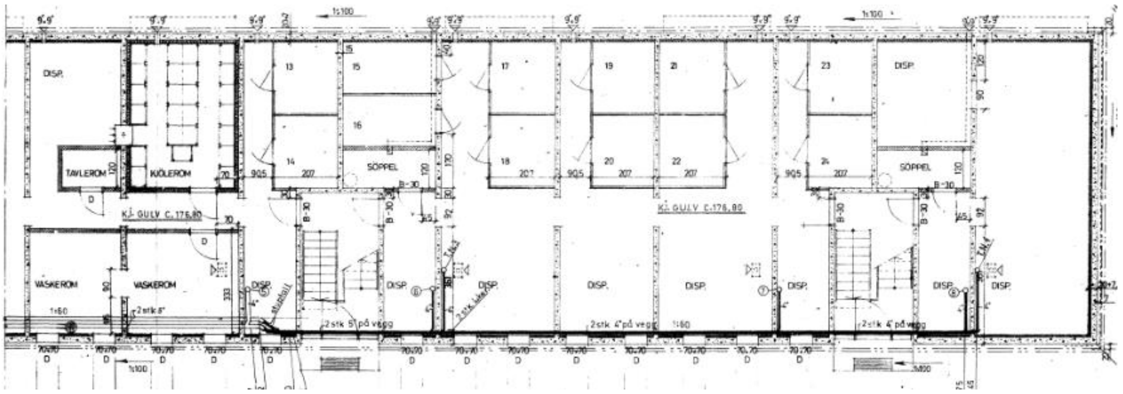


Figure 13. Myhrerenga: Plan of the inhabited floors and plan of the basement.

Small maintenance was done during the eighties, and the renovation regarded mostly the windows replacement. The need of a renovation after that small maintenance depends from the façade that was obsolete, indeed the residents complained about the draft, cold floors and poor air quality, and for these motivations, this building was interested from a renovation during the years 2009/2010.

The original structure consist in parallel concrete walls. These walls delimit each apartment and they represent the load-bearing structure. The gable walls present on the South-North facades consist of poorly insulated concrete sandwich elements where the insulation is 8 cm or less. The external walls on the East and West side consist in a wooden framework, where the elements are 5x10 cm spaces every 60 cm and the cavity in filled with 10 cm of mineral wool with the internal and external layer made of gypsum plasterboard, and the timber frame is covered with wood cladding.

The structure consists in concrete slabs with concrete walls that constitute the load-bearing framework. The roof is finished with a wood frame that is insulated with 10 cm of mineral wood that stand on the concrete slabs. Regarding the floors against the unheated basement, they are insulated with 5 cm of EPS, where the structure is always a concrete slab. The Figure 14 shows a detail from the East façade where it is shown the connection between structural walls and the external walls.

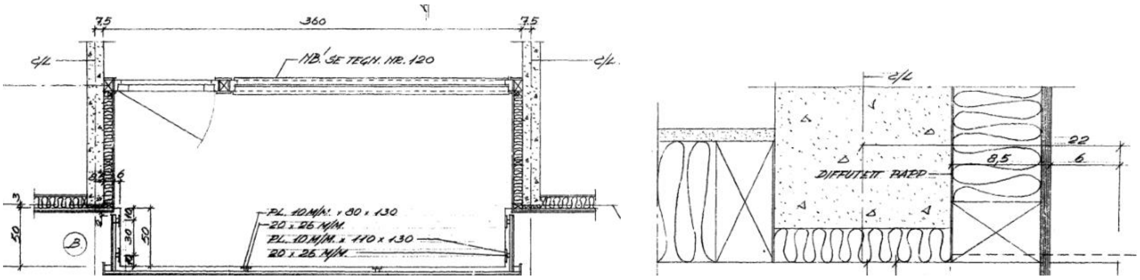


Figure 14 Myhrerenga: detail in the connection between the structural walls and the external walls

The windows was two glazed type with a wooden frame and these are mounted during the eighties and they presented a U-value of 2.6 W/m^{2}K, that was not good for the energy requirements.

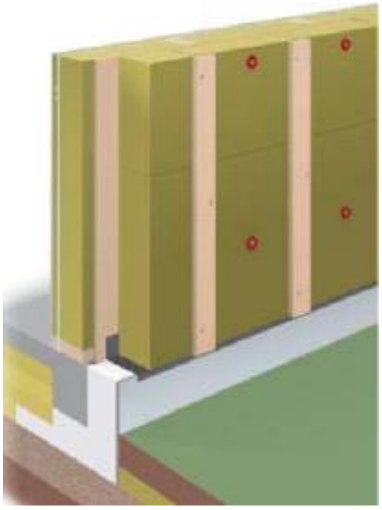
Balconies are present in each apartment and these presented moisture damage. The balcony slabs were not cantilever, but there were brackets that connected with the load bearing wall elements. For this, it is possible to replace the balconies using only wise point of penetration of the insulation, so that it is possible to reduce the thermal bridges.

A require from the resident was to have bigger balconies, that before the refurbishment was present only on the east side of the building, thus this is a request that will be evaluate during the refurbishment design.

3.3 The renovation of Myhrerenga.

A renovation process started in the 2010 and the aim of this renovation was to have a building that followed the standard of the low energy building using also a Passive house component (Triple glazed window), this is the first work with so high ambition in Norway.

The renovation of the construction started by adding 200 mm of insulation (mineral wool) at the existing wooden construction and to the gamble elements. To thermally decouple the unheated rooms from the heated rooms has been added 100 mm of insulation layer. The doors and windows was replaced with new windows adapt to satisfy the passive



house requirements. The new balcony studs was placed outside of the façade, so that the thermal bridges are reduced due to the continuous layer of insulation.

For the roof has been used a non-ventilated solution, that is not common in Norway.

The design was done reaching the “Passive House” air tightness, where the requirement is 0.6 ach, and this requirement has been fulfil. The main layer that ensure the air tightness is the OSB board with the sealed joints. The details around windows, foundations and junctions between the external wall and the roof was carefully designed to reach the desired airtightness.

The centralized exhaust fan system that served 6 apartments has been replaced with a centralised balanced ventilation system with the AHU placed above each stair case.

The existing central energy system was renovated, substituting the old oil-and electric boilers with air-to water heat pumps.

The solar collector system, consists in 44 vacuum solar collector placed on the roof, these will complement the heat pump system in the summer. Both heat-pump and solar system cover most of the space heating and DHW demand.

Figure 15. Illustration of Myhrerenga after the refurbishment. SOURCE [7]

All these decisions was useful for the reduction of net space heating demand of 80-90%.

3.4 Other studies on Myhrerenga.

The aim of the following pages is to investigate the other researches that have been done regard the selected building after the renovation that is highlight above.

A research finished in 2014 from N. Lolli [25] define the influence that the façade have on the apartment buildings, using Myhrerenga as model. This study proposed several alternative of both façade types and conditions that has been compared with the reference building. In this study, the reference building is defined as the building in the current condition, so as the building after the renovation that was done in 2010.

The study take in account several modification at the façade and study both the energy demand and the CO2 emissions for the alternatives presented and for the reference building. The proposed alternatives are shown below:

- Different insulation material with different insulation thickness: Mineral wool, Vacuum panels and Aerogel mats;
- Different windows type: triple glazed windows with argon and double glazed windows with monolithic aerogel;
- Different window to wall ratio:24%, 33% and 50%;
- Different finishing material for the outside layer of the external wall: cement tiles, untreated wood, copper impregnated wood, insulated sandwich panels and polymer-cement tiles. In this part is not consider the energy analysis, but only the CO2 emission because it has assumed that the finishing does not have any influence on the building energy demand.
- Different balconies solution: the first solution is the one as proposed in the reference building and the second propose the balconies with glass panels to create sunspace.

This study is fundamental for this work to evaluate what the best solution is to define a retrofit toward the Zero Energy level. Specifically this study is important to evaluate what solution have less energy demand and the attention will be focused at the insulation types, at the window to wall ratio and at the balconies type.

For the insulation types this study set the U-value for the different components and changes the materials, consequently are compared walls with the same U-value, but with different insulation thickness. In this section are not present difference in the energy demand between the different solutions but difference of CO_2 emission are present. The only difference is between the reference building and the other solutions, because the reference building presents a U-value of 0.12 W/m2K and the proposed solution have a U-value of 0.10 W/m2K. The energy demand difference is 2 KWh/m2 where obviously is higher in the reference building.

Another analysis regards the external wall taking in account three different U-value for the proposed alternatives (0.18, 0.15, 0.10 W/m2K). The result highlight that the difference between the last and the best insulation solution is approximately 9 kWh/m2y that is approximately the 10% of the total energy demand.

Regarding the variation of the glazing ratio, the study sets alternatives combining the three different materials in the external façade with three different window to wall ratios. The alternatives however set for the wall the same U-value that is equal to 0.1 KW/m2K. In this situation the comparison, regard only the window to wall ratio and regards the energy demand. The results highlight that the best solution is the one with the window to wall ratio sets equal to 24 % (the one of the reference building). The yearly energy saving is equal to 3 % compared with the reference building, due to the difference wall U-Value. The other two solutions give an higher value of energy demand.

The choice to use this window to wall ratio is also supported by the study that evaluate the use of natural ventilation during the summer (condition studied in July monthly temperature). In this part is shown that for the 24% window to wall ratio the indoor temperature is below 25° (optimal condition for the summer temperature) for most of the time. Instead, the worse conditions are extracted with window to wall ratio equal to 50 %.

The comparison between different balcony types show several combinations between the window to wall ratio and the balcony types. There are also alternatives where is presented the possibility to add a balcony on the East façade, where now there is no balconies. This part however show that the best alternative is the one that presents sunspaces and with the lower window to wall ratio, and this is the only one alternative that presents an energy demand reduction of 2.3%. The reduction is explained by the reduction of thermal losses of the windows and glazed door, due to the sunspaces and the low window to wall ratio. However in the work is presented that the energy saving given by the use of the sunspaces is approximately 2 KWh/m2y regardless of the glazing ratio of the façade.

This work has been used to evaluate the best solution regard the energy demand of the building. It is important to understand that the study presented by N. Lolli is focused on the evaluation of the CO2 components' emission. In the parts highlighted in this section are presented only the important information that deal with the energy saving of the building.

It is also important to highlight that the energy demand in the study presented is calculate considering the energy used for heating the spaces and the energy to produce Domestic Hot Water, this is because the same air-to-water heat pump serves them. This consideration is important to set some parameter in this work that will be shown in the next chapters.

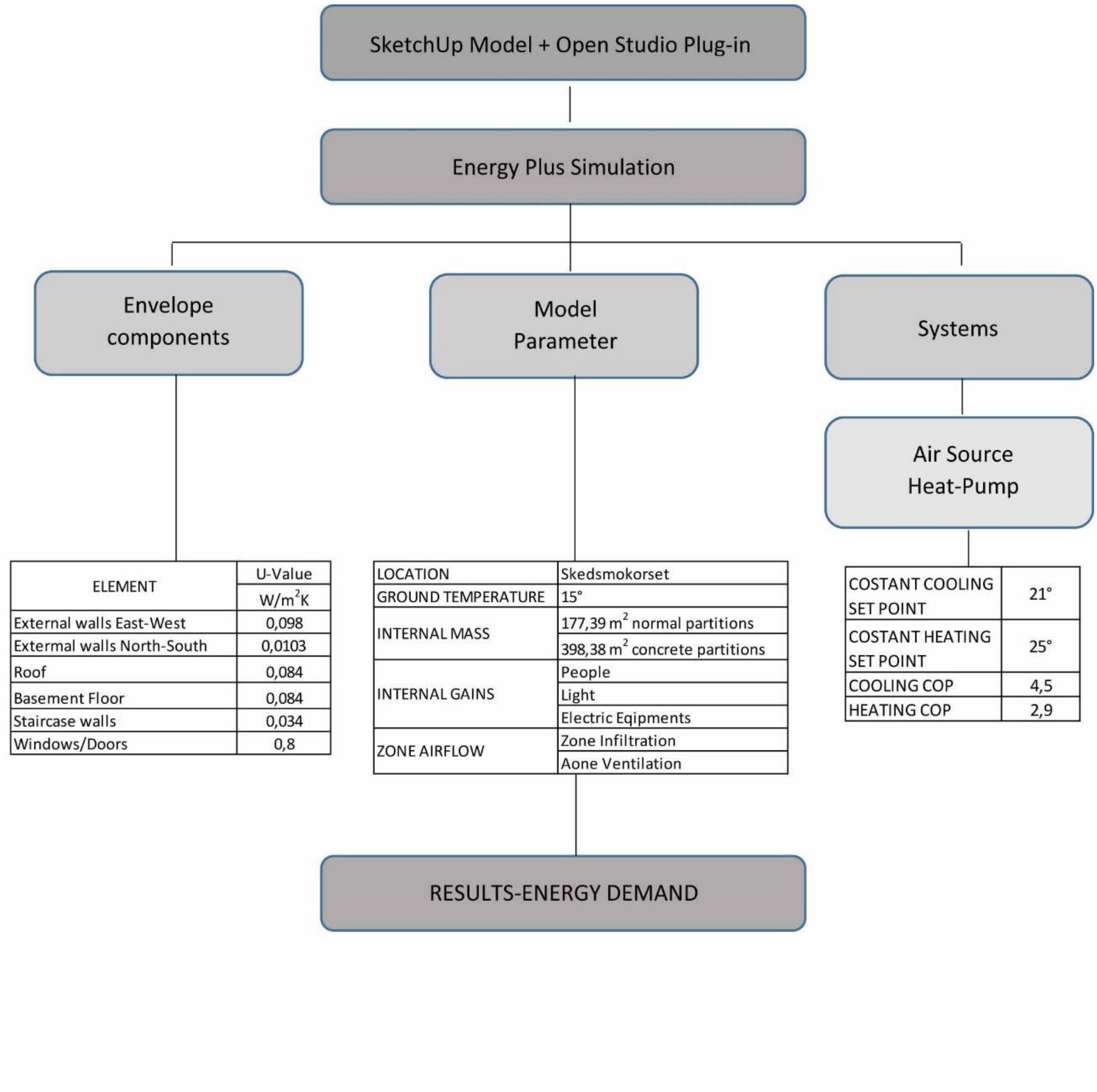
3.5 Description of the energy model

The energy calculations of the building were done using two different models, where the first dealt with the calculation of the energy used by the building and the second dealt with the calculation of the same PV panel differently arranged. The next two chapters (3.5.1, 3.5.2) will show the main parameters that characterize the two models.

3.5.1 Declaration of the energy demand calculation

The energy model has not been implemented with extreme accuracy; indeed extreme accuracy does not give necessarily better results, while a too simple model can give poor information about the energy transfer in different parts of a building. In this work a model that is a compromise between geometrical complexity and richness of energy information has been used.

Moreover, in this work, only one of the seven building of Myhrerenga Housing Cooperative has been modelled and the other building are not modelled. The Figure 16 shows the flow chart of the methodology that had characterized the energy use calculation.



ELEMENT	U-Value W/m^{2}K
External walls East-West	0,098
Extermal walls North-South	0,0103
Roof	0,084
Basement Floor	0,084
Staircase walls	0,034
Windows/Doors	0,8

LOCATION	Skedsmokorset
GROUND TEMPERATURE	15°
INTERNAL MASS	177,39 m^2 normal partitions
	398,38 m^2 concrete partitions
INTERNAL GAINS	People
	Light
	Electric Eqipments
ZONE AIRFLOW	Zone Infiltration
	Aone Ventilation

COSTANT COOLING SET POINT	21°
COSTANT HEATING SET POINT	25°
COOLING COP	4,5
HEATING COP	2,9

Figure 16. The flow chart shows the methodology to define the energy demand of the building.

The Figure 17 shows the model of the building made using the software Sketch-Up 2015 [34] and the OpenStudio Plug-in [35] that is a tool to support whole building energy modelling necessary to obtain the building energy demand.

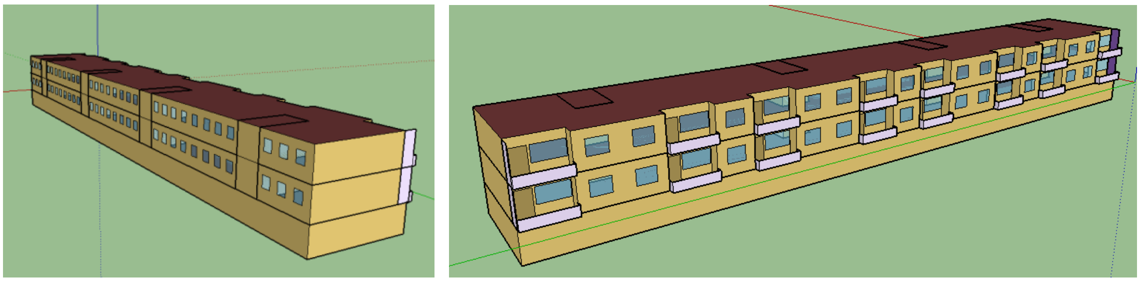


Figure 17. The model of Myhrerenga Housing Cooperative in SketchUp2015 with OpenStudio Plug-in. The picture shows that in the model, all the shadings were considered and the windows toward the unheated spaces (basement, staircases) were omitted.

The single building block has been modelled not using the different apartments as thermal zone, but using a continuous uniform space for each floor and several thermal zone for the stairs. In this model, the 1st the 2nd and the 3rd floor are defined as heated zone, instead the stairs zone and the basement are defined as unheated zone. The indoor partitions in each residential unit are not geometrically described but their approximate thermal masses are included in the model. For the internal partitions is not designed a refurbishment so that the thermal mass included in the model use two different type of partitions. The first is a 150 mm concrete partition (400 m^2 for each floor) that represent the structural walls and the second is a 130 mm thick normal internal partition (180 m^2 for each floor) that represent the partition between different rooms.

The basement external wall are considered to be against the ground and so in the energy model was not considered the terrain gently slopes down towards the east side of the building, but all the basement wall was considered as wall against the ground.

Regarding the basement walls there is exchange temperature with the ground, where the ground temperature it was set equal to 15° in all the months. Regarding the unheated space such as stairs and basement was considered without windows that actually are presents in these spaces. This last simplification does not give worst result than a detailed model because the omitted windows are toward unheated spaces.

The settings of the indoor environmental controls and variables are harmonized to the Norwegian Standards NS 3700 and NS 3031 and are summarized in Table 5.

Class	Value	Schedule (hh/d/ww)
Occupancy	100%	16/7/52
Installed light power	1,95 W m^{-2}	16/7/52
Installed appliance power	3,00 W m^{-3}	16/7/52
Infiltration rate	0,6 ach	24/7/52
Ventilation rate	0,023 - 0,026 $m^2s^{-1}m^{-2}$	24/7/52
Designed indoor temperature	21 C	16/7/52
Designed indoor temperature	19 C	8/7/52

Table 5- List of the variables used in the energy model

The calculation are performed using Energy Plus [36] and the extracted results are based on yearly and monthly energy use for heating, cooling, ventilation fans, light appliances and heat pumps. In the model was also included the energy use for cooling in the summer and this it is supposed in combination with the natural ventilation.

The heating system is modelled as a single air-to-water heat pump considering an ideal heat pump that heat and cool the 1st, 2nd and 3rd floors (conditioned spaces).

In the model was considered the internal gains due to the people presence, light and electric equipment. The internal gains due to the people was defined considering the habitants for each floor that were equal to 28 people. To define the habitants for each floor, 2 people were considered for each bedroom bigger than 18 m^2 and 1 person were considered for each bedroom smaller than 10 m^2. The lights are not modelled placing correctly the lighting points but using a design level set in Watts/Area and the value was set to 1.95 W/m^2, the same way of thinking was used for the Electric Equipment setting a value of 3 W/m^2. These data are important to evaluate the internal gains.

The HVAC system was modelled as an air source heat pump and the heat-pump was modelled using data from a commercial product using a Cooling Coil Gross Rated COP equal to 4.5 W/W and heating coil rated COP equal to 2.9. Explanations about the determination of the COP in winter and summer situations are explained in the chapter 4.1.6. The heating and cooling set-point was set respectively to 19° and 21°.

No ventilation and DHW systems has been modelled for this work.

The Table 22 in the Appendix II shows all the value that are explained in this section.

3.5.2 Declaration of the energy production calculation

For the production of the PV calculation one panel in three different arrangements was modelled. The proposed arrangement are are shown in the Figure 18 , and are the following:

- PV panel with tilt of 40° and facing toward south totally exposed to the sun
- PV panel with tilt of 40° facing toward south shaded from another PV panel in the same conditions, where the distance between the two panels is 1,2 m
- PV panel facing toward south with tilt of 90° (vertical)

The daily, monthly and yearly energy production of one panel in the proposed arrangements were extracted using three different models (Figure 18). The energy produced by each single panel in the proposed arrangement was obtained using Energy Plus. Moreover the panel in each situation was modelled using the data of a commercial product [37] where according with the producer the cell efficiency of the chosen panel is 20,40 % and this data was used as input to extract the results in energy production of the single panel. The Figure 18 shows the flow chart followed to extract the energy production of the same panel but arranged in three different way.

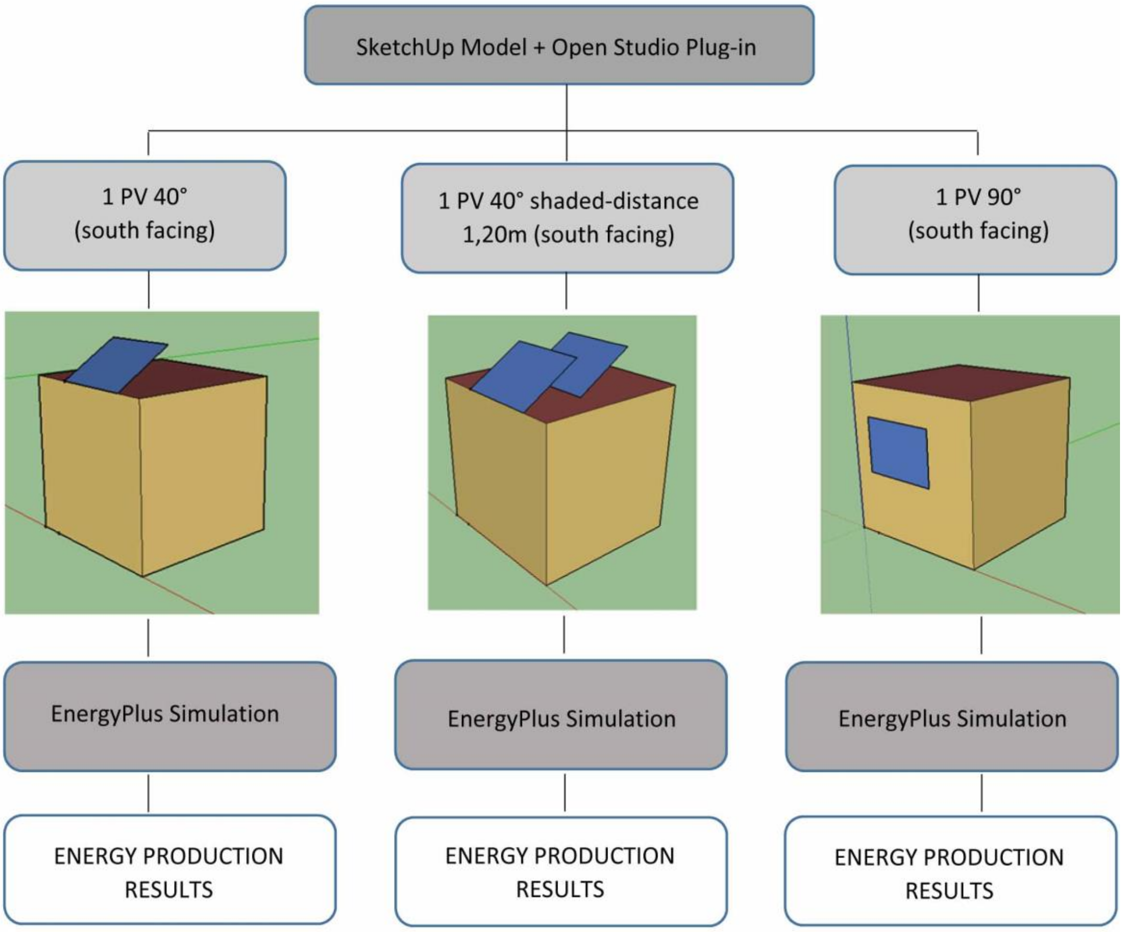


Figure 18. The flow chart shows the followed methodology to extract the energy production of 1 PV panel arranged in three different way: not shaded with a tilt of 40°, shaded with a tilt of 40° where the shading surface has the same tilt and vertical not shaded.

3.6 Declaration of the embodied energy calculation

A descriptive lifecycle of a building cover the following stages:

- Material production
- Transportation
- Construction
- Building use and maintenance
- Demolition
- Transportation
- End-of-life (EOL)

I has been already defined that the production and the end-of-life stages gain increasing importance for the lifecycle impact of low-energy buildings. However, since this work is focused to set the 3rd level of the ZEB definition, that is called ZEB-OM, it will be evaluated only the energy used during the production of the material. Indeed, regarding the considered ZEB ambition level and in general the ZEB definitions stated in the chapter 1.4, these are based to the standard EN15978 [1].

The Figure 19 shows the different life cycle stages according to EN15978.

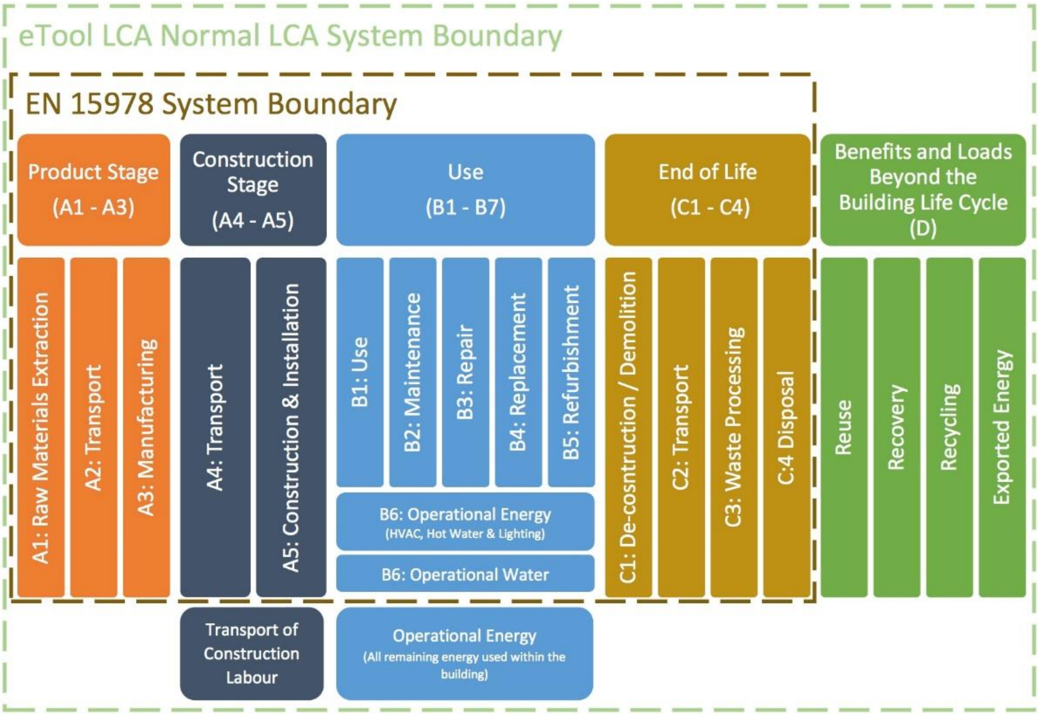


Figure 19. The different stages of the life cycle of a building. SOURCE [1].

Using the ZEB-OM definition that considers the embodied energy of the materials used for the refurbishment, the "M" of the stated definition imply the compensation for the emissions related to the product phase of the materials, A1-A3.

In this study, the "M" will regard only the insulations and the windows used for the refurbishment. Indeed this work has the aim to define the best insulation solution for a refurbishment between the most common and the newest solutions. Thus, the embodied energy calculation will be done only for the insulation products and the windows that was taken among commercial products to give results that are more plausible.

The data to calculate the embodied energy for each proposed solution were extracted using the Environmental Product Declaration. The solutions that will be compared are the following:

- Mineral wool boards
- Wood fibre boards
- VIP panels
- PUR sandwich panels and XPS panels

The unitary embodied energy for mineral wool, wood fibre, VIP, XPS panels and windows were taken from the environmental product declaration published by the Institut Bauen und Umwelt e.V [38-41], instead for the PUR sandwich panels the environmental product declaration used is according with the producer [42].

Finally, it is important to state that with the goal to have comparable data between the energy demand, the energy produced by the PV and the embodied energy of the materials (windows and insulations) all the results will be shown in kWh/m^2 or kWh/m^2y^{-1}.

4 SCENARIOS

4.1 The design of the Retrofit

The design of the retrofit of the Myhrerenga building blocks complex take in account a sustainable refurbishment of the component. This is a fundamental decision for an energy upgrading. The solution that will be shown are useful to reach the NZEB or ZEB level. The following element will be analysed in this chapter:

- Building Envelope
- Windows
- Thermal Bridges
- Ventilation System
- Heating system
- Domestic hot water
- PV system

4.1.1 The design of the Retrofit

EXTERNAL WALLS

To retrofit the building envelope the first stage is to remove the external existing layers from the external walls. These are the most damaged layers. Another reason why the external layers are removed is to place the new insulations in contact with the old insulation layer. The Figure 20 shows the façades East – West where it is possible to notice that the external layers are in need to be replaced.

Figure 20. The façade in the West and East walls is worn out.

There are different layers that need to be removed in the different part of the envelope.

For the façade East – West it is important to remove both the external layer of the façade and the support studs that support the external leaf. The Figure 22 shows the wall construction of the West and East façade before the renovation. The hatched red parts are the layers that need to be removed, and the green parts represents the new layers that need to be placed for the energy upgrading. In this stage is not important consider the thickness of the new insulation used, but only the main idea of the refurbishment of the component under consideration.

The detail after the renovation shows that the refurbishment will consist in placing a thick layer of insulation. After the insulation an air gap will include the stud structure that will support an external timber layer.

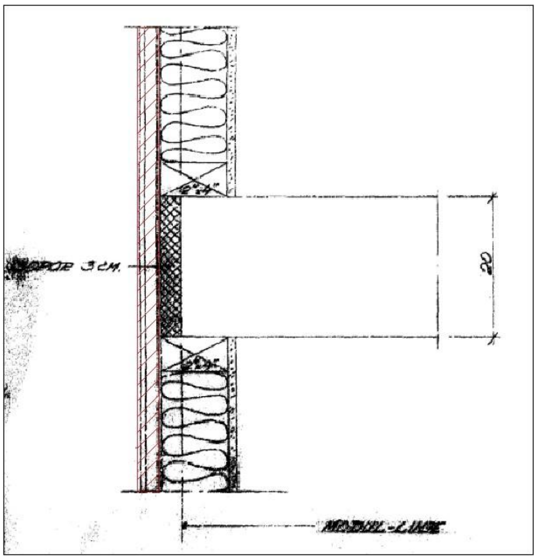


Figure 22. The façade East and West, before the renovation. The red hatched part is the part to remove

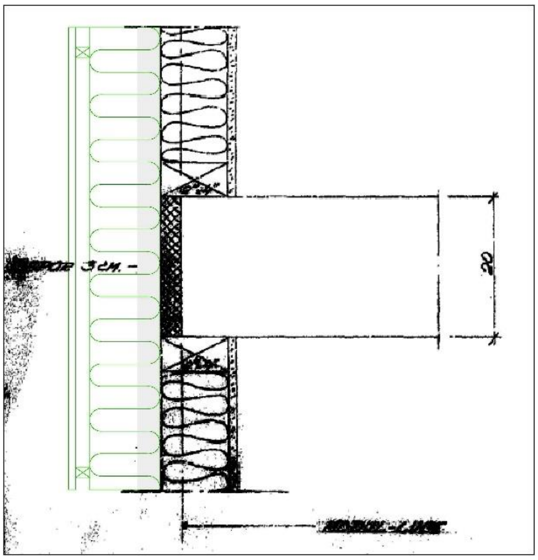


Figure 21. The façade East and West, after the renovation. The green parts represent the new layers

For the gable walls that are on the North and South sides, the original construction consists in poorly insulated concrete sandwich elements. The refurbishment methodology in this case consists in stripping the façade surface from the external painting and the cement plaster that covers the walls from the outside. For the energy upgrading, it is proposed a solution similar at the façade West and East that consists in a thick layer of insulation and an external timber layer supported by a timber stud, where the maximum spacing between vertical and horizontal studs must be less than 600mm.

For both West - East walls and North – South walls it is indispensable place a wind barrier and a vapour barrier. The vapour barrier should be placed between the existing and the new construction, thus it should be placed before the new insulation. Instead the wind barrier should be placed after the new insulation layers, therefore it will be between the insulation layer and the new timber studs. The requirement after the renovation is 0.6 ach (“Passive house” air tightness) and to reach this level of air tightness all the details around the window, the foundation, the junction between the walls and the roof should be carefully designed.

Considerations about the thickness of the insulation boards need to be done. Indeed, the internal convection increase when the insulation thickness increase. Indeed when the necessary insulation is thicker than 200mm to avoid this problem linked with the convection is better to use more boards detached from a convection membranes. This solution avoid the heat losses due to the big insulation thickness. The Figure 23 shows a sketch of an inadequate solution (left) with heat losses due to the conductivity and a good solution (right) that highlight the convection barrier.

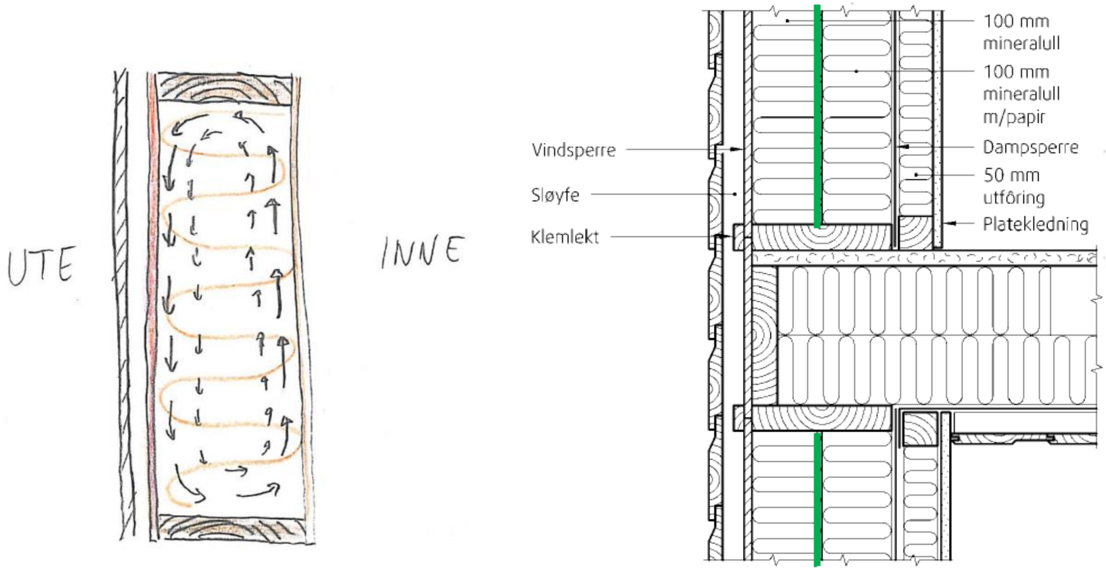


Figure 23. LEFT[4]: sketch a bad arrangement of the insulation. The thick layer facilitate the heat losses by internal convection. RIGHT [9]: a good solution where the green line indicates the convection barrier.

ROOF

The existing solution of the external roof is a ventilated roof. This solution present 10 mm of mineral wool directly placed on the concrete slab. To have the correct slope to conduct the water towards the drainage systems it presents a timber frame that support the finishing layers. The refurbishment of this element consider the removal of the wooden frame and the finishing layer. The new solution is a non-ventilated roof (also called compact roof) with the insulation placed on the top of the existing insulation that should not be damaged. To have the correct movement of the water towards the drainage the insulation panels should have the correct slope (Figure 24. Slope-Cut insulations to make slope in Compact roof). The slope for flat roof should be between 1:40 and 1:60 in Norway. Another important consideration about the drainage is that this should be placed where the snow melt first. So the central position of the drainage is better.

The reference building presents correctly the drainage in the central part of the roof, so the position of the drainage must remain the same.

Figure 24. Slope-Cut insulations to make slope in Compact roof

The Figure 25 shows which should be the best practice to design the construction arrangement of the roof. This study dealt with the refurbishment of an existing building and so both the concrete slab and the first layer of insulation are already presents in the existing construction. The layers important for the refurbishment are the following:

- membrane that is useful to avoid water infiltrations
- insulation layers that are useful to reach the desired U-Value
- Separation layer useful to avoid that the finishing layer damages the insulation

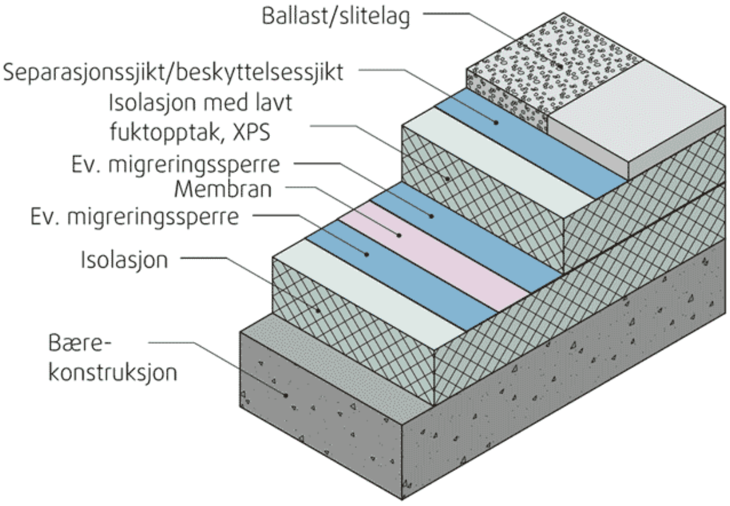


Figure 25. Compact roof layers arrangement. Source [2]

The following roof’s details of the reference building (Figure 26and Figure 27) explain the previous description about the refurbishment work. As stated before the red hatch indicate the layer that may be removed and the green parts represents the new layers that need to be placed for the energy upgrading.

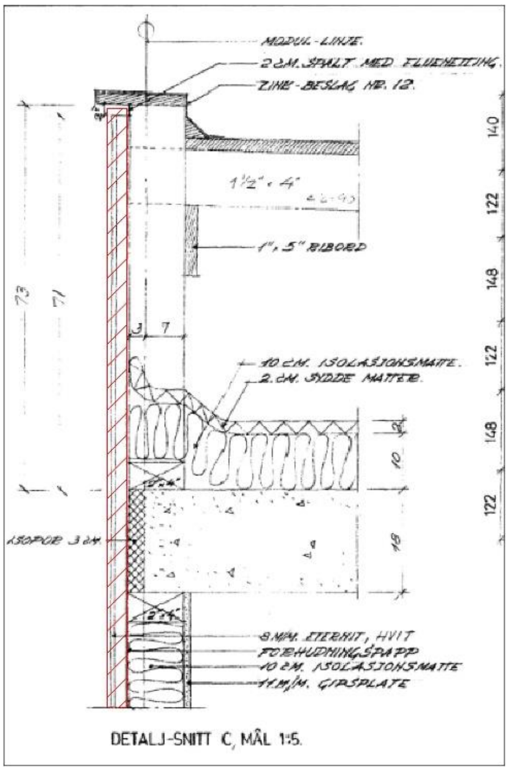


Figure 26.Detail roof/façade before the renovation. The red indicate the layers that must be removed

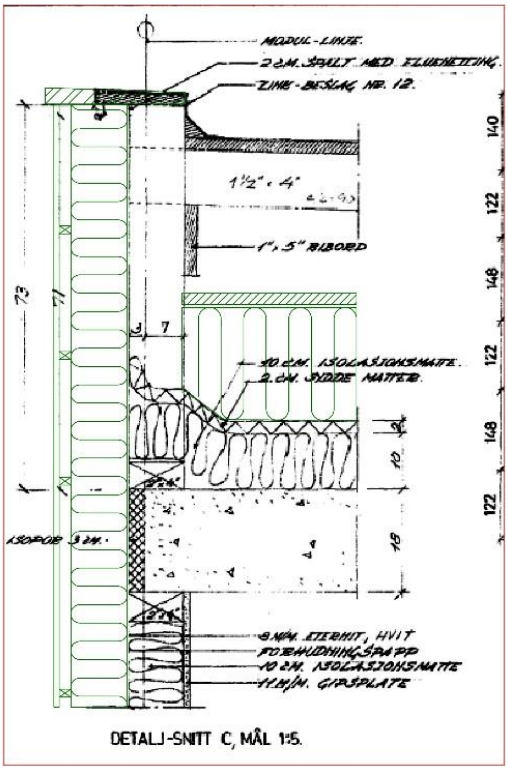


Figure 27. Detail roof/façade after the renovation. The green indicate the new layers/components.

BASEMENT CEILING AND STAIRS WALLS

Both the basement ceiling and the stairs walls represent components against unheated spaces. The proposed solution is to strip out the surface that face towards the unheated space and then insulation will be added on these surfaces. Summarizing insulation will be added at both ceiling of the basement and stair walls towards the stairs side. The finishing layer in these two situations will be added directly on the insulation, but different solutions need to be studied according to the different insulation that are chosen between the alternatives. The alternative insulation materials are explained in the chapter 4.2.

4.1.2 Windows

The existing windows are from the eighteens and need to be replaced. The proposed solution is to place the window in the middle of the wall to reduce the thermal bridges effect and to increase the air tightness. The following graphic shown that the optimal distance between the external wind barrier and the external part of the window is 80/90 mm [43].

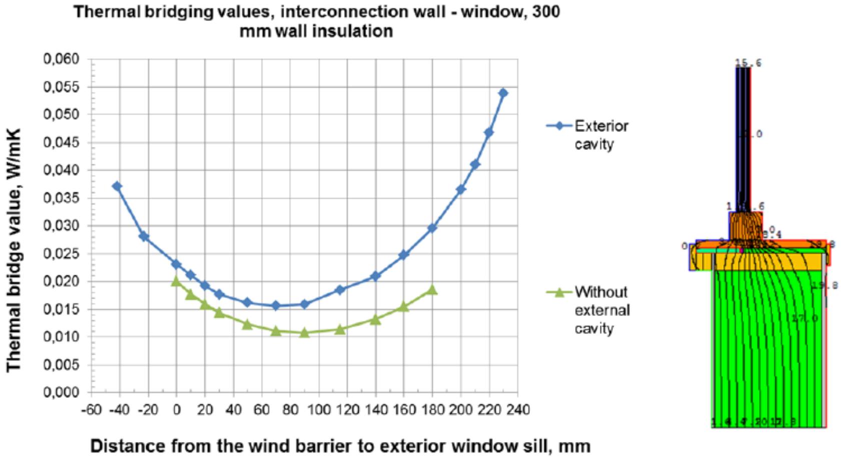


Figure 28. The graph shows calculated thermal bridge values, depending on the position of the window.

The windows used in the model for the energy demand calculation is and argon filled triple glazed window with U-Value of 0.8 W/m^{2}K, where the glazing thickness is 4 mm and the argon gap thickness is 8 mm. The triple-glazed window argon filled is nowadays the best practice used in the Zero Energy Buildings and Passive Houses.

4.1.3 Thermal Bridges

The thermal bridge are mostly break down using the external insulation for all the envelope (external walls and roof). The main thermal bridges that cannot be solved using only the external insulation are present between the concrete balconies and the concrete floor.

The solutions that can be used are the followings:

- Renovation of the balcony without thermal break [3];
- Reconstruction of the balcony using a thermal break.

For the first solution the renovation is done by applying insulation to the balconies. Indeed the renovation consist of applying to the top and bottom side the insulation. Appling thermal insulation the energy loss of the balcony could be cut by half, however the thermal loss are still elevated. The picture below shows this renovation technology.

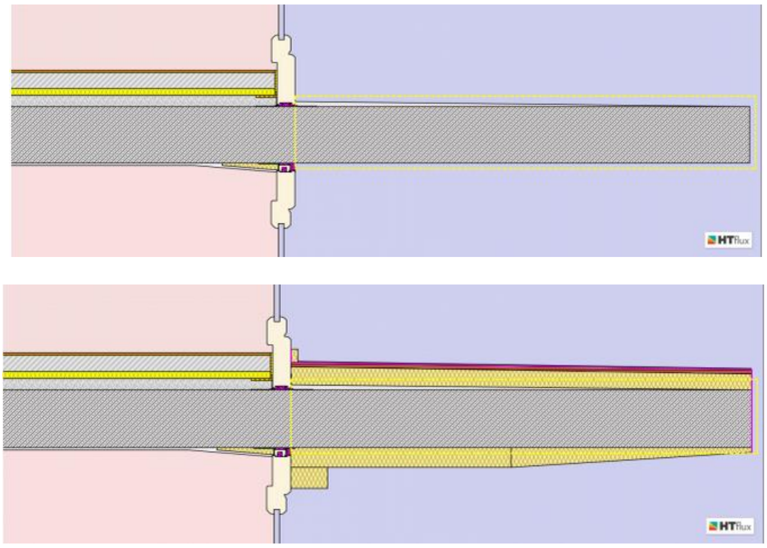


Figure 29. The balcony solution before and after the renovation without use a thermal break. Source [3].

The second presented solution use an element that is both an element that thermally detach the concrete floor from the balconies and a structural component. In the studied case the first step is represented cutting the concrete back, exposing the reinforcement of the floor. After that a steel angle is fixed on site, pouring concrete in the cut back area. The thermal break is obtained using a commercial [5] product that is fixed to the steel angle plate. After these steps a steel balcony can be used using the front plate as connection.

This solution allow to reduce the thermal bridge using not a continuous connection between the floor and the balconies, but using selected points that however have very low heat losses. The Figure 30 represents the technology that is intended to be used in this work.

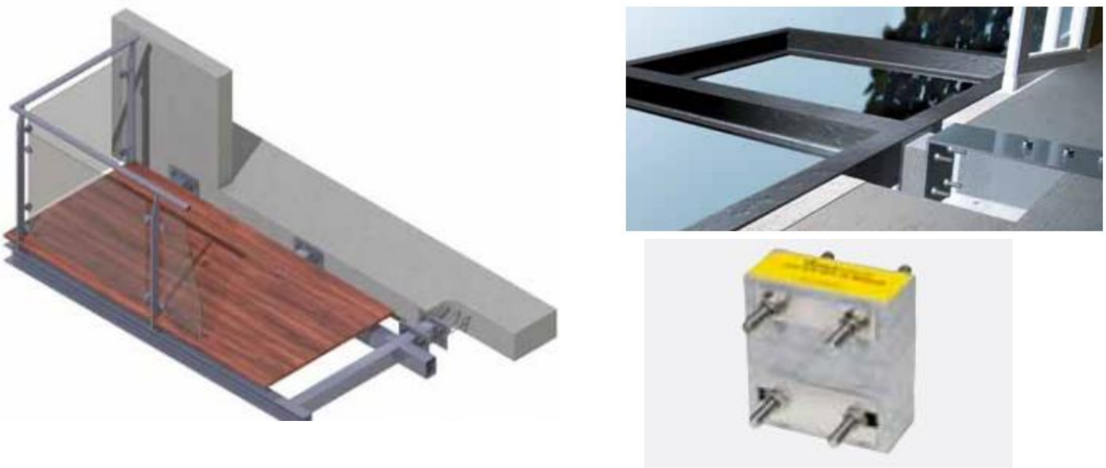


Figure 30. Thermal break technology between reinforced concrete inner slab and steel balconies. Source [5].

4.1.4 Ventilation system

For the ventilation system the proposed solution is to place the air handling unit (AHU) on the roof above each stair case. Each air-handling unit will serve six apartments and the apartments served by the same stair case are also served by the same AHU. The proposed air handling unit have a temperature efficiency of 85 %. For the vertical ducting should be used the existing *skylight well.*

The duct will have different function respect the room’s use that we consider. The bathroom and kitchen will be interested from air extraction, instead the other rooms (living room and bedroom) will be interested from air supply. The supplied and extracted air should be correctly balanced so that the extracted air is equal to the supplied air.

4.1.5 Domestic Hot water

The normalized energy demand for the DHW is according to NS3031 [23] and is equal to 30 kWh/m^{2}a. This value is used for the energy demand calculation, but for this work the DHW system was not studied deeply, but general solution ideas are presented in this chapter.

Solutions to reduce the normalized energy demand for Domestic Hot Water could be the use of solar collectors and grey water heat exchanger.

The solar collector is a device that collects heat by absorbing sunlight. Most of the time in Low energy building the solar collectors produce hot water that cover completely the energy demand for the DHW calculation.

The heat exchanger is a simple section made by copper drainpipe installed beneath a hot wastewater source. The section of drainpipe has small diameter and is wrapped tightly around it. The cold-water supply pipe leading into the water heater is diverted so that it flows through the small-diameter copper pipe.

The Figure 31 shows that when the hot water is being pulled from the hot water supply, the water that is going into the water heater is preheated by the wastewater going down the shower drain.

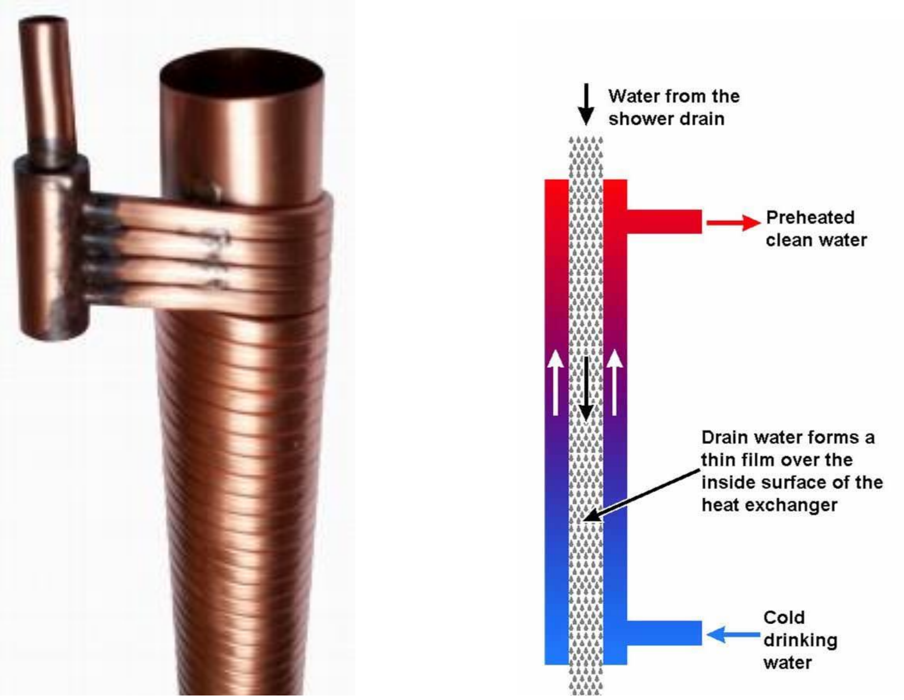


Figure 31. LEFT: Heat exchanger.The heat from the hot water going down the drain pipe is transferred to water passing through the smaller diameter pipes. RIGHT: Sketch that shows the operation of an heat exchanger

The use of grey water heat exchanger gives the possibility to do not lose the heat contained in the water coming from dishwasher, showers/bathtubs and washing machine.

The last proposal about how to serve energy in a low-energy building are not implemented in the following chapter that deal with the energy demand calculation of the building.

4.1.6 Heat Pump system

Heating and cooling of the conditioned spaces/floors are guaranteed for this work by an air source heat pump that is connected with the existing radiators. This heat pump use the outdoor air as heat source, so we can state that the efficiency of the heat pump depends from the outdoor temperature. The temperature variation throughout the year gives a variation of the heat-pump COP.

The COP used for the energy simulation it has been extracted from a commercial product [6], assuming a delivered temperature from the heat pump of 40°C and the monthly external temperature in Oslo. The Table 6 shows the data supplied from the producer, instead the Table 7 shows the used COP that have been extracted using a linear interpolation. The input data for the calculation used are two different COP values, one for the winter and one for the summer. For this work, only the months between May and September have been considered as summer as is stated in the Table 7. The used COPs (winter COP and summer COP) have been calculated using the COPs belonging to the season of interest.

The winter and summer COPs are extracted from the Table 7 respectively as an average between the months belonging to the corresponding season. The complete technical sheet used to extract the following data are shown in the Appendix I.

T_k	T_L	Q	P	COP
°C	°C	kW	kW	-
40	20	17.3	3.4	5.1
	15	15	3.4	4.5
	10	13.1	3.3	4
	7	11.8	3.3	3.6
	4	10.3	3.2	3.2
	2	9.4	3.2	2.9
	0	9.1	3.3	2.8
	-4	8.4	3.3	2.6
	-7	7.8	3.3	2.4
	-10	6.9	3.3	2.1
	-15	5.3	3.3	1.6

Table 6. Technical information AEROTOP T10 with temperature of water 40° and external temperature given by the producer. Source [6]

Month	Ext Temper.	COP	SEASON
-	°C	-	W
January	-3,7	2,615	W
February	-4,8	2,546667	W
March	-0,5	2,775	W
April	4,8	3,306667	W
May	11,7	4,17	S
June	16,5	4,68	S
July	17,5	4,75	S
August	16,9	4,92	S
September	11,5	4,15	S
October	6,4	3,52	W
November	0,5	2,825	W
December	-2,5	2,675	W

Table 7. COP of the air-source heat pump AREOTOP 10. The table shows the COP for the different months. The letter W means that the months was considered as winter and the letter S means that the correspondent month was considered as summer.

4.1.7 PV system

The way to organize PV-Panels will be shown in the chapter 6 and 7. The reason why no arrangement of PV array is shown in this chapter is because of the parametric way to conduct this study, so the number and consequently the arrangement of the PV panels will depend from the energy balance to reach the NZEB level.

In general, for this work the panel energy production is calculated using an optimal tilt for this latitude (40 degrees).

The module used is a commercial module from the manufacturer SunPower [37]. The panel present monocrystalline cell type with high nominal efficiency (20.3 %). The used module is 1.56 m high and 1.05 wide.

The total energy production of the PV system will be calculated using the same panel but arranged in three different ways. The three arrangement of the panel are shown in the Figure 32. At the end, the total production of the PV system will be calculated using the energy production of the single panel multiplied for the quantity of the panels that compose the PV system.

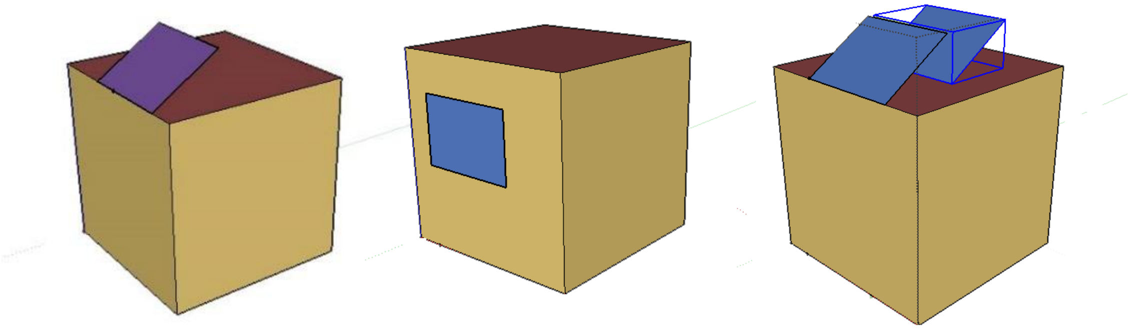


Figure 32. The different PV panel arrangements. LEFT: PV panel with the tilt of 40° not shaded. CENTER: PV panel vertically arranged not shaded. RIGHT: The considered panel is highlighted with the blue box, the PV panel is with the tilt of 40° and shaded from the panel in front of it (the distance between the two panels is 1.20 m)

The monthly and hourly production of a single panel has been calculated in the latitude and longitude of Skedsmokorset. The calculations for the energy production of the single panel has been done using 6 time steps per hour, but only monthly energy production has been extracted. The energy production of the single panel in the different arrangement and the energy production of the PV system is shown in the chapters 6.2, 6.3 and 7.2.

4.2 The alternatives proposed (insulations alternatives)

The alternative proposed are useful to show how different materials have different production stages, different features (e.g. thermal conductivity) and consequently different amounts of embodied energy even if the final results of U-Value of the component after the refurbishment will be the same. These considerations will be necessary to reach the 3rd level of the ZEB definition that is ZEB-OM as stated in the first chapter. This level takes in account the energy related to all operational energy (O) and the embodied energy from the materials (M) and the technical installations that shall be compensated with on-site renewable energy generation to reach the Nearly Zero Energy concept or the Zero Energy concept.

In this work will be evaluated only the embodied energy related with the insulation material, windows and the PV Panels that are the components that mainly increase the embodied energy during a building energy upgrading. Thus, it will not be evaluated the embodied energy from the technical installations.

The energy retrofit action proposed fulfil the requirement of the Norwegian Standard NS3700, criteria for passive house and low energy house. According to the NS 3700:2010 to achieve the Passive House standard the U-Values for exterior walls, roof, floor and windows are respectively equal or less than 0.15, 0.13, 0.15 and 0.8 Wm^2/K.

In this work to reduce the number of variables the components present the same U-Value for the different alternative proposed so that the difference between the different alternatives will be the thickness of the insulation changing the materials. Indeed changing the materials different thermal conductivity propriety are extracted and so it is essential to increase and decrease the thicknesses of the insulations depending on the thermal proprieties (thermal conductivity of the specific material).

The Table 8 shows a comparison between the U-Values of the existing building components, and the U-Value of the components after the refurbishment. The presented value above will be reached independently from the thermal conductivity of the material, trying to add different thickness depending on the thermal propriety of the material.

Construction	U-values before the renovation (calculated value)	U-values after the renovation
-	W/m^{2}K	W/m^{2}K
External walls main façade	0.4	0.10
External walls gable	0.45	0.10
Roof	0.35	0.08
Basement ceiling	0.58	0.08
Staircase walls	3.14	0.34
Windows and Balcony doors	2.8	0.8

Table 8. Proposed U-Value of the different components after the refurbishment.

The proposed solutions use VIP panels, mineral wool slabs, Oil based polymers insulations (XPS panels and PUR sandwich panels) and wood fibre insulation slabs. The thicknesses of the materials that belong to different solutions, have been chosen to match the desired thermal resistance as stated in the Table 8. The materials have been chosen among commercial products to follow a more realistic methodology.

MINERAL WOOL

Figure 33. Application of Mineral Wool at the external wall.

The solution called MINERAL WOOL presents mineral wool slabs on all the construction parts that need to be retrofit. This means that external walls, roof, staircase walls and basement ceiling are all renovated using Mineral Wool slabs in this first solution.

The mineral wool (stone wool and glass wool) is composed from man-made mineral fibres include vitreous fibres with content of sodium, potassium, calcium, magnesium and barium. For this work is used stone wool insulating materials that is manufactured in the form of slabs of mats. The stone wool in mats or slabs can be used for walls, ceilings and roofs and the thermal conductivity can depend from the thickness of the panel that is take in account [44]. The mineral wool insulation panels have different density from 20 kgm^{-3} to 180 Kgm^{-3}, and above and the thermal conductivity of the stone wool can be between 0.032 $Wm^{-1}K^{-1}$ and 0.048 $Wm^{-1}K^{-1}$ [38].

For this study the Rockwool technology is used, which consist in boards of Rockwool boards of 91 kgm^{-3} with thermal conductivity included between 0.034 $Wm^{-1}K^{-1}$ and 0.038 $Wm^{-1}K^{-1}$. Indeed, for thickness smaller than 140 mm the mineral wool slabs present a thermal conductivity of 0.038 $Wm^{-1}K^{-1}$, instead the procured thermal conductivity for thickness greater than 120 mm is 0.034 $Wm^{-1}K^{-1}$.

The refurbishment using the Mineral wool as new insulation need different thickness of insulation to meet the requirement explained in the Table 8. For both the gable walls and the main façade walls are necessary 0.26 m of mineral wool insulation to achieve respectively a U-Value of 0.10 $Wm^{-1}K^{-1}$ and 0.098 $Wm^{-1}K^{-1}$ (that approach 0.10 $Wm^{-1}K^{-1}$). For the refurbishment of the roof and the basement ceiling are necessary respectively thickness of 0.32 m and 0.36 m of Mineral wool insulation to achieve a U-Value of 0.083 $Wm^{-1}K^{-1}$, this value approach the value of 0.8 $Wm^{-1}K^{-1}$. Finally for the internal stair walls that are important to reduce the heat losses from the heated zone to the unheated staircases a thickness of 0.1 m of Mineral wool insulation is necessary to achieve a U-Value of 0.34 $Wm^{-1}K^{-1}$. The tables below summarize the concept of the refurbishment in this first scenario.

EXTERNAL WALL (East-West side)

MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
GYPSUM	0,013	0,17	0,098
Mineral wool	0,1	0,042	
ROCKWOOL	0,12	0,035	
ROCKWOOL	0,14	0,035	
Air	0,028	-	
External timber layer	0,02	0,17	

EXTERNAL WALL (North-South side)

MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,1	1	0,10
Mineral wool	0,08	0,042	
Concrete	0,06	1	
ROCKWOOL	0,12	0,035	
ROCKWOOL	0,14	0,035	
Plaster	0,025	0,71	

ROOF

MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,2	1	0,083
Mineral wool	0,1	0,042	
ROCKWOOL	0,14	0,035	
ROCKWOOL	0,18	0,035	
Air	0,02		
Concrete Tile	0,03	0,9	

BASEMENT FLOOR

MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,05	0,037	0,084
Mineral wool	0,15	1	
ROCKWOOL	0,18	0,035	
ROCKWOOL	0,18	0,035	

STAIRCASE WALLS (internal)

MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,15	1	0,34
ROCKWOOL	0,1	0,038	

Table 9. The thicknesses of the different components using the alternative MINERAL WOOL (where tha components are: external walls, roof, basement ceiling and staircase walls)

WOOD FIBRE INSULATION

The solution called WOOD INSULATION presents wood fibre insulation batts applied on all the construction parts that need to be retrofitted. This means that external walls, roof, staircase walls and basement ceiling are all renovated using wood fibre insulation batts.

Figure 34. Wood fibre insulation batt

The wood fibre insulation batts can be produced following two different process, dry process and wet process. The raw material for the production of insulation boards are wood chips that in the dry process need small amount of synthetic resin in order to make the mixture homogeneous. Instead, in the wet process the wood chips are exposed to water vapour and soaked at a pressure level of 3 to 8 bar. In this work, the material chosen is produced with a wet process. Any addition of adhesives to promote the bonding is therefore not necessary in the wet process.

The wood fibre insulation batts can be used for both new construction and retrofit. The chosen technology for this study is manufactured from GUTEX. According to the producer this insulation batts are suitable for walls, ceilings and roofs. The thermal conductivity is included between 0.037 $Wm^{-1}K^{-1}$ and 0.05 $Wm^{-1}K^{-1}$. Moreover, these batts have different density that is included between 80 kgm^{-3} and 250 kgm^{-3} [39].

For this study the product called “thermosafe” has been chosen with a thermal conductivity of 0.037 $Wm^{-1}K^{-1}$ and a density of 173 kgm^{-3}. In this case the thermal conductivity is the same for all the thickness that are available [45].

The refurbishment using the wood fibre batts as new insulation need different thickness of insulation to meet the requirement explained in the table Table 8. For the external walls that face towards the East and West side 0.26 m of wood fibre insulation are necessary to achieve a U – Value of 0.10 $Wm^{-2}K^{-1}$. For the gable walls (North-South sides) 0.28 m of wood insulation fibre are necessary to achieve a U-Value of 0.10 $Wm^{-2}K^{-1}$. For the refurbishment of the roof and the basement ceiling 0.34 m of insulation are necessary respectively to achieve a U-Value of 0.082 $Wm^{-1}K^{-1}$ (that approach 0.10 $Wm^{-1}K^{-1}$) and 0.24 m to achieve a U-Value of 0.080 $Wm^{-1}K^{-1}$. At the end for the internal staircase walls a thickness of 0.1 m of wood fibre insulation is necessary to achieve a U-Value of 0.33 $Wm^{-1}K^{-1}$ (that approach the U-Value of 0.34$Wm^{-1}K^{-1}$).

The tables below show what has been said so far about the refurbishment using the wood fibre insulation.

EXTERNAL WALL (East-West side)

MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
GYPSUM	0,013	0,17	0,10
Mineral wool	0,1	0,042	
WOOD FIBRE INSULATION	0,1	0,037	
WOOD FIBRE INSULATION	0,10	0,037	
WOOD FIBRE INSULATION	0,06	0,037	
Air	0,028	-	
External timber layer	0,02	0,17	

EXTERNAL WALL (North-South side)

MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,1	1	0,10
Mineral wool	0,08	0,042	
Concrete	0,06	1	
WOOD FIBRE INSULATION	0,10	0,037	
WOOD FIBRE INSULATION	0,10	0,037	
WOOD FIBRE INSULATION	0,08	0,037	
Plaster	0,025	0,71	

ROOF			
MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,2	1	0,08
Mineral wool	0,1	0,042	
WOOD FIBRE INSULATION	0,12	0,037	
WOOD FIBRE INSULATION	0,12	0,037	
WOOD FIBRE INSULATION	0,10	0,037	
Air	0,02		
Concrete Tile	0,03	0,9	

BASMENT CEILING			
MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,05	0,037	0,08
Mineral wool	0,15	1	
WOOD FIBRE INSULATION	0,12	0,037	
WOOD FIBRE INSULATION	0,12	0,037	
WOOD FIBRE INSULATION	0,12	0,037	
WOOD FIBRE INSULATION	0,12	0,037	

STAIRCASE WALLS (internal)			
MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,15	1	0,33
WOOD FIBRE INSULATION	0,1	0,037	

Table 10. The thicknesses of the different components using the alternative WOOD FIBRE (where the components are: external walls, roof basement ceiling and staircase walls)

VACUUM INSULATION PANELS

The solution called VIP present Vacuum insulation panels applied on the construction parts that need to be retrofitted. This means that external walls, roof, staircase walls and basement ceiling are all renovated using VIP in this alternative.

As it has been shown in the previous chapters the use of conventional material, need thick insulation in the construction to achieve low U-Values that meet the requirements of Zero Energy Building level. Vacuum insulation panels (VIP) is a new insulation with five time higher resistance than traditional insulation material. Using these type of panels the aesthetic of the building could be preserved, instead using traditional material as mineral wool the result will be a greater component thickness. A VIP panel is composed from an airtight envelope containing an open-micro-pore core in which a low-pressure gas is trapped. The low-pressure gas is used because it is able to decrease the thermal conductivity, so a perfect Vacuum panel should reach an infinite thermal resistance (Figure 35). The material used as core material changed during the years, in the 1990s a precipitated silica was used, but the current technology use Fumed silica that is used because of its thermal conductivity.

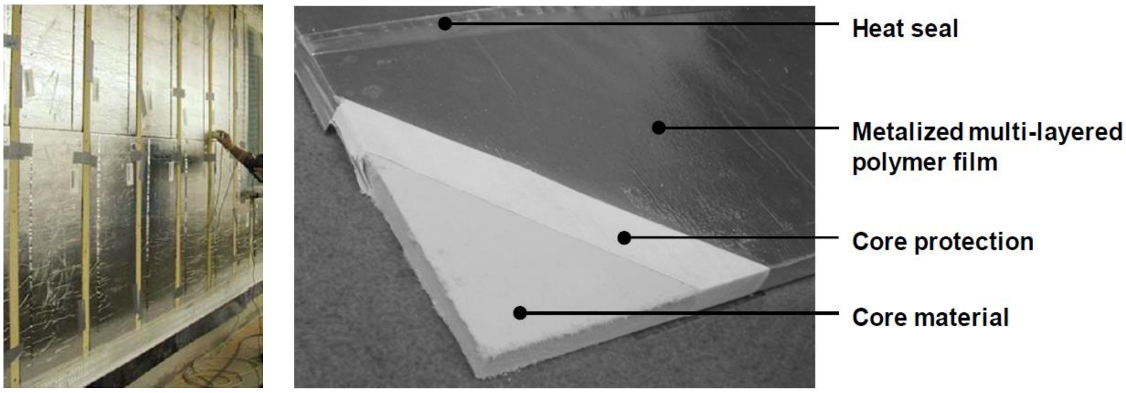


Figure 35. Two pictures of commercial VIP Panels. On the left side the application of the VIPs on an office building. On the right, the different layers that commonly compose the VIPs.

A detailed drawing of where each VIP should be installed in the façade or in the floor is needed because the panels cannot be adjusted on the construction site because they cannot be cut. Important is also to remind speaking about Vacuum insulation panel that a way to avoid risk on the construction site is to integrate the VIPs in prefabricated constructions.

The VIPs needs to be not damage with scratches and holes and has to be handle with care during the construction process otherwise the heat flow through the construction will increase drastically. Moreover, the multilayer film (usually aluminium foils) around the VIP is vapour tight, and even if the vapour permeability of the panel is virtually zero, if the connection between them is insufficiently sealed, it allows transport of air and layer trough the layer. Speaking about the lifetime of the VIPs, accelerated ageing experiments have shown that VIP in roof construction could be expected to have a service life of at least 25 years.

Vacuum insulation panels could be used in both new buildings and old buildings, and both in light-weight timber frame structures and heavy concrete structures. The chosen technology for this study is manufactured from Porextherm [46]. According to the producer, these insulation panels are suitable for walls, ceilings and roofs. The measured thermal conductivity is 0.0044 $Wm^{-1}K^{-1}$ but the thermal conductivity that must be used for the calculation in the buildings application is set to 0.007 $Wm^{-1}K^{-1}$. The density of the panels is between 170 kgm^{-3} and 210 kgm^{-3} [41].

The refurbishment using Vacuum insulation panels as new insulation needs different thickness of insulation to meet the requirement explained in the table Table 8. For the external walls that faces towards the East and West side are necessary 0.05 m of VIP to achieve a U – Value of 0.10 $Wm^{-2}K^{-1}$, where that thickness is reached using a combination of two panels, one with a thickness of 0.02 m and the other one with a thickness of 0.03m. For the gable walls (North-South sides) are necessary 0.055 m of Vacuum insulation panels to achieve a U-Value of 0.098 $Wm^{-2}K^{-1}$ (that approach the U-Value of 0.10 $Wm^{-1}K^{-1}$). For the refurbishment of the roof and the basement ceiling are necessary respectively 0.065 m (combining two 0.02 m thick panels and one 0.025 m thick panel) to achieve a U-Value of 0.082 $Wm^{-1}K^{-1}$ (that approach 0.08 $Wm^{-1}K^{-1}$) and 0.075 m (using three panels of 0.025m) to achieve a U-Value of 0.807 $Wm^{-1}K^{-11}$ (that approach 0.08 $Wm^{-1}K^{-1}$). At the end for the internal staircase walls a thickness of 0.02 m of VIP is necessary to achieve a U-Value of 0.32 $Wm^{-1}K^{-1}$ (that approach the U-Value of 0.34 $Wm^{-1}K^{-1}$).

The tables below show what has been said so far about the refurbishment using the Vacuum Insulation Panels.

EXTERNAL WALL (East-West side)			
MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
GYPSUM	0,013	0,17	0,10
Mineral wool	0,1	0,042	
VACUUM	0,02	0,007	
VACUUM	0,03	0,007	
Air	0,028		
External timber layer	0,02	0,17	

EXTERNAL WALL (North-South)			
MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,1	1	0,098
Mineral wool	0,08	0,042	
Concrete	0,06	1	
VACUUM	0,03	0,007	
VACUUM	0,025	0,007	
Air	0,028		
External timber layer	0,02	0,17	

ROOF			
MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,2	1	0,08
Mineral wool	0,1	0,039	
VACUUM	0,02	0,007	
VACUUM	0,02	0,007	
VACUUM	0,025	0,007	
Concrete floor screed	0,03	0,9	

BASMENT FLOOR			
MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
EPS	0,05	0,037	0,08
Concrete	0,15	1	
VACUUM	0,025	0,007	
VACUUM	0,025	0,007	
VACUUM	0,025	0,007	

STAIR WALLS			
MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,15	1	0,31
VACUUM	0,02	0,007	

Figure 36. The thicknesses of the different components using the alternative VIP (where the components are: external walls, roof, basement ceiling and staircase walls)

PUR SANDWICH PANELS AND XPS BOARDS

The four and last solution is called PUR+XPS. In this solution it was chosen to use two different technologies of insulation for different components that are in need of upgrading. Indeed, the refurbishment for this alternative will contemplate the use of Polyurethane (PUR) sandwich panels to retrofit all the external walls and the use of Extruded Polystyrene (XPS) insulations to retrofit roof, basement ceiling and stair walls. Both XPS and PUR belong to the same family of insulations that is called Oil-based polymers. The reason why it has been chosen to use different materials in different components of the building is because of the current best practice for the refurbishment design. Indeed, the sandwich panels are commonly used to retrofit the external walls and this solution is one of the best in terms of time managing. The prefabricated element will be place directly on the existing external walls after that the external layers are stripped off from the existing walls. To retrofit the other components XPS insulation has been chosen.

Regarding the PUR panels, the core of these panels is Polyurethane that is a closed-cell plastic, and is formed by reacting two monomers in the presence of blowing agent catalyst (polymerisation). The PUR panels have the advantage to have small U-Values in modest material thickness. The Polyurethane is usually made in factory in boards and in combination with various rigid facings as a constructional material or sandwich panels. This material could be also used as in-situ foams that are manufactured directly on the building site. In this work the PUR will be consider as part of sandwich panels that presents a rigid polyurethane foam core with profiled and facings. Differently from the other solutions presented until now, in this solution the insulation panel is with the finishing integrated with the panel, thus in this case it is unnecessary to add the timber layer as protective layer as set in the chapter 3. Furthermore in this case the wind barrier cannot be placed on the external side of the insulation because of the fact that the component is completely made in factory. So the wind barrier should be placed between the existing structure and the new sandwich panels.

Figure 37. PUR insulation panels with metal finishing.

The chosen commercial sandwich panel is composed with a Polyurethane insulation core, coatings made from polyester and the external layers that is made in hot-dip galvanized (HDG) steel plates. These steel plates are usually 0.5mm thick. The thickness of the chosen panel is 160 mm and according to the manufacturer documentations the R-Value of these panels is 8.333 m^2kW^{-1}.

The material chosen to retrofit the roof, the basement ceiling and the stair walls is the Extruded polystyrene foam (XPS). The XPS is a thermoplastic insulation foam available in board shape with a density range between 20 and 50 kgm^{-3}. To meet the need of various applications the boards are produced with different surfaces and with different edge treatments. These edge treatments are useful to connect two neighbouring boards and the types of edges are butt edge, shiplap and tongue and groove. The variety of performance proprieties of XPS thermal insulation make them suitable for use in a large number of applications such as: perimeter insulation, inverted insulation for terrace roofs, insulation of pitched roofs, floor insulations, insulation of cavity walls and building sandwich panels. The XPS boards have different features that can be remarkable in the building use, such as the high thermal insulation performance, the high compressive strength that is advisable for the roofs and the moisture resistance. The Extruded polystyrene foam boards have different density from 20 kgm^{-3} to 50 Kgm^{-3}. Regarding the thermal conductivity of the XPS can be between 0.03 $Wm^{-1}K^{-1}$ and 0.041 $Wm^{-1}K^{-1}$.

For this study the Knauf technology is used, which consist in boards of density of 33.7 kgm^{-3} with thermal conductivity of 0.028 $Wm^{-1}K^{-1}$ [47].

The refurbishment using the XPS boards as new insulation need different thickness of insulation to meet the requirement explained in the table Table 8. For the refurbishment of the roof and the basement ceiling are necessary respectively thickness of 0.25 m to achieve a U-Value of 0.084 $Wm^{-1}K^{-1}$ and 0.3 m of XPS insulation to achieve a U-Value of 0.083 $Wm^{-1}K^{-1}$, these two values approach the value of 0.8 $Wm^{-1}K^{-1}$. Finally, for the internal stair walls a thickness of 0.075 m of XPS boards is necessary to achieve a U-Value of 0.334 $Wm^{-1}K^{-1}$ (that approach the value of 0.34 $Wm^{-1}K^{-1}$). The tables below summarize the concept of the refurbishment in this 4th scenario.

EXTERNAL WALL (East-West side)

MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
GYPSUM	0,013	0,17	0,09
Mineral wool	0,1	0,042	
S-P SP2E-PU	0,16		

EXTERNAL WALL (North-South)

MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,1	1	0,09
Mineral wool	0,08	0,042	
Concrete	0,06	1	
S-P SP2E-PU	0,16		

COMPACT ROOF

MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,2	1	0,08
Mineral wool	0,1	0,039	
XPS Panel	0,075	0,028	
XPS Panel	0,075	0,028	
XPS Panel	0,1	0,028	
Air	0,02		
Concrete Tile	0,03	0,9	

BASMENT CEILING

MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
EPS	0,05	0,037	0,081
Concrete	0,15	1	
XPS Panel	0,1	0,028	
XPS Panel	0,1	0,028	
XPS Panel	0,1	0,028	

STAIR WALLS

MATERIAL	THICKNESS	CONDUCTIVITY	U-VALUE
	m	$Wm^{-1}K^{-1}$	$Wm^{-2}K^{-1}$
Concrete	0,15	1	0,33
XPS Panel	0,075	0,028	

Table 11. The thickness of the different components using the alternative PUR+XPS (where the components are: external walls, roof, basement ceiling and staircase walls).

5 RESULTS INTRODUCTION

Results of the calculations of the yearly energy demand of Myhrerenga Housing Cooperative are presented in the chapter 6 and 7.

The results presented in the 7th chapter shows the energy demand of the building after the refurbishment using only one insulation type. In the 7th chapter the primary energy use of the building before and after the renovation will be shown. In the final part of the first result chapter, the amount of PV panels to achieve the nearly Zero Energy level will be shown.

The 8th chapter will show the results from the comparison among different insulation materials. The meter to compare the different alternative presented in the eighth chapter is the embodied energy. The use of the different alternatives follows the indications explained in chapter 4 and the comparison will be done under the consideration that the energy demand of the building is the same for the different alternatives. The last part of the 8th chapter will show the number of PV panels necessary to compensate the embodied energy to produce the materials in the different alternatives proposed. Therefore, the energy produced from the PV panels will be the same of the embodied energy of the different alternatives.

6 ENERGY RESULTS

In this chapter, the Primary energy use of the building after the refurbishment is presented. The analysis was done using the component as set in the alternative called Mineral Wool in the chapter 4.2. The results will be presented in kWh normalized to 1 year (kWh y^{-1}) and in kWh normalized to 1 m^2 of heated building area per year (kWh $m^{-2}y^{-1}$).

The first set of data will show the results of the energy demand of the building and it will show a comparison between the energy demand of the building before and after the refurbishment.

The second set of data will show the energy production of PV panels placed in Skedsmokorset. The PV panels energy production will be investigated using three different way to arrange the panels. It will be show the energy production of one panel arranged in three different way: with the tilt of 40° and not shaded, with the tilt of 40° and partially shaded from another panel with the same inclination and with 1,2 m of gap between the two panels and the last one arranged vertically. The panel will not be used together but an arrangement criteria is used and will be shown in the following pages.

6.1 Results: Energy demand of the building

The Table 12 shows the energy demand of the building before and after the refurbishment, where the refurbished solution use the alternative called Mineral Wool to the retrofit of the envelope. The systems in the refurbished solution are set as declared in the chapters 3.5 and 4.1.

Energy demand	**Before renovation (measured)**	**After the renovation (simulated)**
	kWh m^{-2} y^{-1}	kWh m^{-2} y^{-1}
Space Heating	195 - 220	28,5
DHW	30	30
Fans	10	6,66
Electricity use (lighting and appliances)	40	40
Space cooling	0	6,84
total	300	112

Table 12. Comparison between the Net energy demand before and after the renovation.

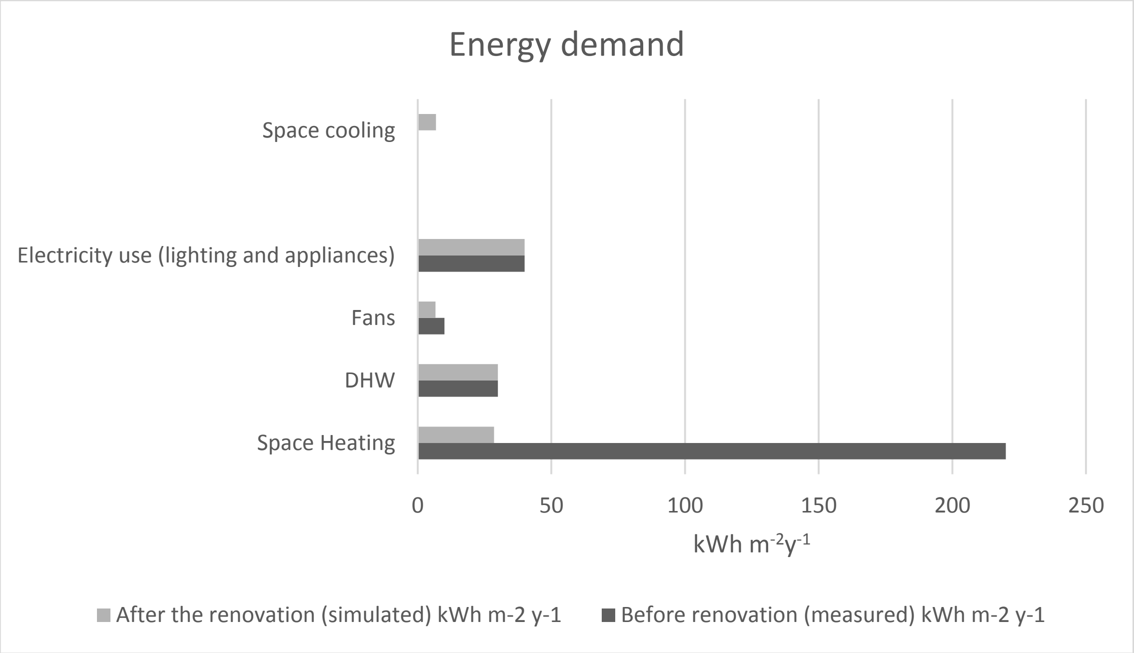


Figure 38. Comparison between the yearly energy demand of the building before and after the refurbishment. The values are normalized to 1 m^2 *of heated area*

As seen from the Table 12 the energy demand before and after the renovation is respectively 300 kWh m^{-2}y^{-1} and 112 kWh m^{-2}y^{-1}. The energy demand reduction after the refurbishment is equal to 62,7 %. It is important to highlight why this difference was achieved. It is possible to see form the Figure 38 that the significant energy demand difference between the old building and the retrofitted building is the energy used for space heating. Indeed, the energy demand for space heating in the refurbished building is 87 % lower than the old building. Moreover, the new solution presents a surplus of energy demand due to the spaces cooling. Despite, after the refurbishment we have an energy demand due to the use of the heat pump and the fans also during the summer, it is important to maintain a comfort condition inside the habited spaces. Thus, the new solution has not only less energy demand, but also guarantee a better indoor comfort for the habitants.

The Figure 39 shows how in the refurbished building the indoor temperature is between 19 °C and 21 °C despite the outdoor temperature oscillate between -5 °C and 18 °C respectively in the months of February and July.

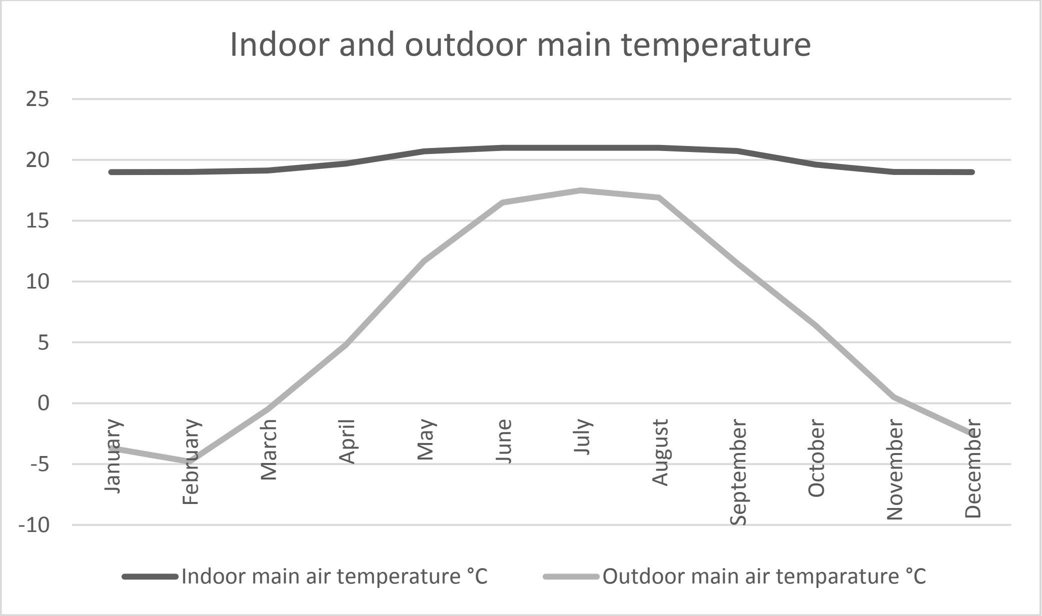


Figure 39. Main indoor and outdoor temperature. The indoor temperature is related to the building after the refurbishment.

The nZEB definition that has been considered in this work include the primary energy use for heating, cooling, domestic hot water, lighting and fans as defined in the chapter 1.5. For the primary energy use for heating, cooling, fan and lighting the data extracted from the Energy simulation result will be shown, instead for the domestic hot water the normalized energy demand is according to NS3031 and is equal to 30 kWh/m^{2}a.

The data presented in the Figure 39 are normalized to 1m^2 of heated building area and 1 year (kWh m^{-2}y^{-1}). The primary energy use for heating is 28,54 kWhm^{-2}y^{-1}, for cooling is 6,84 kWhm^{-2}y^{-1}, for lighting is 11,39 kWhm^{-2}y^{-1}, to supply the fan is 6,66 kWhm^{-2}y^{-1} and finally the primary energy necessary to produce DHW is equal to 30 kWhm^{-2}y^{-1} as stated above. The Figure 40 shows the percentage of the energy use for the different goals. The primary energy use percentage for heating, cooling, fan, lighting and DHW is respectively equal to 36 %, 9%, 8%, 9% and 38%.

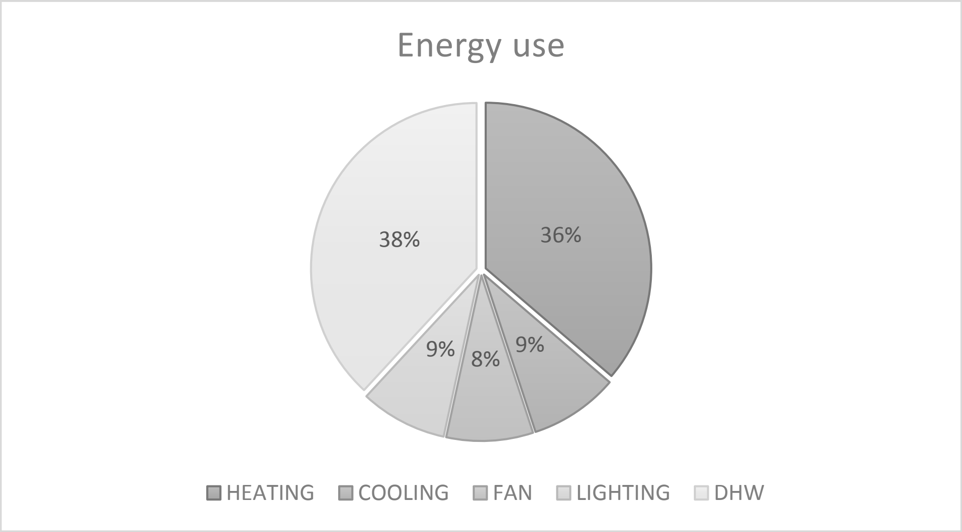


Figure 40. Percentage of Primary energy use of the building after the Refurbishment

The Figure 40 shows that the main part of the energy use is due to the production of the Domestic Hot Water. Indeed, the production of Domestic Hot Water today represents the main issue in Norway if the aim is to build a Zero Energy Building, and this is due to the big values required from the local standards.

The Figure 41 shows the monthly energy demand of the refurbished building divided for different energy uses. During the cold months as January, February, March, November and December the heat pump uses most of the energy for heating. Moreover important it is also to notice that the fans has bigger consumption when the energy demand for cooling or heating is bigger. This means that the fans need more energy in January, December and July. The highest monthly total energy demand calculated is 12,8 kWhm^{-2}y^{-1} and was obtained in January and the lowest monthly total energy use is equal to 4,1 kWhm^{-2}y^{-1} and was obtained in the months of April and September. The low energy demand in these months is due to the local temperature that allow a smaller use of both the heat pump and the fans. The difference between the months of April and September is that in April the heat pump is used for heating and in September for cooling. These concepts are better shown in the Figure 41 where the energy demand use is shown separately for heating, cooling, fans, lighting and domestic hot water. The percentage difference between the month with the lowest monthly energy use and the highest monthly energy use is equal to 68 %. The Table 24 in the Appendix III shows the values used to carry out the graphs that have been shown above.

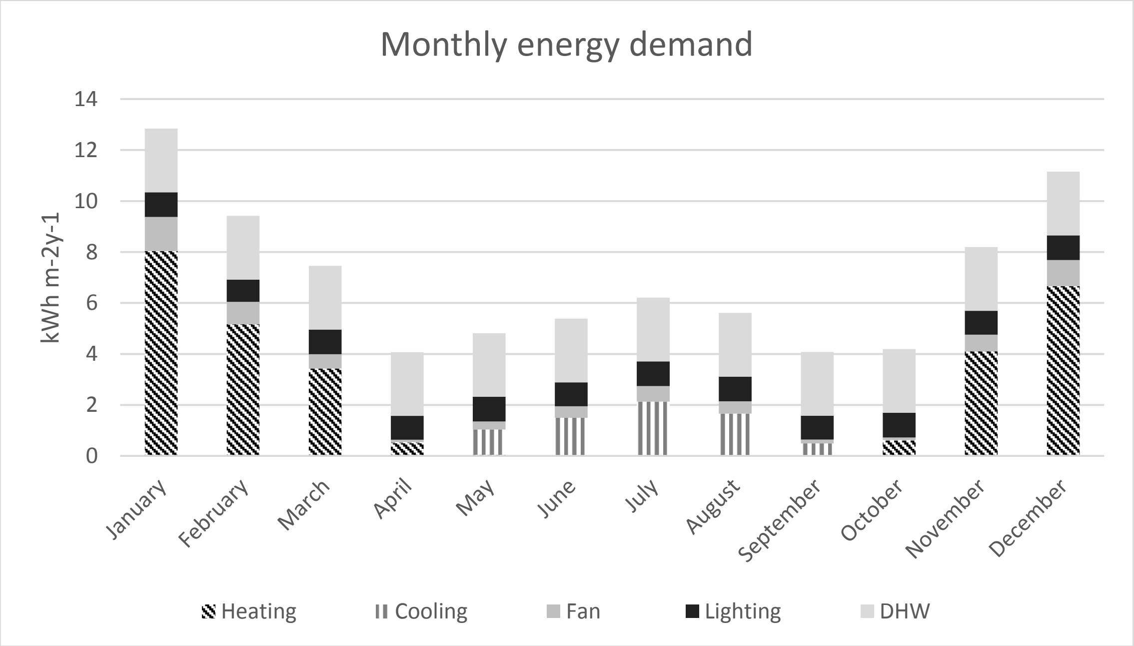
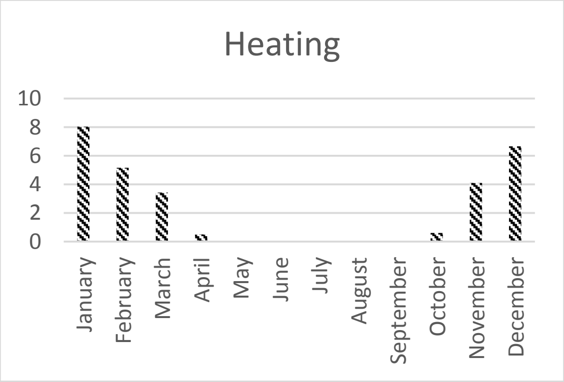
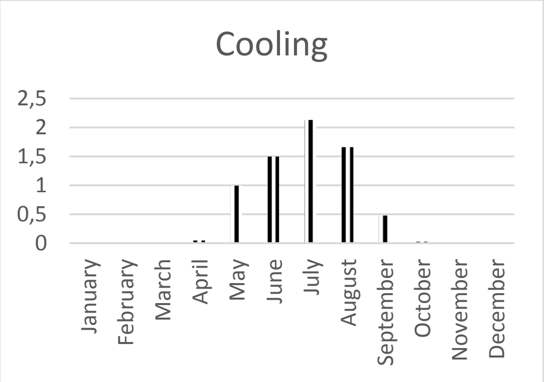


Figure 41. Monthly energy demand for Heating, Cooling, Fans, Lighting and Domestic Hot Water (DHW). The results are in kWhm^{-2}y^{-1}and shows the amount of primary energy for the different uses.

The Figure 41 shows the monthly energy demand detaching the different use of the energy. It is obvious that the heat pumps will not work for heating during the summer and vice-versa during the winter. The fans energy demand is lower when less energy is required for cooling or heating as stated above. Regarding the enegy demand for lighting the values put in input in the sortware are the values extracted from the norwegian standard NS3031:2014 that set the lighting energy demand indipendently from the exact necessity, the visible difference in the graphic are present only becouse the months have different number of days, indeed in february (28 days) the energy demand for lighting is the lowest and in the months with 31 days the energy demand is the biggest. For the energy demand to produce domestic hot water (DHW) the values are presented as defined from the standard NS3031.





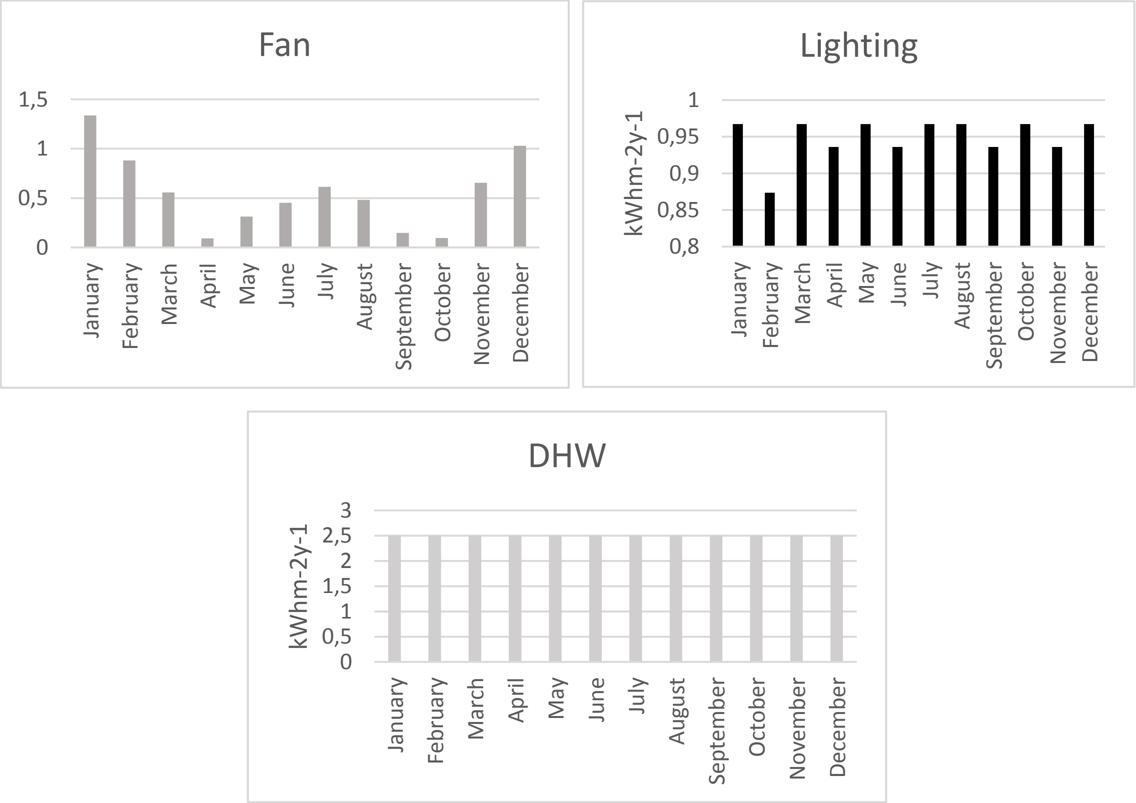


Figure 42. Energy use for different goals: heating, cooling, fans, lighting and DHW. The bars show the monthly energy uses expressed in kWhm^{-2}y^{-1}. All the value are normalized to 1 m^{2}of heated building area for 1 year.

The value of the monthly energy demand for different use are presented in the Table 24 in the Appendix III.

6.2 PV production in the different alternatives

In this section, the energy production of a single panel in three different arrangement will be shown. These three alternatives present the same orientation of the panel (south), but different tilt and shading condition. The panel that was chosen is a commercial PV panel [37] as stated in the chapters 3.5.2 and 4.1.7. The set of results will be expressed in kWhm^{-2} and will show the production of 1 panel in the different proposed arrangement. The results will show monthly and yearly production of the panel placed as explained in the following lines:

- A not shaded panel with tilt of 40° facing toward south.

- A shaded panel with tilt of 40° facing toward south. The shading comes from a panel which is with the same tilt and distant 1,20 m. The gap of 1,20 m is measured seen the panel in projection from the top (Figure 43)
- A panel with tilt of 90° (vertical) without any shading.

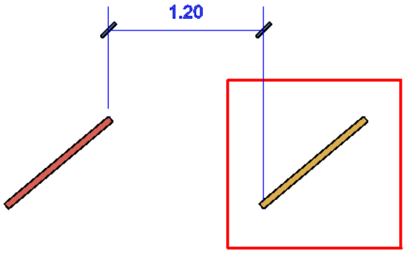


Figure 43. PV panel with tilt of 40° and gap of 1,20 m between the panels. The PV highlighted with the red rectangle is the shaded panel.

The first two panels are supposed to be placed in combination both on the roof and ground-mounted as parking-spot roofing. The third alternative proposed contemplates the panel placed on the gable wall that faces toward south.

The Figure 44 shows the monthly energy production of the first arrangement of the panel, that is not shaded and with a tilt of 40°.

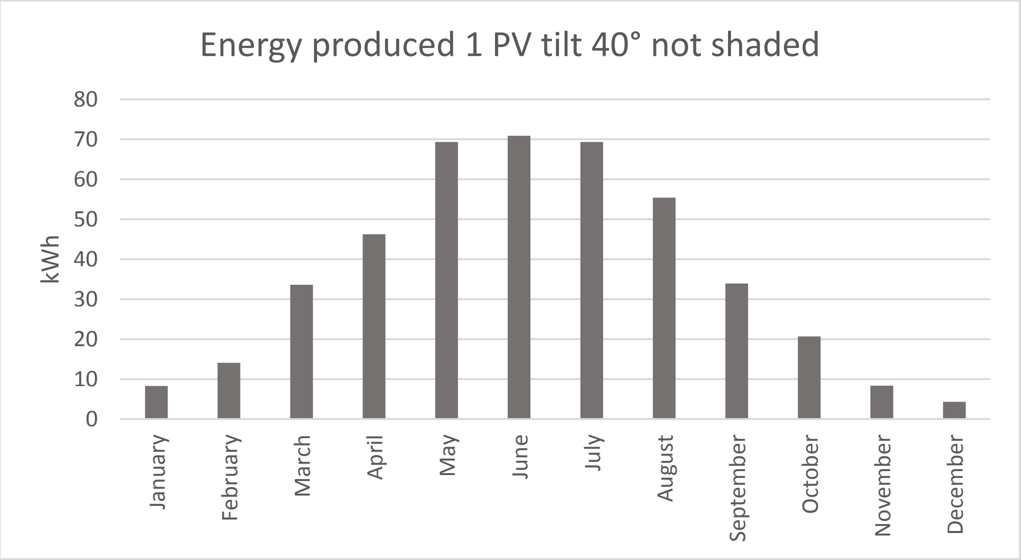


Figure 44. Monthly energy production of one panel facing toward south with tilt of 40° and not shaded. The results are presented in kWh and normalized for 1 year.

As expected, the Figure 44 shows that the energy production of the panel arranged as stated above is bigger in the summer than in the winter. The highest energy production is equal to 69,32 kWh and is obtained in July, instead the lowest energy production is equal to 4,32 kWh and is obtained in December. This big difference can be reasonably expressed from the difference of sunny hours from the winter to the summer. Indeed from hourly energy production of the panel it was extracted that the energy production of the panel during December last only 5 hours (between 10 am and 15 pm), instead during July last 17 hours (between 4 am and 21 pm). The yearly energy production of the panel in this arrangement is 434,48 kWh y^{-1} and the yearly energy production normalized to 1 m^2 of heated building area is equal to 0,27 kWh y^{-1} m^{-2}.

The Figure 45 shows the energy production of the second arrangement of the panel. This panel is with tilt of 40° and shaded from a panel that is placed in front of the panel that is analysed in this part.

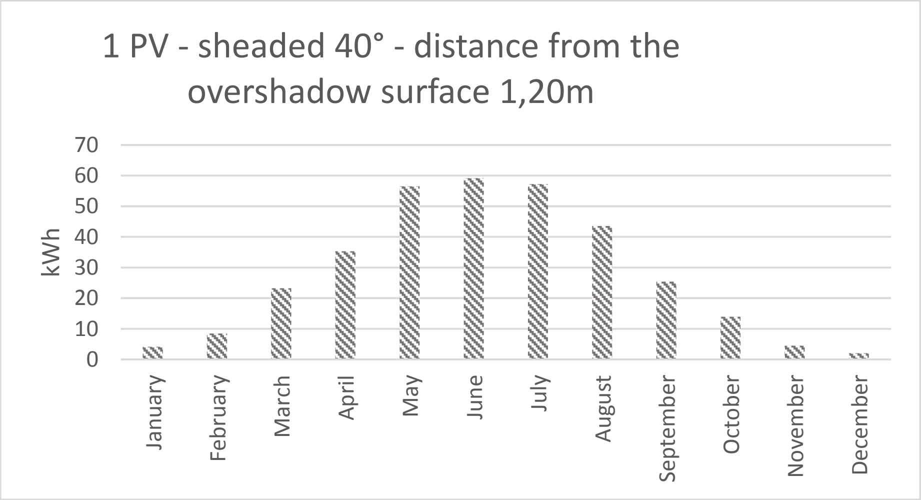


Figure 45. Monthly energy production of one panel facing toward south with tilt of 40° and shaded from another panel distant 1,20m. The results are presented in kWh and normalized for 1 year.

The Figure 45 shows that the energy production of the panel arranged as stated above is bigger during the summer than during the winter. In this case the highest production is equal to 59,15 kWh and is obtained in July, instead the lowest energy production is equal to 2,01 kWh. The yearly production of the panel in this arrangement is 333,54 kWh y^{-1} and the yearly production normalized to 1 m^2 of heated building area is equal to 0,18 kWh y^{-1} m^{-2}. The yearly energy production of the panel not shaded is 52% higher than the yearly energy production of the panel shaded with the same tilt (40°).

The Figure 46 shows the monthly production of the third arrangement of the panel. This panel is not shaded and vertically arranged (tilt 90°).

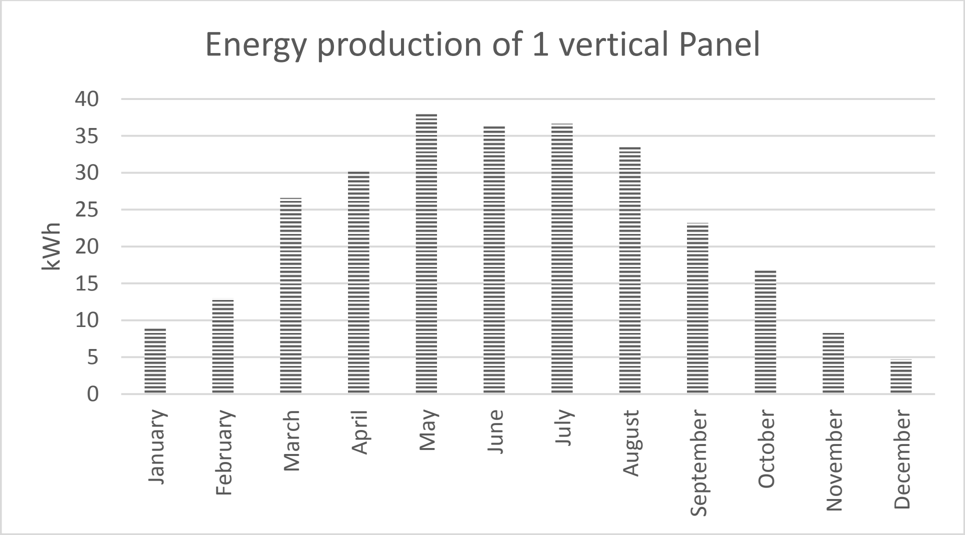


Figure 46. Monthly energy production of one panel facing toward south with tilt of 90° and not shaded. The results are presented in kWh and normalized for 1 year.

The Figure 46 shows for the vertical panel that the energy production is bigger in the summer than in the winter. It is possible to see that the highest production is equal to 38,06 kWh and it is obtained in May, differently from the other arrangements presented, where the highest production was obtained in July. Instead the lowest energy production is equal to 4,07 kWh, and it has been obtained in December. Comparing the panel arranged vertically with the shaded panel with tilt of 40° the energy production of the vertical panel is more uniform during the year. The yearly energy production of the panel in this arrangement is 276,49 $kWhy^{-1}$ and the yearly energy production normalized to 1 m^2 of heated building area is equal to 0,17 kWh y^{-1} m^{-2}. The yearly energy production of the panel not shaded is 63.6% higher than the yearly energy production of the panel vertically arranged. The Table 25 in the Appendix III shows the monthly energy production for the different panel arrangements defined in the previous pages.

6.3 Total PV energy production

The total PV panels' energy production to achieve the NZEB-O level it was carried out using the following panels:

- 22 not shaded panels with tilt of 40° (Figure 44)
- 238 shaded panels with tilt of 40° (Figure 45)

- 48 vertical panels not shaded (Figure 46)

The photovoltaic system proposed uses as hosting surfaces the roof, the gable wall that face toward south and the ground. The photovoltaic system placed on the roof is composed by 33 array of 6 panel, where not shaded panels with tilt of 40° set up the first array and the other 32 arrays are composed from shaded panel with tilt of 40°. The photovoltaic system placed on the gable wall is composed from 9 array of 6 panels, where not shaded panels with tilt of 40° set up the first array from the bottom and the other 8 arrays are composed from vertical panels. The ground-mounted photovoltaic system was thought as roofing of parking spot and is composed from eight arrays. In this system the first array is composed from 10 not shaded photovoltaic panels with tilt of 40° the next five arrays are composed from 10 shaded photovoltaic panels with tilt of 40° and the last array is composed from two shaded panels with tilt of 40° (Figure 47).

The Figure 47 shows the panels arrangement in both the arrangement on the building and on the ground, where different colours indicate different energy production of the panels. The quantity and the arrangement of the panels that are shown in the Figure 47 follow the condition that are stated above.

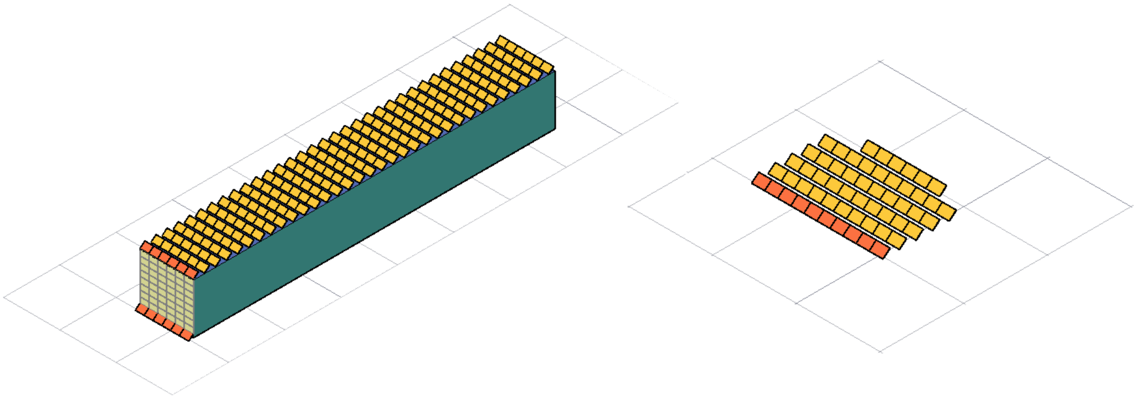


Figure 47. The arrangement of the PV panels on the building and on the ground. The orange PV panels are with tilt of 40° and not shaded, the dark yellow PV panels are with tilt of 40° and shaded and the light yellow PV panels are vertically arranged.

The yearly production of the complete PV system is equal to 102213,7 kWh. The results of the energy use of the building and the energy production of the PV system will be presented normalized to 1 m^2 of heated building area and 1 year, where the conditioned building area is equal to 1610, 88 m^2. Therefore the energy production of the PV system is equal to 63,45 kWh m^2y^{-1}. The Figure 48 shows the monthly energy production of the complete system differentiating the energy production of the PV system mounted on the roof, on the south wall and on the ground, where this energy production is in line with the NZEB definition stated in the chapter 1.5.

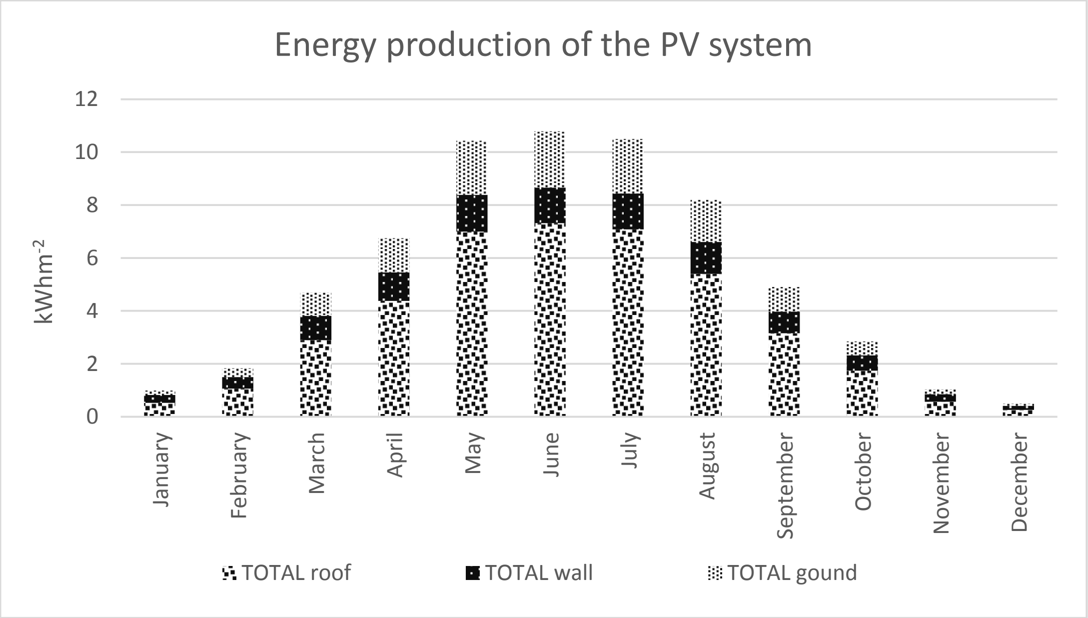


Figure 48. Energy production of the total PV system to reach the nZEB level. The results are presented normalized on 1 m^2 of conditioned building.

The Figure 48 shows the energy production of the PV system, and it produce much more energy in the months of May, June and July. The highest and the lowest monthly energy production are respectively in June and in December. Indeed the energy production in June is equal to 10, 80 $kWhm^{-2}y^{-1}$ and the energy production in December is equal to 0, 5 $kWhm^{-2}y^{-1}$. Thus the energy production in June is 85, 37 % higher than the energy production in the month of December and moreover the energy production in the month of June is 51,1 % higher than the yearly average energy production. The Table 26 in the Appendix III show the monthly energy production of the PV system.

6.4 The ZEB-O results

As defined in the chapter 1.4 the ZEB-O concept [18] consider the operational energy demand that must be compensated with on-site renewable energy.

The Table 13 shows the energy produced and the energy demanded expressed in kWh and normalized to 1 m^2 of conditioned building area and in 1 year. The difference between the energy demand and the energy production is according with the NZEB definition stated in the chapter 1.5. This definition says that the yearly primary energy use from non-renewable sources of the building must be smaller than 20 kWhm^{-2}.

Total energy demand	Heating+ cooling+ lighting+ DHW+ Fans	(kWhm^{-2}y^{-1})	83,44
Total Energy produced	PV panels	(kWhm^{-2}y^{-1})	63,45
Energy from non-Renewable sources	-	(kWhm-2y-1)	19,99

Table 13. Net Nearly ZEB-O energy balance of the building. The energy use and production are presented normalized to 1 m^2 of conditioned building area and 1 year.

The Figure 49 shows together the energy demand of the building and the energy production of the proposed PV system. Important is to highlight from the Figure 49 that the energy production and the energy demand of the building are out-of-phase between summer and winter. For this reason to achieve the Nearly Zero Energy level the building cannot be only an energy-efficient building, but it need to be a greed-connected building. Thus, the refurbishment has reached the concept of nearly NET Zero Energy Building [17], where the term Net emphasize the boundary of the building, and this concept is well expressed in the Figure 5 (Pag. 22).

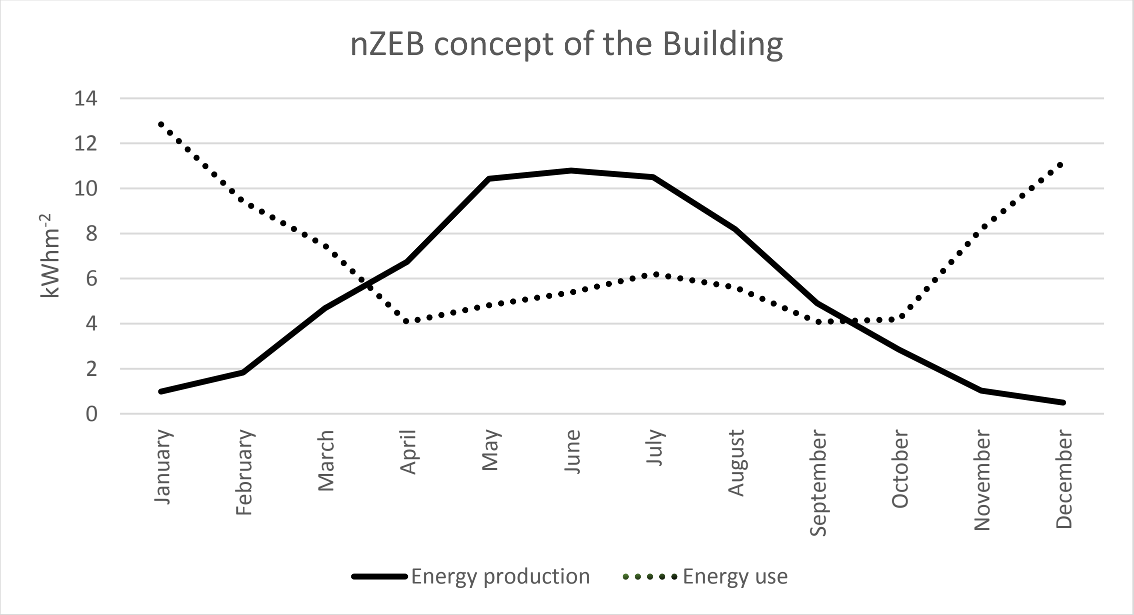


Figure 49. Monthly energy balance of the building after the refurbishment.

6.5 Modelling Inaccuracies

Modelling inaccuracies are present in each section of these results.

Regarding the energy demand calculations the main limitations are present for the systems that was modelled using EnergyPlus. The heat pump used in the energy model is an air-source heat pump and this is not the most efficient system that can be found on the market, so it is not the best solution to use in a Zero Energy Building. The best solution might have been to use a water-source or a geothermal heat pump that have a bigger efficiency in both summer and winter. Indeed a geothermal heat pump could reach a winter CoP between 3 to 6 instead of an air-source heat pump in cold winter with a CoP of 3. The ground source heat pumps are considered nowadays to be the most efficient technologies for providing HVAC and water heating. The reason why an air source heat pump was used in this work is that modelling an air source heat pump is much easier and the energy use is not much bigger. It was estimated comparing the results of this work with the results obtained from N. Lolli [25] that the water source heat pump needs 10 $kWhm^{-2}y^{-1}$ less than the air source heat pump that was used for this work.

Since Norway is so far north the daylight cycles are very different depending on the seasons. This result in different lighting behaviour by the people. This effect was not modelled in this work. Instead, the values for the primary energy use for lighting are taken from the Norwegian standard NS3031. So the monthly energy demand presented is not representative of a real monthly energy use, but is more a yearly average.

The energy demand and the energy production calculations were done using two different models. One model for the energy demand calculations and one for the energy production calculations. The use of two different models does not provide the possibility to calculate the shadows of the panels on the roof, thus the energy demand calculations are affected by this limitation. Considering the panel on the roof, we could have a warmer roof during the winter due to high sunlight absorption of the panel and a colder roof during the summer due to shading of the panels on the roof.

Regarding the energy production of the panels, three different arrangements are modelled with varying orientation and shading. Both the panels without shade with a tilt of 40° and 90° present small challenges when modelling. However, the model of the shaded panel with a tilt of 40° has certain inaccuracies due to shadow considerations. The modelled panel is shaded by one panel in front of it and this shading is less than the shading that it would have received by the whole array of panels. Furthermore, the shaded panels in the array have different energy production depending on the panel position in the array.

Indeed, a shaded panel that is in the centre of the array produces less energy than a shaded panel that is on the edge of the array. This effect has not been modelled in this work.

7 RESULTS: COMPARISON OF DIFFERENT INSULATIONS

In this chapter, the results from the comparison of four different insulation proposed for the refurbishment are presented. The proposed alternatives presume different insulations material that have thicknesses as defined in the chapter 4.2. In a first step, to achieve the same U-values for the different components, the thicknesses of the insulations were chosen. This also defines how much material is necessary to insulate the building with each alternative. The first set of data shows the embodied energy necessary to produce the insulation in the different alternatives proposed. The results in this part will be shown both in kWh normalized to 1 year and in kWh normalized to 1 m^2 of building conditioned surface and 1 year. The second set of data will show the embodied energy necessary to produce the panels that were used in the previous chapter to reach the NZEB-O level. After that the total embodied energy of each alternative is calculated, indeed the third set of data will show the PV panel necessary to compensate the embodied energy to produce the materials. This last step is important to achieve the NZEB-OM level as defined in the chapter 1.4.

In this section the volume of insulation necessary to retrofit with the different alternatives was calculated using the BIM model of the building that was developed using Revit Architecture 2015 [48]. In this section, the embodied energy has the meaning stated in the chapter 1.6 and the concept of non-renewable primary energy use to produce materials is the same to the concept of embodied energy use.

7.1 Results: the embodied energy use.

7.1.1 The embodied energy use for the different insulations

The first alternative presented is called MINERALWOOL and the embodied energy necessary to produce 1 m^3 of mineral wool as declared from [38] is equal to 1072,44MJ that means 297.9002 $kWhm^{-3}$. In the first alternative it is supposed that mineral wool boards are used to retrofit all the components, thus mineral wool is used to retrofit external walls, roof, basement ceiling and staircase internal walls. The necessary insulation to retrofit the building with the insulation thickness as declared in the chapter 4.2 is 706.04 m^3, where 265 m^3 are used to retrofit the external walls, 208 m^3 to retrofit the basement ceiling, 194.4 m^3 for the roof and 37.6 m^3 for the staircases internal walls. The total primary energy used for this first alternative is equal to 210329 kWh. Considering the service life of the mineral wool boards is declared equal to the service life of the building [38] the yearly embodied energy of this solution is 4206,58 $kWhy^{-1}$, when the service life of the building has been set to 50 years.

The second alternative presented is called WOOD FIBRE INSULATION and the embodied energy necessary to produce 1 m^3 of wood fibre board as declared from [39] is equal to 1830 MJ that means 508,337 $kWhm^{-3}$. In the second alternative wood fibre insulation boards are supposed to be used to retrofit all the components, thus wood fibre insulation is used to retrofit external walls, roof, basement ceiling and staircase internal walls. The volume of insulation necessary to retrofit the building with the thicknesses declared in the chapter 4.2 is 744.62 m^3, where 285,5 m^3 are used to retrofit the external walls, 231,9 m^3 for the basement ceiling, 206,6 m^3 for the roof and 37.6 m^3 for the stair case internal walls. Comparing the volume of insulation necessary to retrofit the building using the first and the second alternative is possible to notice that the quantity of insulation necessary is very similar and this is due to the similar thermal conductivity of the two materials[44, 45]. The total primary energy used for this first alternative is equal to 378515 kWh. Considering the service life of the wood fibre insulation boards is declared equal to the service life of the building the yearly embodied energy of this solution is 7575,31 $kWhy^{-1}$, when the service life of the building was set to 50 years.

The third alternative presented is called VIP and considers the use of vacuum insulation panels to retrofit all the components, thus VIPs are used to retrofit external walls, roof, basement ceiling and staircase internal walls. The embodied energy necessary to produce 1 m^2 of vacuum insulation panel as declared from [41] is equal to 719,23 MJ that means 199,79 $kWhm^{-2}$. The thickness of the panel considered in the environmental product declaration is equal to 0,025 m. For this alternative the embodied energy of the VIPs was normalized respect 1 m^3 of product, and it was extracted that the embodied energy used to produce 1m^3 of VIP is equal to 7991,45 kWh. The insulation necessary to retrofit the building with the insulation as declared in the chapter 4.2 is 142,32 m^3, where 51,83 m^3 are used for the external walls, 43,48 m^3 for the basement ceiling, 39,5 m^3 for the roof and 7,52 m^3 for the stair case internal walls. In this alternative, the quantity of insulation necessary is much smaller than the quantity of insulation used in the first or the second alternative, and this is because the VIPs have a smaller U-Value than both the mineral wool and the fibre wood insulations. The total primary energy used for this third alternative is equal to 1137371,633 kWh. Considering that the service life of the Vacuum insulation panels is declared equal to 30 years [41], if the goal is to normalize the embodied energy of the material to the service life of the building, the panels should be replaced after 30 years, and new VIPs will be used for the next 20 years. So that it is possible to declare that the number of panels necessary for the refurbishment need to be multiply to 1,67 to consider the panels during the whole service life of the building (50 years). After these assessments it is possible to affirm that the total embodied energy of this solution is 37912,39 $kWhy^{-1}$, where the service life of the building was set to 50 years.

The fourth alternative presented is called PUR+XPS and consist in the use of different technologies to retrofit different components (chapter 4.2). Polyurethane sandwich panels (PUR) are used to retrofit the external walls and Extruded Polystyrene (XPS) insulation boards are used to retrofit the roof, the basement ceiling and the internal staircase walls. The embodied energy necessary to produce PUR sandwich panels and XPS insulation panels are different. Regarding the PUR sandwich panels the non-renewable primary energy necessary to produce 1 m^2 of 120-mm thick panel is equal to 380,5 MJ that means 106 $kWhm^{-2}$ according to [42]. However, the panel used for the refurbishment as stated in the chapter 4.2 is 160-mm thick, and the sandwich panel is composed from three different layers: steel,coatings-polyester for the finishing part and the PUR insulation that is the core of the panel. For this reason, the data from the environmental product declarations was normalized using the weight composition of the used panel, where 40% of the panel is PUR, 1.5% is coatings polyester and 58% is hot-dip galvanised steel [42]. Using this weight percentage data of 1 m^2 of sandwich panel, the value in the Table 14 have been extracted.

PARAMETER	**Galvanized steel**		**Coatings Polyester**		**PUR insulation**	
	MJ	kWh	MJ	kWh	MJ	kWh
Non-renewable primary energy as energy carrier	220,69	61,30	5,71	1,59	204,96	56,93

Table 14. Primary energy use to produce each part of a PUR sandwich panel. The thickness of the presented panel is 120 mm.

The table Table 14 gives the possibility to extract the primary energy use to produce 1m^2 of 160-mm thick PUR sandwich panel that is equal to 431.36 MJ that means 119.82 kWh, indeed, to retrofit the external walls as stated in the chapter 4.2 are necessary 160-mm of PUR sandwich panel. To complete the refurbishment for all the external walls are necessary 1063.63 m^2 of these panels. The embodied energy used to produce these quantities of sandwich panels is equal to 127000 kWh. So considering that the service life of the PUR sandwich panel is declared equal to 50 years the total embodied energy of this solution is 255 kWhy^{-1}, when the service life of the building has been set to 50 years.

Regarding the same solution (PUR+XPS), XPS boards was used to retrofit the roof, the basement ceiling and the staircase internal walls. The embodied energy to produce 1 m^3 of XPS board is equal to 1513.36 MJ that means 420.38 kWh/m^3 [40]. The volume of XPS insulation to retrofit the roof, the internal staircase walls and the basement ceiling with the insulation thicknesses declared in the chapter 4.2 is equal to 354.01 m^3. The total embodied energy in this case is equal to 148819.5 kWh. So, considering that the declared service life of the XPS boards is declared equal to the service life of the building [40], the embodied energy for this solution is 2976.29 kWhy^{-1}. Therefore, combining the embodied energy to produce the XPS boards and the PUR sandwich panels, is possible to define also the embodied energy of the fourth solution (XPS+PUR) that is equal to 5530 kWhy^{-1}.

The Table 15 shows a summary of the parameters that are important for each solution presented in the last pages and presents the embodied energy for the different solutions expressed in kWh normalized to 1 year. The yearly-embodied energy use normalized to 1 m^2 of conditioned building surface area is also presented, where the conditioned building surface area is equal to 1610.9 m^2.

The data to calculate the embodied energy for each solution was taken from [38] for the mineral wool boards, from [39] for the wood fibre insulations, from [41] for the vacuum insulation panels, from [42] for the polyurethane sandwich panels and from [40] for the extruded polystyrene insulation. Extracts of the environmental product declaration are presented in the Appendix IV.

Parameter	UNIT	SOLUTION 1	SOLUTION 2	SOLUTION 3	SOLUTION 4	
SOLUTION CODE	-	MINERALWOOL	WOOD FIBRE INSULATION	VIP	PUR+XPS	
MATERIAL OR PRODUCT	-	Mineral wool	Wood fibre insulation	Vacuum insulation panels	PUR	XPS
Non-renewable primary enegy as energy carrier	kWh/m^3	297,9002383	508,33374	7991,450838	-	420,3781141
Non-renewable primary enegy as energy carrier	kWh/m^2	-	-	199,7862709	1,20E+02	42,03781141
Service life	y	50	50	30	50	50
Volume of insulation for EXTERNAL WALL	m^3	265,31115	268,55115	51,831375	1063,6275	
Voolume of insulation for ROOF	m^3	194,437056	206,589372	39,495027		151,90395
Volume of insulation for BASEMENT CEILING	m^3	208,7056584	231,895176	43,4803455		173,921382
Volume of insulation for STAIR INTERNAL WALLS	m^3	37,584	37,584	7,5168		28,188
Total insulation	m^3	706,0378644	744,619698	142,3235475	1063,6275	354,013332
Embodied energy	$kWhy^{-1}$	4206,576961	7570,306319	37912,38776	2548,927237	2976,389137
					5525,316375	
Embodied energy	$kWhy^{-1}m^{-2}$	2,611353398	4,699484952	23,53520297	1,582319749	

Table 15. Embodied energy use for the different solutions presented. The last result are normalized to 1m² of heated building surface and 1 year.

7.1.2 The embodied energy for the new windows and PV panels.

As stated in the chapter 4.1.2 in the refurbished building the windows need to be replaced with new windows with low U-Value (0,8 Wm^{-2}K^{-1}). The embodied energy use to produce one window was extracted from the Environmental Product Declaration for a window with dimensions of 1,23x1,48 m and insulated triple-glazing glass [49]. The embodied energy of the reference window is equal to 2353 MJ that means 653,61 kWh. The window that was considered is an insulated triple-glazing with PVC frame and transparent glass filling. The embodied energy of the standard window was normalized to 1 m^2 of window surface and the embodied energy to produce 1 m^2 of new window is equal to 418,98 kWh. From this information, the embodied energy for each type of window present in the building was extracted. The Table 16 summarize the embodied energy for each type of window, and shows that the embodied energy to produce all the windows that need to be replaced is equal to 114306.6 kWh.

WINDOW CODE	**N**	**dimensions (m)**		**Normalized embodied energy**	**Embodied energy for single window**	**Embodied energy total**	**TOTAL EMBODIED ENERGY**	
	-	width	height	kWh	kWh	kWh	kWh	kWhy^{-1}
WIND 1	33	1,5	1,1	418,98	691,32	22813,56	114306,62	2286,13
WIND 2	24	1,5	2,4	418,98	1508,33	36200,03		
DOOR	24	2,45	0,9	418,98	923,85	22172,52		
WIND 3	93	0,85	1	418,98	356,13	33120,51		

Table 16. Embodied energy of the new windows. The embodied energy of the single type of window and the embodied energy of all the windows are shown.

Considering that the declared service life of this plastic windows is 50 years [49], it is also possible to define the embodied energy of the window normalized to 1 year that is equal to 2286,13 kWhy^{-1}.

Regarding the PV panels, a commercial product was chosen [37]. The embodied energy to produce one PV Panel was extracted from [50] which is a comprehensive life cycle analysis based on process data from the manufacture of the commercial product that was chosen.

Unit	**Total**	**Cells**	**Frame**	**Back sheet**	**Glass**	**EVA**	**Electricity**	**Other**
MJ/m^2	4662	3948	379	60	117	79	52	27
MJ/W	22,95	19,44	1,87	0,3	0,58	0,39	0,25	0,13
%		85	8	1	3	2	1	1

Table 17. Energy used to produce 1m^2 of PV panel. The data are extracted from [50]

The Table 17 shows that to produce 1 m^2 of the chosen PV panel the embodied energy is 4662 MJ, that means 1295 kWh. Therefore, considering that the panel is 1.56 m wide and 1.09 m high, is possible to conclude that the embodied energy to produce 1 PV panel is equal to 2202,02 kWh. The life time of the panel is 30 years without degradation of the PV panel [50], resulting in an embodied energy of 73,40 kWh.

According to the chapter 6.3 the total number of panel used to reach the NZEB-O level is equal to 308 panels, so the embodied energy to produce 308 PV panels is equal to 678222,0866 kWh. The Table 18 shows schematically the considerations that have been stated in the previous lines. In the next table the embodied energy used is normalized to 1 year and the PV lifetime was considered equal to 30 years as declared by the producer.

Yearly embodied energy for 1 PV panel	Number of panel for NZEB-O level	Embodied energy for PV system NZEB-O
Kwhy^{-1}	-	kWhy^{-1}
73,40065872	308	22607,40289

Table 18. Embodied energy use to produce the PV system that is necessary to reach the NZEB-O level. The results are presented normalized to 1 year.

7.1.3 The embodied energy for the different alternatives.

This section summarizes the considerations and the results present in the chapters 7.1.1 and 7.1.2. The four solutions presented have different insulation types but same number of windows. The alternatives proposed are summarized in the Table 19, showing the differences between the alternative proposed.

SLUTION NAME	MINERAL WOOL	WOOD FIBRE INSUL	VIP	PUR+XPS	NEW WINDOWS
Alternative 1	v				v
Alternative 2		v			v
Alternative 3			v		v
Alternative 4				v	v

Table 19. Solution proposed to define the NZEB-OM level. The different alternatives present different type of insulations.

The Figure 50 shows the yearly-embodied energy use for the proposed alternatives, which are 4,01 kWhy^{-1}m^{-2}, 6,11 kWhy^{-1}m^{-2}, 24,95 kWhy^{-1}m^{-2} and 4,85 kWhy^{-1}m^{-2} respectively for the solutions 1-4.

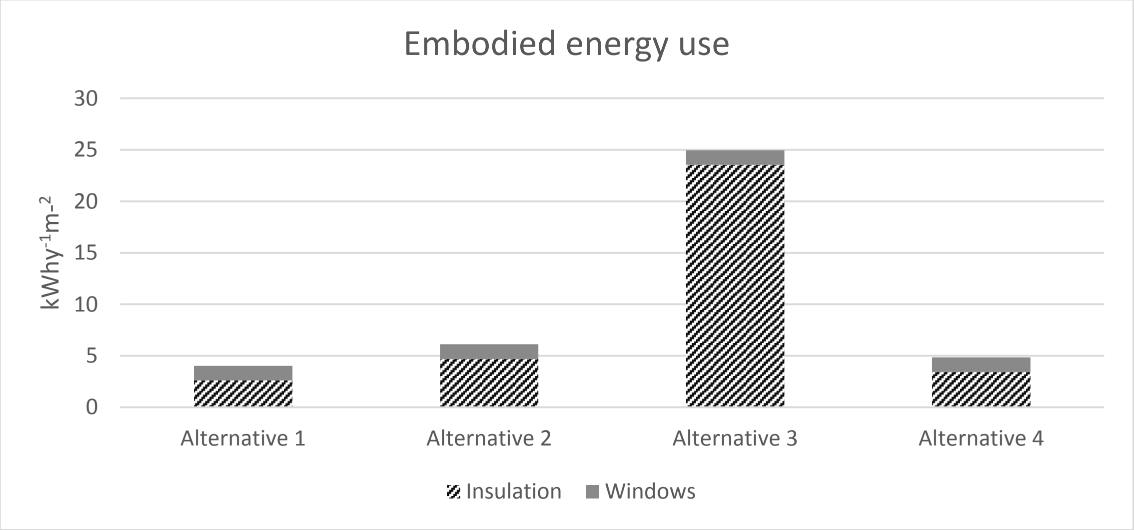


Figure 50. Embodied energy (non-renewable primary energy) use to retrofit the building using the different proposed alternatives.

The Figure 50 shows that the Alternative 3 has the highest embodied energy use, and the big difference between the Alternative 3 and the other alternatives is due to the use of the VIP as insulation. In the Alternative 3 the embodied energy use is 83,93 % higher than the Alternative 1. The exact values of the Embodied energy of the different alternatives are fully shown in the Appendix V, Table 27.

7.2 Total PV energy production to reach the NZEB-OM level

The aim of this part is to show that it is possible to reach the NZEB-OM level adding panels to the ground-mounted system that was thought as parking spot roofing. The definition of the ZEB-OM as stated in the chapter 1.4 considers the emission related to all the operational energy (O) use and embodied emission from materials (M) and technical installations that shall be compensated for with on-site renewable energy generation (e.g. PV panels). In this work directly the energy use (embodied energy, primary energy) is considered to define the NZEB-OM level instead of the emission related to the energy use (CO_2).

The operational energy use was defined in chapter 6 and the embodied energy of the used materials will include only the insulation used for the refurbishment and the windows that were replaced. For the different alternatives proposed the results will show the same operational energy (O) use but different embodied energy use (M) for the materials (insulation and window).

The PV panel that will be considered in this section to achieve the NZEB-OM level is the shaded panel with tilt of 40° as defined in the chapter 6.2. One panel in this condition has a yearly production of 333,54 kWh y^{-1} and the yearly production normalized to 1 m^2 of heated building area is equal to 0,207 kWh y^{-1} m^{-2}.

Due to the different insulation types and consequently different energy use, different volumes of PV panels are necessary to reach the NZEB-OM level in each proposed alternative.

Table 20 shows how many panels are needed to achieve the NZEB-OM level for each alternative. In addition the embodied energy to produced these panels is included. For the alternative 1 (Mineral wool+ windows) is possible to reach the NZEB-OM level with 20 shaded panel with a tilt of 40° to add at the 308 panels that was used to reach the NZEB-O level. The energy production of these PV panels is 6670,9 $kWhy^{-1}$ that is equal to 4,14 kWh y^{-1} m^{-2}. For the alternative 2 (Wood fibre + windows) is possible to reach the NZEB-OM level with 30 PV panels to add at the 308 panels that was used to reach the NZEB-O level. These PV panels produce 10006,34 $kWhy^{-1}$ that is equal to 6,21 kWh y^{-1} m^{-2}. For the alternative 3 (VIP + windows) is possible to reach the NZEB-OM level by adding 121 PV panels at the 308 panels that was used to reach the NZEB-O level. These PV panels produce 40358,93 $kWhy^{-1}$ that is equal to 25,05 kWh y^{-1} m^{-2}. For the alternative 4 (PUR+XPS + windows) is possible to reach the NZEB-OM level by adding 23 PV panels at the 308 panels that was used to reach the NZEB-O level. These PV panels produce 7671,53 $kWhy^{-1}$ that is equal to 4,76 kWh y^{-1} m^{-2}.

The Figure 51 shows the different arrangement of the ground-mounted PV system in the different alternatives, where the PV panels highlighted in grey was added to reach the NZEB-OM level for the different alternatives proposed.

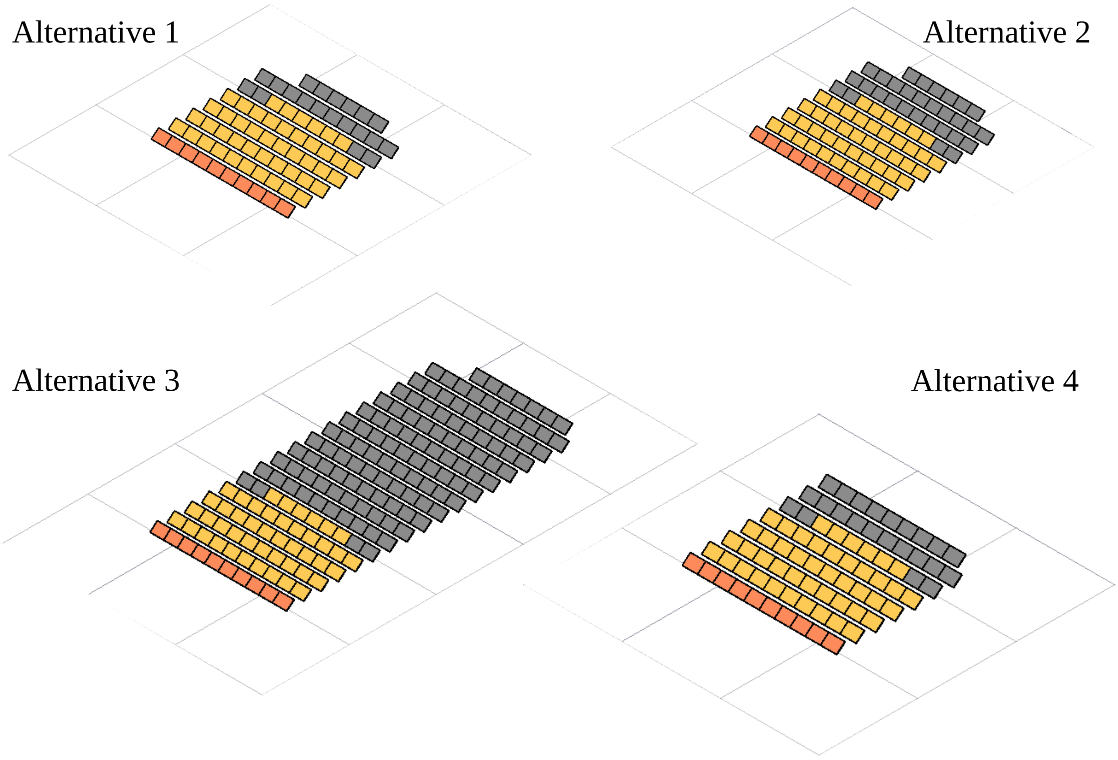


Figure 51. PV arrangement to reach the NZEB-OM level in the different alternatives. The difference between the alternative is the used insulation type for the renovation. The grey PV panels are added to reach the NZEB-OM level in the different alternative proposed in this chapter. The "alternative1" consider the use of MineralWool, the "alternative2" consider the use of WoodFibre Insulation Panels, the "Alternative 3" consider the use of VIPs and the "Alternative 4" consider the use of PUR sandwich Panels and XPS boards.

The results of the Figure 50 shows that for the different alternatives different number of PV panels are necessary to reach the NZEB-OM level , whereas for NZEB-O level the numbers stay the same. The Table 20 shows the number of panels necessary for each alternative to neutralize the embodied energy used to produce the material. In other words, it shows the number of panels to add to the starting PV system (308 panels) to reach the NZEB-OM level for each alternative. It also shows the energy produced from the added panels that is useful to reach the NZEB-OM level (grey panels in the Figure 50).

Solution name	Total embodied energy	Additional PV	Energy produced from 1 PV	Total energy produced NZEB-OM	
	$kWhy^{-1}m^{-2}$	-	$kWhy^{-1}m^{-2}$	$kWhy^{-1}m^{-2}$	$kWhy^{-1}$
Alternative 1	4,03	20	0,21	4,14	6670,9
Alternative 2	6,12	30		6,21	10006,3
Alternative 3	24,95	121		25,05	40358,9
Alternative 4	4,849	23		4,76	7671,53

Table 20. Energy produced from the new PV panels added to achieve the NZEB-OM level. The table shows the number of the panel necessary and the total energy produced by them.

It is important to understand that the total embodied energy (Table 20) includes only the embodied energy to produce the insulation and the windows (chapter 6.3: Total PV energy production).

The Figure 52 shows the balance in the NZEB-OM concept of the refurbished building, which shows that the energy produced is smaller than the energy used, which is the sum of the operational energy (O) and the embodied energy of the materials (M).

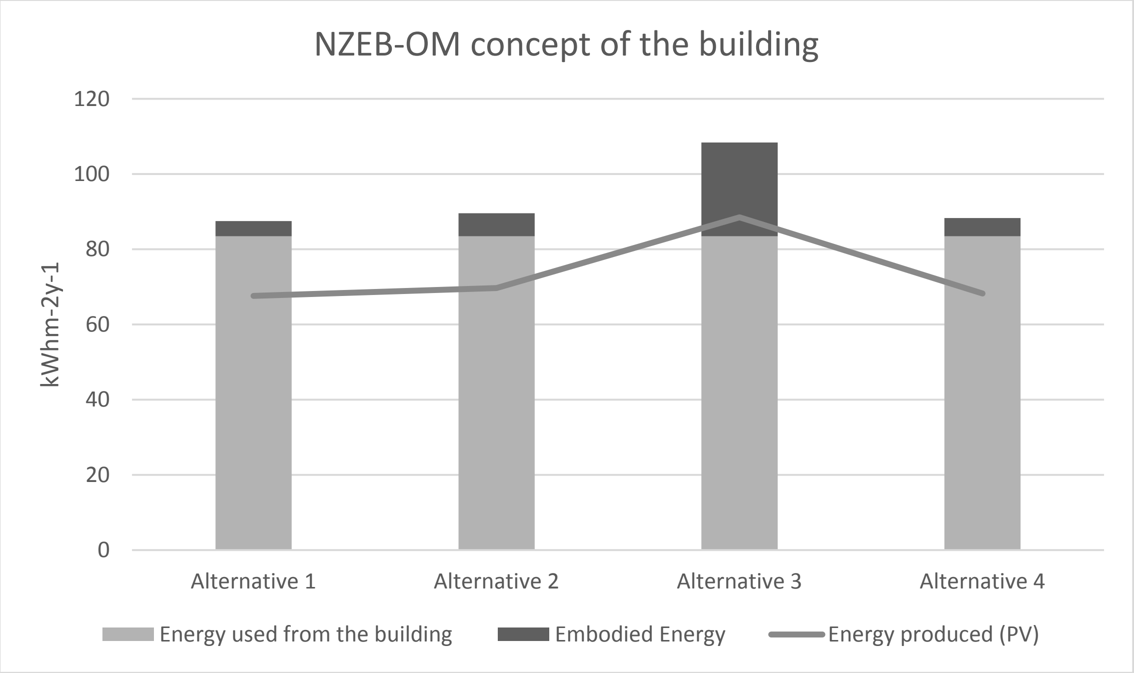


Figure 52. The Nearly ZEB-OM balance of the building in the 4 alternative proposed. Alternative 1 uses MineralWool as insulation, Alterative 2 uses Wood fibre boards as insulation, Alternative 3 uses VIPs as insulation, Alternative 4 uses PUR sandwich panels and XPS boards. The energy use and production are presented normalized to 1 m^2 of conditioned building area and 1 year.

The Figure 52 demonstrates clearly the “nearly” concept of the building through the difference between the energy produced and the energy used during the lifetime of the building and for the materials production. This is in line with the definition of Nearly Zero Energy Buildings stated in the chapter 1.5, where the building can use energy from non-renewable sources in quantities smaller than 20 kWh y^{-1} m^{-2} and also this last requirement is satisfied. These value that are present in the Figure 52 are fully presented in the table Table 28 of the Appendix V.

7.3 The PV panels’ embodied energy of the alternatives

The last issue regards the embodied energy to produce the PV panels that was used to satisfy the NZEB-OM level in the different alternatives proposed, indeed each alternative uses different number of PV panels and consequently different embodied energy to produce the PV system. The Figure 53 shows the total energy use for each alternative, where the energy used for the building during the service life and the embodied energy to produce both the materials (insulations and windows) and the PV panels.

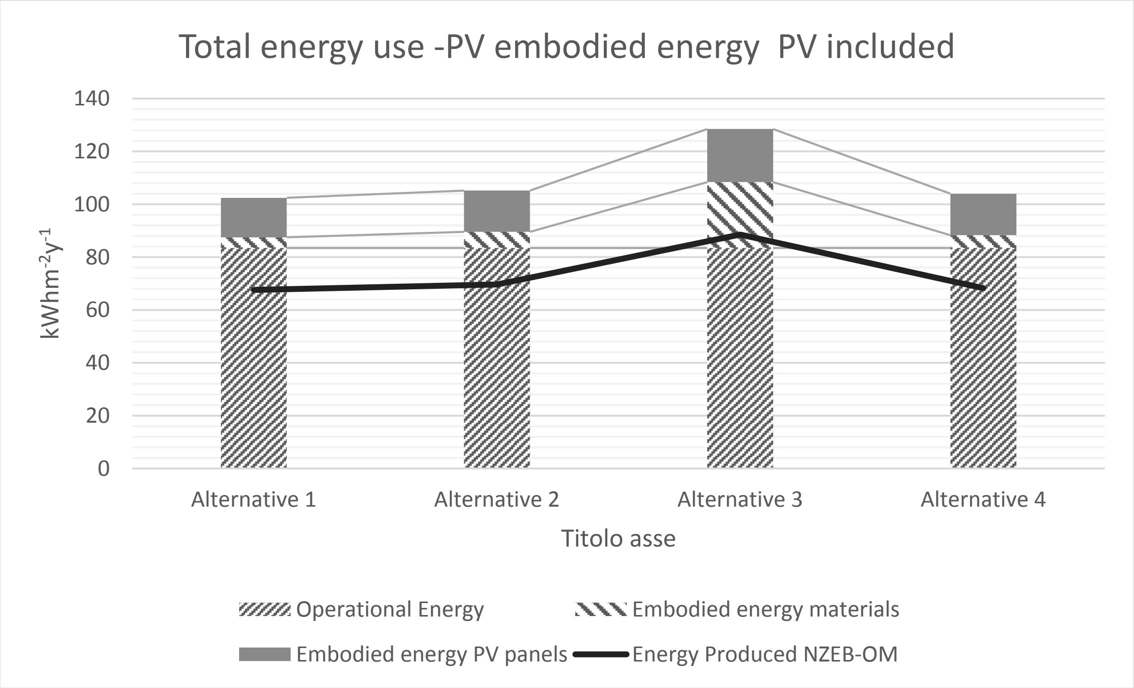


Figure 53. Total energy use of the alternatives. In the picture the embodied energy to produce the PV panels are calculated. The Alternative 1 uses 328 PV panels, the Alternative 2 uses 338 PV panels, the Alternative 3 uses 429 PV panels and the Alternative 4 uses 331 PV panels. The energy use and energy production are normalized to 1m^2 *of conditioned building surface and 1 year.*

The Figure 53 highlights the embodied energy of the PVs and its percentage of total energy for refurbishment for the alternatives 1-4 respectively: 14,95 kWhy^{-1}m^{-2} (14,6%), 15,61 kWhy^{-1}m^{-2} (14,84%), 20,1 kWhy^{-1}m^{-2} (15,63%) and 15,7 kWhy^{-1}m^{-2} (15,1%). These value are fully presented in the Table 29 (Appendix V)

The Figure 54 shows the different embodied energies uses of the different PV systems, including the energy necessary for both NZEB-O and NZEB-OM levels.

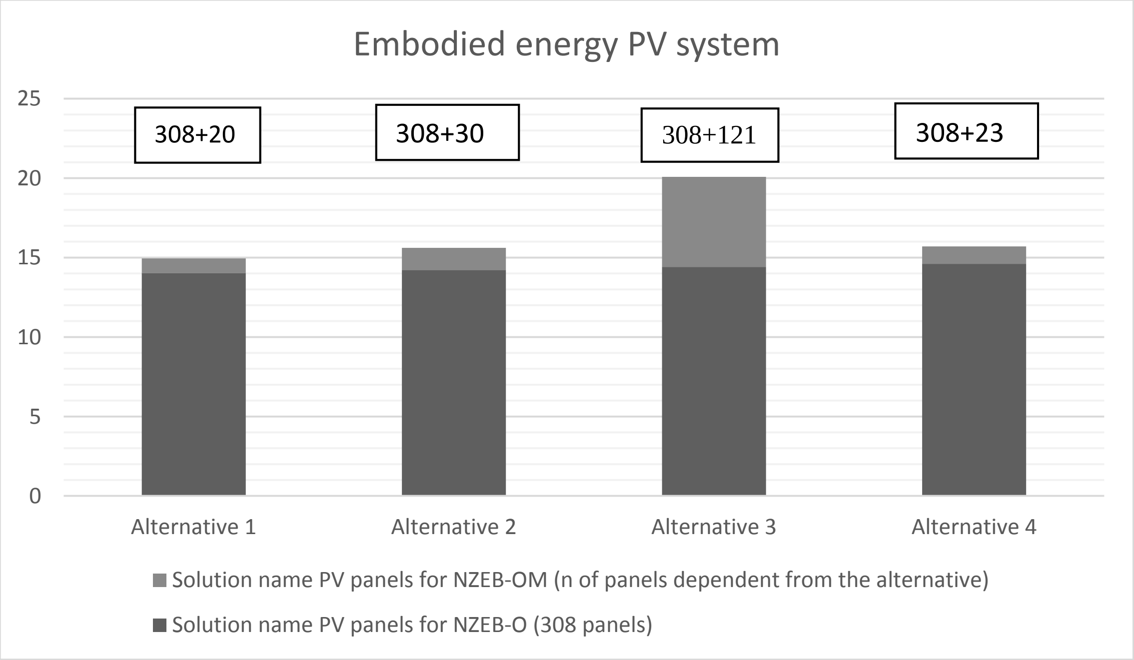


Figure 54. Embodied energy use to produce the PV systems in the different alternative proposed. The figure differentiate the embodied energy necessary to produce the PV panels to reach the NZEB-O level and the embodied energy necessary to produce the PV panels to reach the NZEB-OM level.

It is clear from the previous figure that as the embodied energy to produce the necessary VIP panels is bigger, more panels are necessary to achieve the NZEB-OM level for this alternative and consequently the embodied energy to produce the panels for the alternative 4 is bigger than the other alternatives.

The Figure 55, Figure 56, Figure 57 and Figure 58 shows the difference by considering and not considering the embodied energy of the PV panels. In the following graphs the line below, indicate the energy balance of the building by including the energy used from the systems, the embodied energy of windows and insulation and the production of the PV panels. Instead, the line above indicate the energy balance of the building by adding at the previous the embodied of the PV panels necessary for the different alternatives. So is is easy to summarize that the gap between the two lines represents the embodied energy to produce the PV panels using the different alternatives. Regarding the line that is above, the step that is visible after 30 years is due to the end-of-life to the used panels and their replacement with new panels.

The four proposed alternatives have same energy for both, energy used by the building during the service life and embodied energy to replace the windows, but simultaneously different embodied energy for both the insulation and the PV panels that in the different alternative are present. Indeed as we have seen in this study changing the insulation we need different energy production by the PV systems to compensate the energy used to produce the insulation.

The graphs show the energy balance in the whole lifetime, and consider that in 30 years the PV panels and the VIP need to be replaced according with the producers advices [41, 50]. The Appendix VI shows the values used to define the next five graphs.

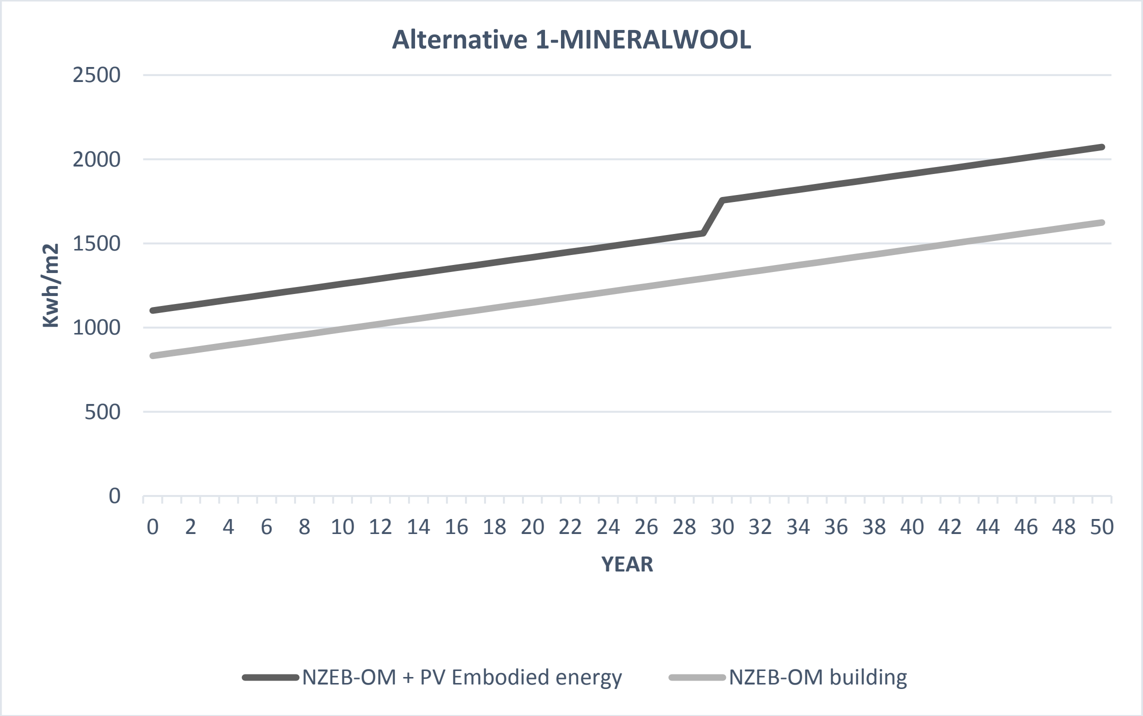


Figure 55.Energy used for the Alternative 1- MINERALWOOL. The line below include the energy used by the building during the service life and the embodied energy to produce the insulation and the windows necessary for the refurbishment. The PV system is replaced after 30 year.

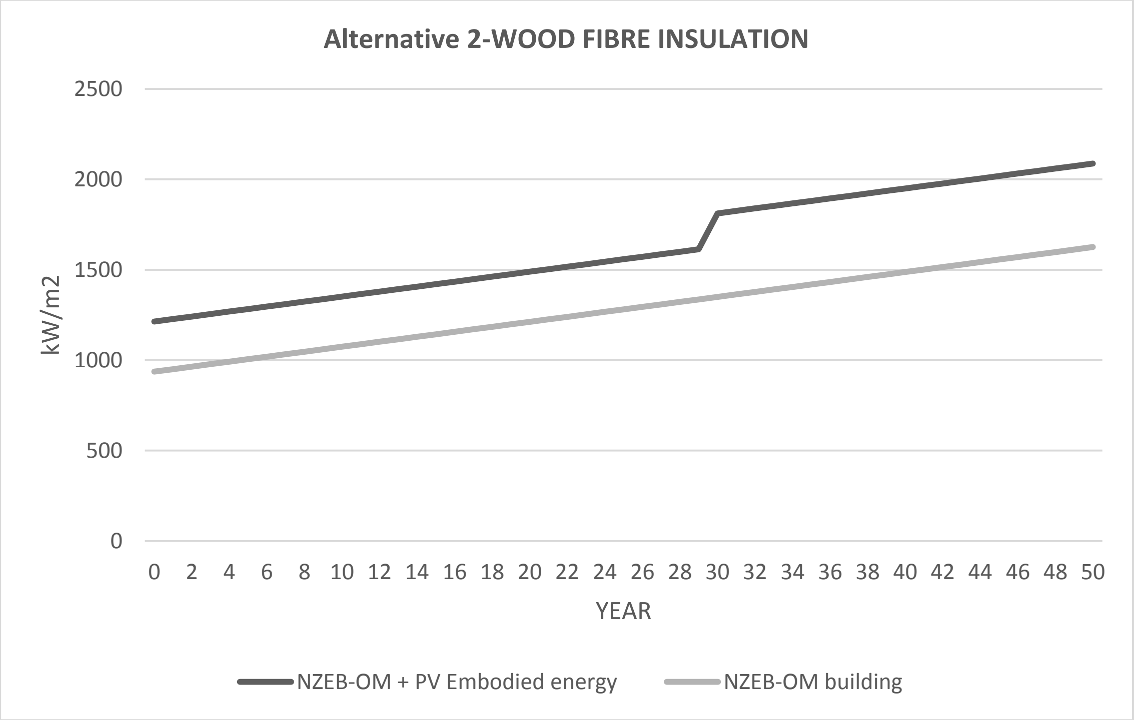


Figure 56. Energy used for the Alternative 2- WOOD FIBRE INSULATION. The line below include the energy used by the building during the service life and the embodied energy to produce the insulation and the windows necessary for the refurbishment. The PV system is replaced after 30 year.

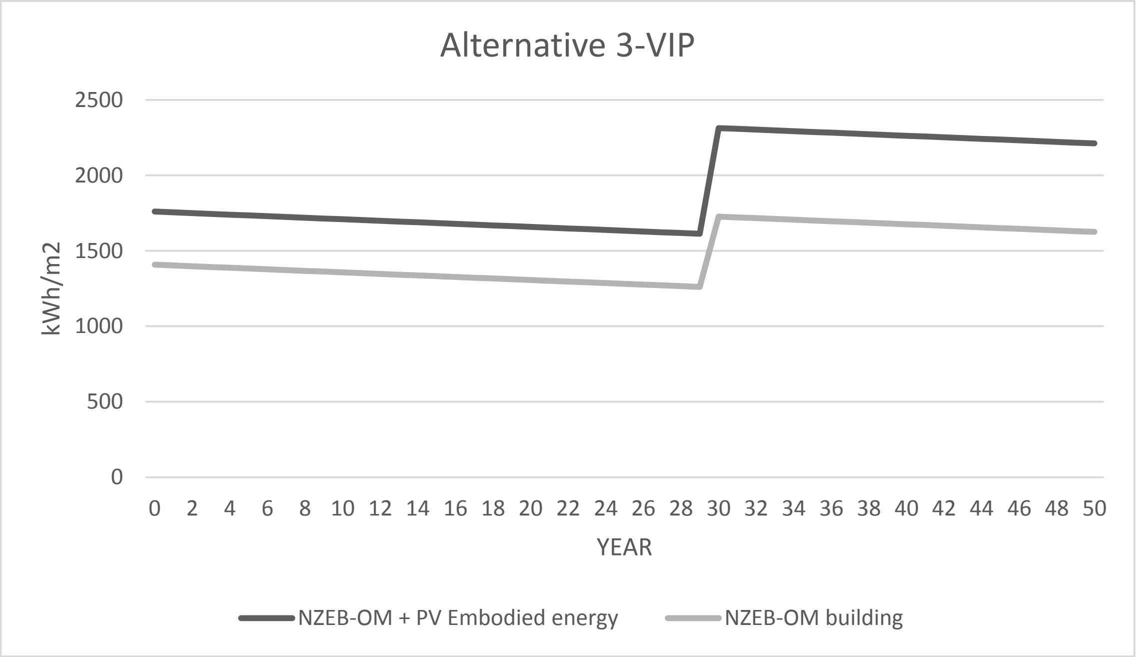


Figure 58. Energy used for the Alternative 3- VIP. The line below include the energy used by the building during the service life and the embodied energy to produce the insulation and the windows necessary for the refurbishment. Both, the PV system and the Vacuum Insulation Panels are replaced after 30 year.

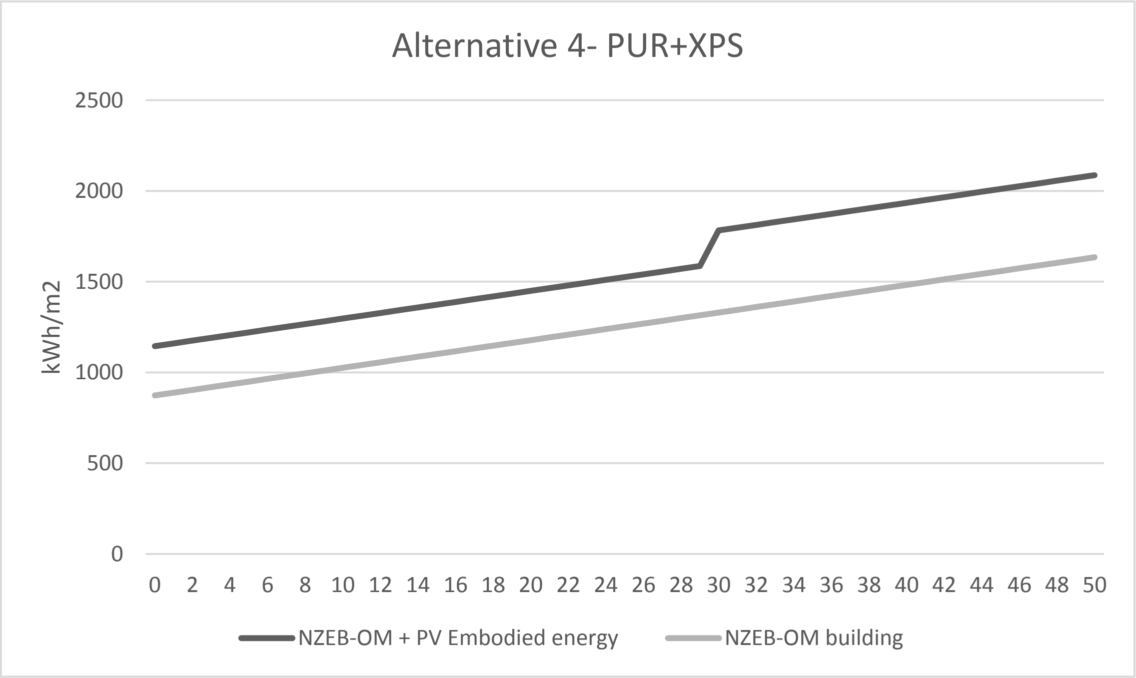


Figure 57. Energy used for the Alternative 4- PUR+XPS. The line below include the energy used by the building during the service life and the embodied energy to produce the insulation and the windows necessary for the refurbishment. The PV system is replaced after 30 year.

The Figure 55, Figure 56, Figure 57 and Figure 58 shows how different is the energy consumption in the different alternatives proposed and how much the embodied energy of the panels can affect the energy balance. Indeed, the gap between the lines visible in each of the previous figures represent the embodied energy used to produce the PV system in need to achieve the NZEB-OM concept.

The Figure 59 shows a comparison between the four alternative, where the energy used in the year 0 is the embodied energy to produce the insulation, windows and PV panels for the different alternatives.

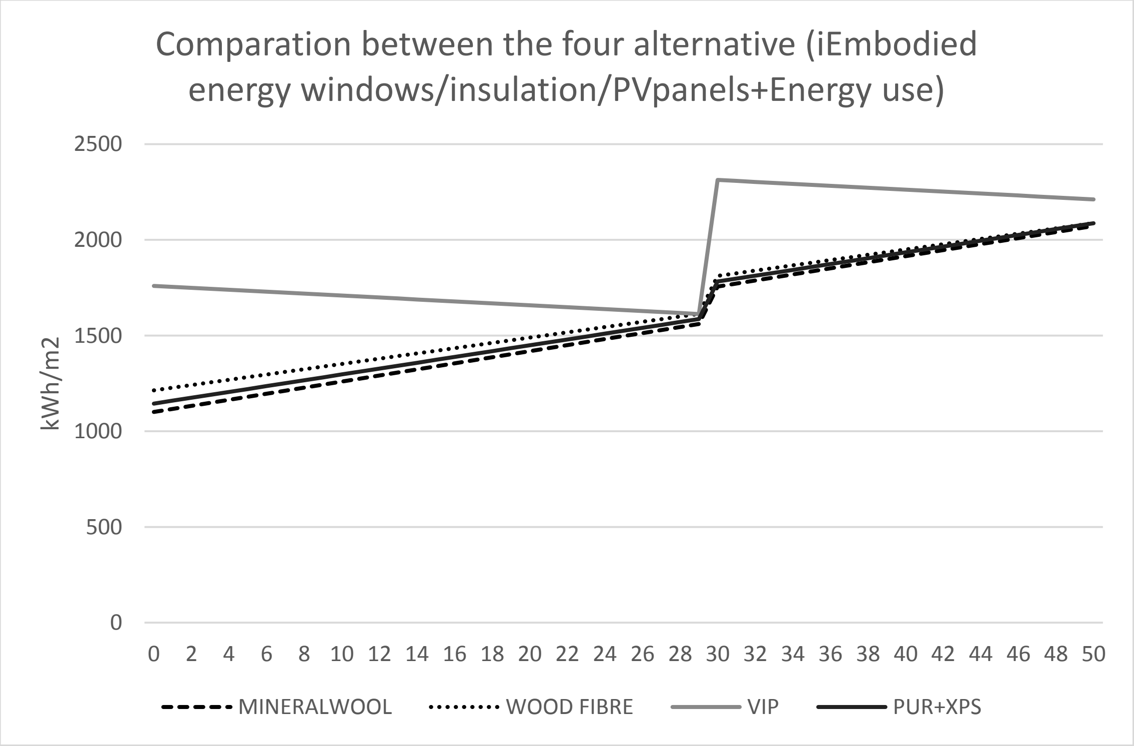


Figure 59. Comparation of the different alternatives. The energy use include the embodied energy to produce PV panels, insulations, windows and the energy used by the building.

The last figure shows that even if the solutions have big differences of energy used normalized to 1 year (Figure 54, Figure 53, Figure 52, Figure 50), the final result is almost the same for each alternative. Indeed, at the 50th year the solutions will consume 2072.9 kWh/m^2, 2087.4 kWh/m^2, 2211.5 kWh/m^2, 2086.8 kWh/m^2 respectively for the alternatives 1-4. All the calculation to extract the graph in the Figure 59 are fully shown in the Appendix VI.

The Figure 59 helps us also to define that the benefit of the different solutions depends from how long we set the lifetime of the building after the refurbishment. Indeed comparing the alternatives it is possible to notice that after 10 years the Alternative 3 consumes much more energy than the other solutions, indeed after 10 years the alternative 3 (VIP) consume 36 % more energy than the alternative 1 (MINERALWOOL). However after 50 years the alternative 3 consumes only 7 % more energy than the alternative 1. After these considerations, we can assert that according with the Figure 59 the best solutions in the defined conditions is the Mineral wool.

Interesting is compare the energy use of building retrofitted with Mineral wool that achieve the nZEB-OM level and the same building but without PV panels. The second building could be still defined a low energy building but without any energy production on site or nearby.

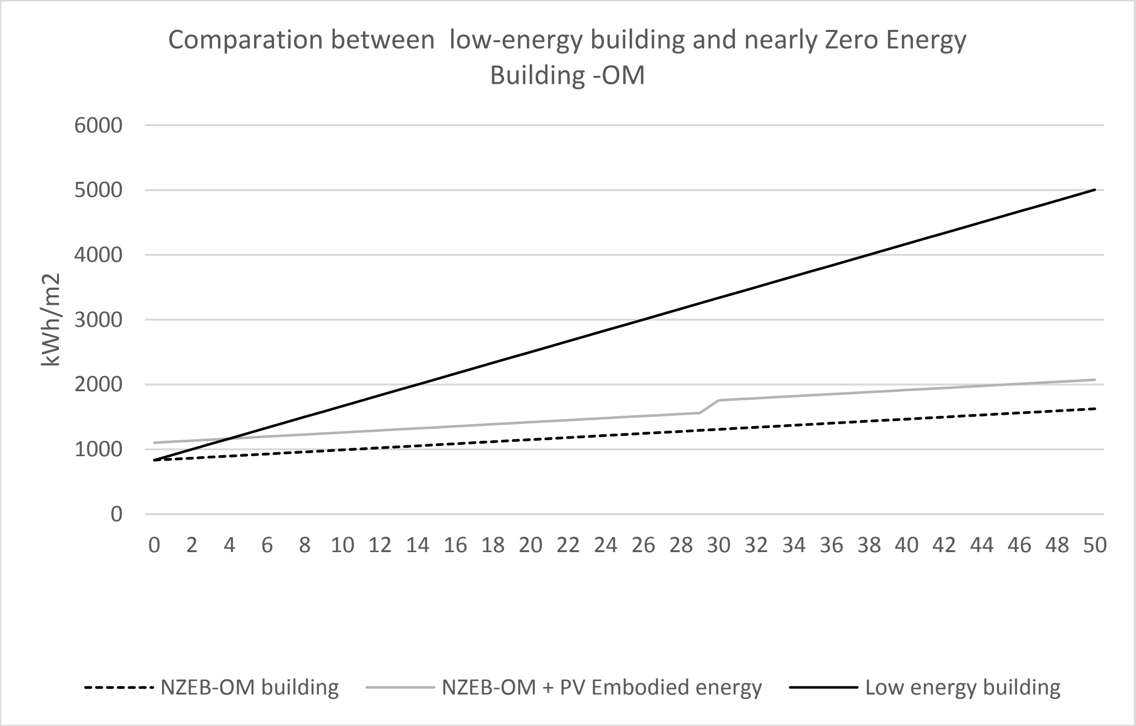


Figure 60. Comparison of the retrofitted building with different aim: achieve the NZEB-OM concept, achieve the NZEB-OM concept including the PV system embodied energy, and achieve the low-energy level (without PV panels). The results are in kWh normalized on 1 m^2 of conditioned floor area. The figure shows that the energy use of the retrofitted building without PV systems is much higher than the NZEB-OM retrofitted building.

From the Figure 60 is possible to notice that the difference due to the PV production is high. Indeed comparing the NZEB-OM building and the low energy building that use the same technology the energy used after 50 years is respectively 1624,49 kWh/m^2 and

5004,16 kWh/m^2, so the low-energy building consume 208 % more energy than the nZEB building, and this difference is due to the energy produced by the PV panels.

In the Figure 60 is also visible that this difference is a bit smaller if in the computation we include also the embodied energy of the PV system. The embodied energy of the PV system is also easily visible in the year 0, where the embodied energy of both the low-energy building and the NZEB-OM building is the same. However, if in the NZEB-OM building we include also the embodied energy to produce the PV system, the embodied energy in the year 0 is 32 % higher.

With the aim to take in account the embodied energy to produce the necessary PV system is also possible to notice from the Figure 60 that until the 4th year the low-energy building consume generally less energy that the NZEB-OM building. This is because of the absence of the PV system in the low-energy building.

7.4 Limitations

The limitations of this section regard the data chosen to calculate the embodied energy use for each alternative. These could influence the result presented. The main uncertainties regard the embodied energy for some materials presented and the decision to omit some materials in the computation of the embodied energy to simplify the number of variables.

The uncertainties regards the embodied energy of the materials in the VIPs, PUR panels, windows and PV panels. For the VIPs the uncertainties are related with the service life of the VIPs. Indeed their service life is 30 years according to [50], but the building service life is 50 years, so the panels should be replaced after 30 years with new panels. The embodied energy in this work was considered the same for the panels that are replaced after 30 years, but actually, the embodied energy of panels that will be produced in 30 years can be different due to technology evolutions.

Regarding the PUR panels the embodied energy was extracted from the environmental product declaration of a panel that is thinner than the used panel. To obtain the embodied energy of the used panel the normalization was done using the percentage in weight. This might be debatable because the embodied energy does not depend proportionally from the weight, but includes other factors. However the weight is surely a factor that condition the embodied energy, but not proportionally.

For the windows the embodied energy was calculated using the environmental product declaration of a window with different dimensions from the windows that are necessary. So a geometrically normalization was done to have the embodied energy of the used windows. However, the embodied energy of the window include the embodied energy of the materials. Changing the dimensions of the windows also the quantities of the materials and the embodied energy of the windows change but not proportionally. This error however is small because the windows present in this work have dimension comparable with the window that was used to extract the embodied energy.

Regarding the PV panels used, the same embodied energy was used for the different panel arrangements. This conduce to ignore the different technologies to place the panels in the different arrangements. Indeed the panel that is placed vertically presents a different supporting structure from the ground-mounted panel and so on. This simplification does not affect tragically the results but a most accurate study should include the different technologies in need to place the panels.

For each alternative to achieve the NZEB-OM level only embodied energy of the insulation and the windows was calculated. Actually, the different wall alternatives need different technologies to be placed (i.e. Timber stood, nails…). These were not included in the calculation of the embodied energy for the alternatives to reduce the variables and to focus the attention of the work on the different insulation types.

Indeed the energy production of the system depend obviously from the panel arrangement, and the embodied energy depend from the m^2 of PV panels used. So, even if the work present the embodied energy to produce the PV panels, these data are strongly dependent from the different arrangement of the panels.

8 CONCLUSIONS

This work shows how difficult is to define the NZEB concept and how many lacks are present in the existing NZEB definitions. The work shows how important are the considerations about the embodied energy, and how the total energy balance can change using different insulation types and considering or not the embodied energy to produce the PV panels that are necessary to achieve the aim of nearly zero energy building. The main goal of the work it has shown in the figures Figure 55-Figure 58 and Figure 59 where is visible the difference between the alternatives due to different embodied energy of the proposed materials. These figures show also both the importance to consider the maintenance phases and the big uncertainties due to the refurbishment works that need to be done in the future. Indeed considering the embodied energy that the PV panels will use in 30 years is a big limit of this study. This limitation is due to the evolving technologies that can reduce the embodied energy of the industrial processes and consequently the future prospective of the building change. Therefore, even if this work considers the embodied energy to produce the PV panels in 30 years the same of the today's embodied energy, the real embodied energy of the panel in 30 years could be different due to the current evolving technologies.

The results presented in the chapter 6 show the energy balance of a Nearly Zero Energy Building as defined from the most part of the Member States. However, the results of the chapter 6 are not very complete if the aim is the reduction of the total energy demand. For this motivation the energy used to produce the materials it has analysed in the chapter 7.

The results in the chapter 7 show the importance to choose the right material for the refurbishment. Indeed the difference between the material that have got the smallest and the highest embodied energy is high and the Figure 52 shows that the worst solution (VIP) has an embodied energy equal to 40% of the total energy used by the building, instead the best solution (MineralWool) has an embodied energy equal to 6,5 % of the total energy use. Therefore, it is possible to state that considering the embodied energy is extremely important because the variation of the embodied energy could be between the 5% and 40% of the energy used depending on the chosen material.

It is important to define that this work ignores aesthetical considerations that sometime can play an important role especially in the building sector and in the field of the Refurbishment Technology. Indeed, the worst solution considering the embodied energy use is at the same time the best solution considering the aesthetical preservation of the building. The best solution presented in the chapter 7 (Mineralwool) give as aesthetical result very thick components and consequently the building is not preserved considering aesthetical factors, so this solution under certain point of view is not the best.

Other important considerations need to be done regarding the maintenance and the end-of-life energy use. Indeed due to the high uncertainty of these data, this work does not consider the embodied energy used for both the maintenance and the end-of-life processes. One easy example regards the PV panels. Indeed, even if the replacement of the PV panels has been considered after 30 years according with the manufacturer, actually, other electrical components need to be replaced every 5/10 years. This work do not consider the replacement of these components that however affect a bit the embodied energy during the operational life.

The last part of this work however make consideration about the service life of the building. Regarding this topic, the work identify the worst solution speaking about the insulation. The worst solution for this work is the Vacuum Insulation Panel, but is important to state that could be less bad depending on the end-of life cycle for the different solutions. However, this work do not consider the end-of-life cycle of the solutions. Therefore, it is possible to state that according with this study the VIP panels represent the worst solution, but if we consider the end-of-life cycle this solution could be not the worst or less worst due to the different option to recycle and to reuse this material.

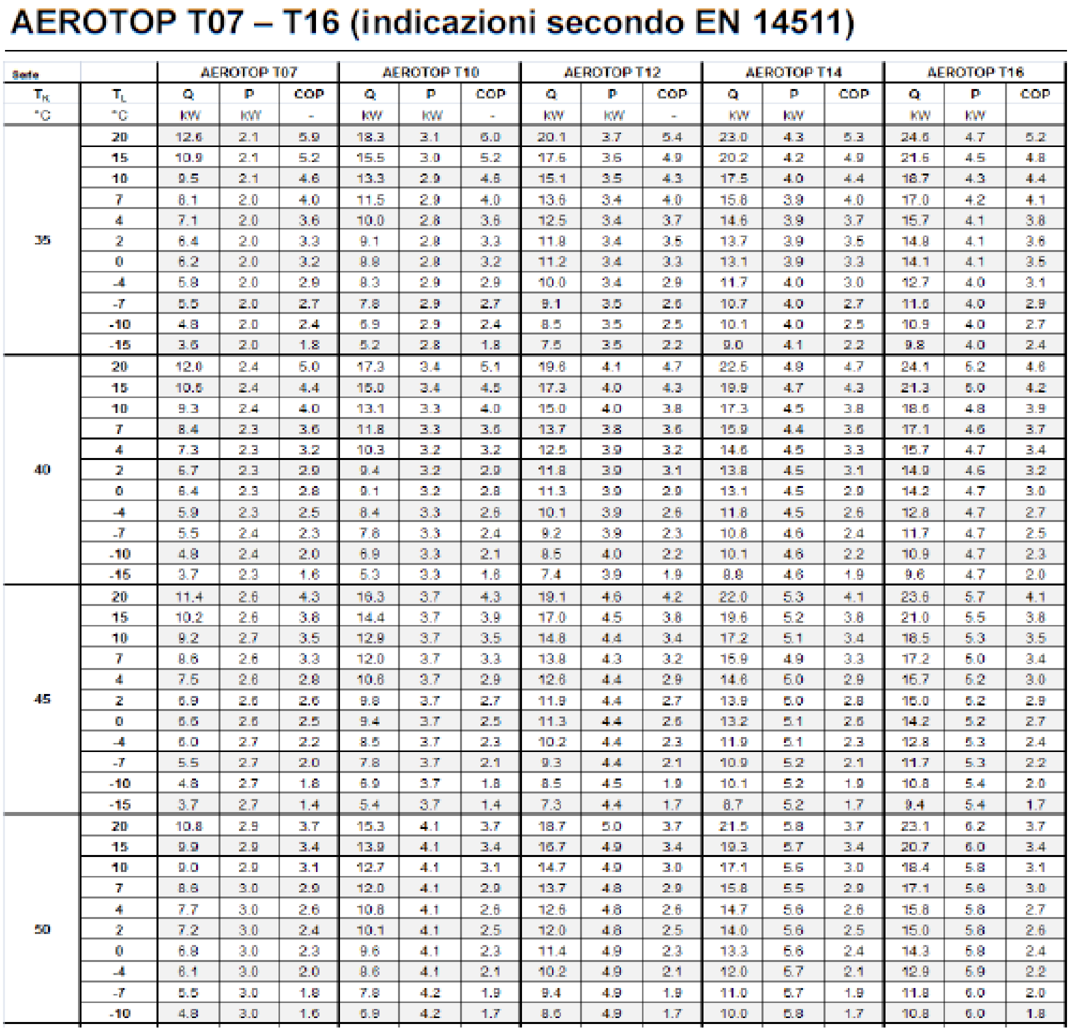
Interesting could be develop this study, focusing the attention on the different end-of-life scenarios. This can give an understanding on the importance of the end-of-life cycle for Refurbishment works. The results than can be integrated with both the energy used by the building and the embodied energy of the different alternatives.

The definitely conclusion of this work is that even if both energy used by the building and embodied energy of the material define a solution better than another, other considerations need to be included. These considerations are not treasurable. However, with its limitations this work shows that the European Union with the aim to reduce the energy use and the emission related with the construction industry considers only a small part of the whole problem that deal with the energy use in the building industry. The importance of the energy use of the building industry has huge importance as shown in the first picture of this work and the energy used to produce the material plays a central role.

The final consideration of this work shows that is not possible to define an optimal solution to retrofit a building considering that many variables goes inside the problem. However, together in some case it is possible to reject the worst solution that for the boundary condition of this work is the Vacuum Insulation Panel.

The work shows that the Refurbishment achieving the NZEB level have better effect if the engineer make considerations regarding the used materials. Thus, the NZEB design is always dependent from the aim of the design that influence the results.

9 Appendix I



AEROTOP T07 – T16 (indicazioni secondo EN 14511)

Serie		AEROTOP T07			AEROTOP T10			AEROTOP T12			AEROTOP T14			AEROTOP T16		
T_K	T_L	Q	P	COP	Q	P	COP	Q	P	COP	Q	P	COP	Q	P	COP
°C	°C	kW	kW	-	kW	kW	-	kW	kW	-	kW	kW		kW	kW	
35	20	12.6	2.1	5.9	18.3	3.1	6.0	20.1	3.7	5.4	23.0	4.3	5.3	24.6	4.7	5.2
	15	10.9	2.1	5.2	15.5	3.0	5.2	17.6	3.6	4.9	20.2	4.2	4.9	21.6	4.5	4.8
	10	9.5	2.1	4.6	13.3	2.9	4.6	15.1	3.5	4.3	17.5	4.0	4.4	18.7	4.3	4.4
	7	8.1	2.0	4.0	11.5	2.9	4.0	13.6	3.4	4.0	15.6	3.9	4.0	17.0	4.2	4.1
	4	7.1	2.0	3.6	10.0	2.8	3.6	12.5	3.4	3.7	14.6	3.9	3.7	15.7	4.1	3.8
	2	6.4	2.0	3.3	9.1	2.8	3.3	11.8	3.4	3.5	13.7	3.9	3.5	14.8	4.1	3.6
	0	6.2	2.0	3.2	8.8	2.8	3.2	11.2	3.4	3.3	13.1	3.9	3.3	14.1	4.1	3.5
	-4	5.8	2.0	2.9	8.3	2.9	2.9	10.0	3.4	2.9	11.7	4.0	3.0	12.7	4.0	3.1
	-7	5.5	2.0	2.7	7.8	2.9	2.7	9.1	3.5	2.6	10.7	4.0	2.7	11.6	4.0	2.9
	-10	4.8	2.0	2.4	6.9	2.9	2.4	8.5	3.5	2.5	10.1	4.0	2.5	10.9	4.0	2.7
	-15	3.6	2.0	1.8	5.2	2.8	1.8	7.5	3.5	2.2	9.0	4.1	2.2	9.8	4.0	2.4
40	20	12.0	2.4	5.0	17.3	3.4	5.1	19.6	4.1	4.7	22.5	4.8	4.7	24.1	5.2	4.6
	15	10.6	2.4	4.4	15.0	3.4	4.5	17.3	4.0	4.3	19.9	4.7	4.3	21.3	5.0	4.2
	10	9.3	2.4	4.0	13.1	3.3	4.0	15.0	4.0	3.8	17.3	4.5	3.8	18.6	4.8	3.9
	7	8.4	2.3	3.6	11.8	3.3	3.6	13.7	3.8	3.6	15.9	4.4	3.6	17.1	4.6	3.7
	4	7.3	2.3	3.2	10.3	3.2	3.2	12.5	3.9	3.2	14.6	4.5	3.3	15.7	4.7	3.4
	2	6.7	2.3	2.9	9.4	3.2	2.9	11.8	3.9	3.1	13.8	4.5	3.1	14.9	4.6	3.2
	0	6.4	2.3	2.8	9.1	3.2	2.8	11.3	3.9	2.9	13.1	4.5	2.9	14.2	4.7	3.0
	-4	5.9	2.3	2.5	8.4	3.3	2.6	10.1	3.9	2.6	11.8	4.5	2.6	12.8	4.7	2.7
	-7	5.5	2.4	2.3	7.6	3.3	2.4	9.2	3.9	2.3	10.8	4.6	2.4	11.7	4.7	2.5
	-10	4.8	2.4	2.0	6.9	3.3	2.1	8.5	4.0	2.2	10.1	4.6	2.2	10.9	4.7	2.3
	-15	3.7	2.3	1.6	5.3	3.3	1.6	7.4	3.9	1.9	8.8	4.6	1.9	9.6	4.7	2.0
45	20	11.4	2.6	4.3	16.3	3.7	4.3	19.1	4.6	4.2	22.0	5.3	4.1	23.6	5.7	4.1
	15	10.2	2.6	3.8	14.4	3.7	3.9	17.0	4.5	3.8	19.6	5.2	3.8	21.0	5.5	3.8
	10	9.2	2.7	3.5	12.9	3.7	3.5	14.8	4.4	3.4	17.2	5.1	3.4	18.5	5.3	3.5
	7	8.6	2.6	3.3	12.0	3.7	3.3	13.8	4.3	3.2	15.9	4.9	3.3	17.2	5.0	3.4
	4	7.5	2.6	2.8	10.8	3.7	2.9	12.6	4.4	2.9	14.6	5.0	2.9	15.7	5.2	3.0
	2	6.9	2.6	2.6	9.8	3.7	2.7	11.9	4.4	2.7	13.9	5.0	2.8	15.0	5.2	2.9
	0	6.6	2.6	2.5	9.4	3.7	2.5	11.3	4.4	2.6	13.2	5.1	2.6	14.2	5.2	2.7
	-4	6.0	2.7	2.2	8.5	3.7	2.3	10.2	4.4	2.3	11.9	5.1	2.3	12.8	5.3	2.4
	-7	5.5	2.7	2.0	7.8	3.7	2.1	9.3	4.4	2.1	10.9	5.2	2.1	11.7	5.3	2.2
	-10	4.8	2.7	1.8	6.9	3.7	1.8	8.5	4.5	1.9	10.1	5.2	1.9	10.8	5.4	2.0
	-15	3.7	2.7	1.4	5.4	3.7	1.4	7.3	4.4	1.7	8.7	5.2	1.7	9.4	5.4	1.7
50	20	10.8	2.9	3.7	15.3	4.1	3.7	18.7	5.0	3.7	21.5	5.8	3.7	23.1	6.2	3.7
	15	9.9	2.9	3.4	13.9	4.1	3.4	16.7	4.9	3.4	19.3	5.7	3.4	20.7	6.0	3.4
	10	9.0	2.9	3.1	12.7	4.1	3.1	14.7	4.9	3.0	17.1	5.6	3.0	18.4	5.8	3.1
	7	8.6	3.0	2.9	12.0	4.1	2.9	13.7	4.8	2.9	15.8	5.5	2.9	17.1	5.8	3.0
	4	7.7	3.0	2.6	10.8	4.1	2.6	12.6	4.8	2.6	14.7	5.6	2.6	15.8	5.8	2.7
	2	7.2	3.0	2.4	10.1	4.1	2.5	12.0	4.8	2.5	14.0	5.6	2.5	15.0	5.8	2.6
	0	6.8	3.0	2.3	9.6	4.1	2.3	11.4	4.9	2.3	13.3	5.6	2.4	14.3	5.8	2.4
	-4	6.1	3.0	2.0	8.6	4.1	2.1	10.2	4.9	2.1	12.0	5.7	2.1	12.9	5.9	2.2
	-7	5.5	3.0	1.8	7.8	4.2	1.9	9.4	4.9	1.9	11.0	5.7	1.9	11.8	6.0	2.0
	-10	4.8	3.0	1.6	6.9	4.2	1.7	8.6	4.9	1.7	10.0	5.8	1.7	10.8	6.0	1.8

Table 21. Technical data of the air-source Heat Pump. The chosen Heat Pump is the type called AEROTOP T10 and the chosen temperature of water equal to 40°. Source [6]

10 Appendix II

Parameter	UM	VALUE
External walls U-walls (East-Wall)	W/m²k	0,098
External walls U-walls (North-South)	W/m²k	0,103
Roof U-Value	W/m²k	0,084
Basement Floor U-Value	W/m²k	0,084
Staircase walls U-Value	W/m²k	0,34
Windows/Doors U-Value	W/m²k	0,8
Location	-	SKEDSMOKORSET
Costant Ground Temperature	°C	15
Internal mass normal partition for floor	m^2	177,4
Internal mass structural partition for floor	m^2	398,4
Internal gains prople	n/floor	28
Internal gains light	W/m^2	1,95
Internal gains Electic Equipment	W/m^2	3
Zone infiltration rate	ach	0,6
Zone ventilation rate	m^3/sm^2	0,023-0,026
Design indoor temperature	°C	21
Design indoor temperature	°C	19
Winter COP	-	2,9
Summer COP	-	4,5

Table 22.Value and parameter used in the energy model.

11 Appendix III

Parametre	Energy use	
Heating	kWhy^{-1}	45990,33
	kWhy^{-1}m^{-2}	28,54982
Cooling	kWhy^{-1}	11014,62
	kWhy^{-1}m^{-2}	6,837642
Fan	kWhy^{-1}	10731,84
	kWhy^{-1}m^{-2}	6,662098
Lighting	kWhy^{-1}	18344,7
	kWhy^{-1}m^{-2}	11,388
DHW	kWhy^{-1}	48326,4
	kWhy^{-1}m^{-2}	30
TOTAL	kWhy^{-1}	134407,9
	kWhy^{-1}m^{-2}	83,43756

Table 23. Energy used by the building after the refurbishment. The table presents the energy used for Heating, Lighting, produce Domestic Hot Water and by the Fans

Month	Heating		Cooling		Fan		Lighting		DHW		TOTAL building	
	kWhm^{-2}	kWh	kWhm^{-2}	kWh	kWhm^{-2}	kWh	kWhm^{-2}	kWh	kWhm^{-2}	kWh	kWhm^{-2}	kWh
January	8,038916617	12949,73	0	0	1,337548421	2154,63	0,96720426	1558,05	2,5	4027,2	12,8436693	20689,61
February	5,163910409	8318,44	0	0	0,88218241	1421,09	0,87360325	1407,27	2,5	4027,2	9,41969607	15174
March	3,432124056	5528,74	6,82857E-05	0,11	0,558551847	899,76	0,96720426	1558,05	2,5	4027,2	7,45794845	12013,86
April	0,4954559	798,12	0,049289829	79,4	0,093569974	150,73	0,93599151	1507,77	2,5	4027,2	4,07430721	6563,22
May	0,043181367	69,56	0,994170888	1601,49	0,31261174	503,58	0,96720426	1558,05	2,5	4027,2	4,81716826	7759,88
June	0	0	1,498460469	2413,84	0,452982221	729,7	0,93599151	1507,77	2,5	4027,2	5,3874342	8678,51
July	0	0	2,129351659	3430,13	0,614645411	990,12	0,96720426	1558,05	2,5	4027,2	6,21120133	10005,5
August	0	0	1,660434048	2674,76	0,481780145	776,09	0,96720426	1558,05	2,5	4027,2	5,60941845	9036,1
September	0,013731625	22,12	0,479514303	772,44	0,148297825	238,89	0,93599151	1507,77	2,5	4027,2	4,07753526	6568,42
October	0,600702721	967,66	0,026352056	42,45	0,096884932	156,07	0,96720426	1558,05	2,5	4027,2	4,19114397	6751,43
November	4,102900278	6609,28	0	0	0,654530443	1054,37	0,93599151	1507,77	2,5	4027,2	8,19342223	13198,62
December	6,658894517	10726,68	0	0	1,028512366	1656,81	0,96720426	1558,05	2,5	4027,2	11,1546111	17968,74

Table 24. Monthly energy demand of the building for heating, cooling, fan lighting and DHW

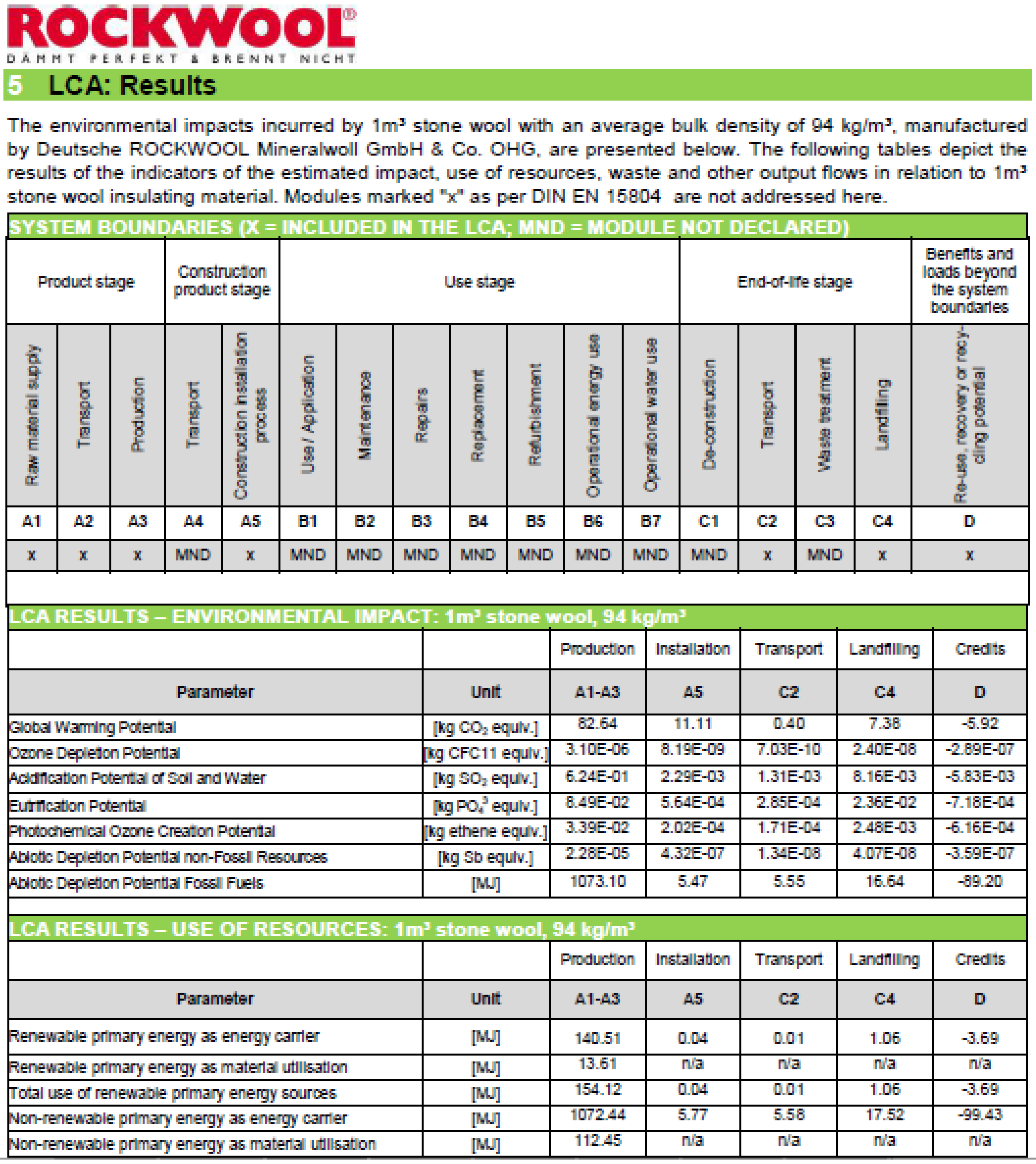
Month	Electicity Produced					
	1 pv 40° not shaded		1 PV 40° sheaded		1 vertical PV	
-	kWh	kWhm^{-2}	kWh	kWhm^{-2}	kWh	kWhm^{-2}
January	8,302080402	13373,65528	4,135233307	6661,364629	8,879307828	14303,49939
February	14,08896496	22695,63187	8,460340886	13628,59393	13,01440763	20964,64897
March	33,58946026	54108,58975	23,26029269	37469,54029	26,59794381	42846,09573
April	46,24432327	74494,05548	35,30661546	56874,72072	30,21319566	48669,83263
May	69,31191944	111653,1848	56,5162296	91040,86393	38,06714998	61321,61057
June	70,8881971	114192,3789	59,15442007	95290,67221	36,35278677	58559,97715
July	69,32681386	111677,1779	57,25822199	92236,12463	36,65750779	59050,84615
August	55,41183113	89261,81054	43,57438012	70193,09745	33,49926873	53963,30201
September	33,92512848	54649,31096	25,39157361	40902,7781	23,21345507	37394,09051
October	20,69438478	33336,17056	13,9687786	22502,02607	16,89180036	27210,66336
November	8,369951028	13482,98671	4,506909519	7260,090406	8,395034566	13523,39328
December	4,322381838	6962,838455	2,011898448	3240,926972	4,709684549	7586,736646

Table 25. PV monthly electricity produced for the different arrangements proposed.

Month	Energy productionof the PV system							
	TOTAL roof		TOTAL wall		TOTAL gound		TOTAL PV system	
	kWhm^{-2}	kWhm^{-2}y^{-1}	kWhm^{-2}	kWhm^{-2}y^{-1}	kWhm^{-2}	kWhm^{-2}y^{-1}	kWhm^{-2}	kWhm^{-2}y^{-1}
January	0,523798965	843,7772773	0,295502619	476,0192581	0,169622527	273,2415361	0,988924111	1593,038072
February	1,060860672	1708,91924	0,440271998	709,2253561	0,329053269	530,0653303	1,83018594	2948,209926
March	2,897492649	4667,512958	0,917658711	1478,238065	0,872732957	1405,868066	4,687884317	7551,619089
April	4,38042319	7056,336109	1,072518953	1727,699331	1,295284282	2086,547544	6,748226426	10870,58298
May	6,994305969	11266,9876	1,392465432	2243,094716	2,044140939	3292,865756	10,43091234	16802,94807
June	7,31462172	11782,97784	1,347253022	2170,262947	2,129261829	3429,985294	10,79113657	17383,22608
July	7,082799156	11409,5395	1,350517268	2175,521257	2,065421602	3327,14635	10,49873803	16912,20711
August	5,399999981	8698,75197	1,204581276	1940,435886	1,588287021	2558,539797	8,192868279	13197,72765
September	3,152769235	5078,732905	0,818060075	1317,796614	0,93567719	1507,263671	4,9065065	7903,79319
October	1,742011696	2806,1718	0,580411158	934,972726	0,527356267	849,5076635	2,849779121	4590,65219
November	0,568351667	915,5463338	0,281325341	453,1813653	0,180657372	291,0173482	1,030334381	1659,745047
December	0,255896648	412,218793	0,156435706	251,9991494	0,084283837	135,771147	0,496616191	799,9890894
TOTAL	41,37333155	66647,47233	9,857001559	15878,44667	12,22177909	19687,8195	63,4521122	102213,7385

Table 26. PV system energy production. The results show the production of the different part of the system

12 Appendix IV



ROCKWOOL®
DÄMMT PERFEKT & BRENNT NICHT

5 LCA: Results

The environmental impacts incurred by 1m³ stone wool with an average bulk density of 94 kg/m³, manufactured by Deutsche ROCKWOOL Mineralwoll GmbH & Co. OHG, are presented below. The following tables depict the results of the indicators of the estimated impact, use of resources, waste and other output flows in relation to 1m³ stone wool insulating material. Modules marked "x" as per DIN EN 15804 are not addressed here.

SYSTEM BOUNDARIES (X = INCLUDED IN THE LCA; MND = MODULE NOT DECLARED)

Product stage			Construction product stage		Use stage							End-of-life stage				Benefits and loads beyond the system boundaries
Raw material supply	Transport	Production	Transport	Construction installation process	Use / Application	Maintenance	Repairs	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction	Transport	Waste treatment	Landfilling	Re-use, recovery or recycling potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
x	x	x	MND	x	MND	MND	MND	MND	MND	MND	MND	MND	x	MND	x	x

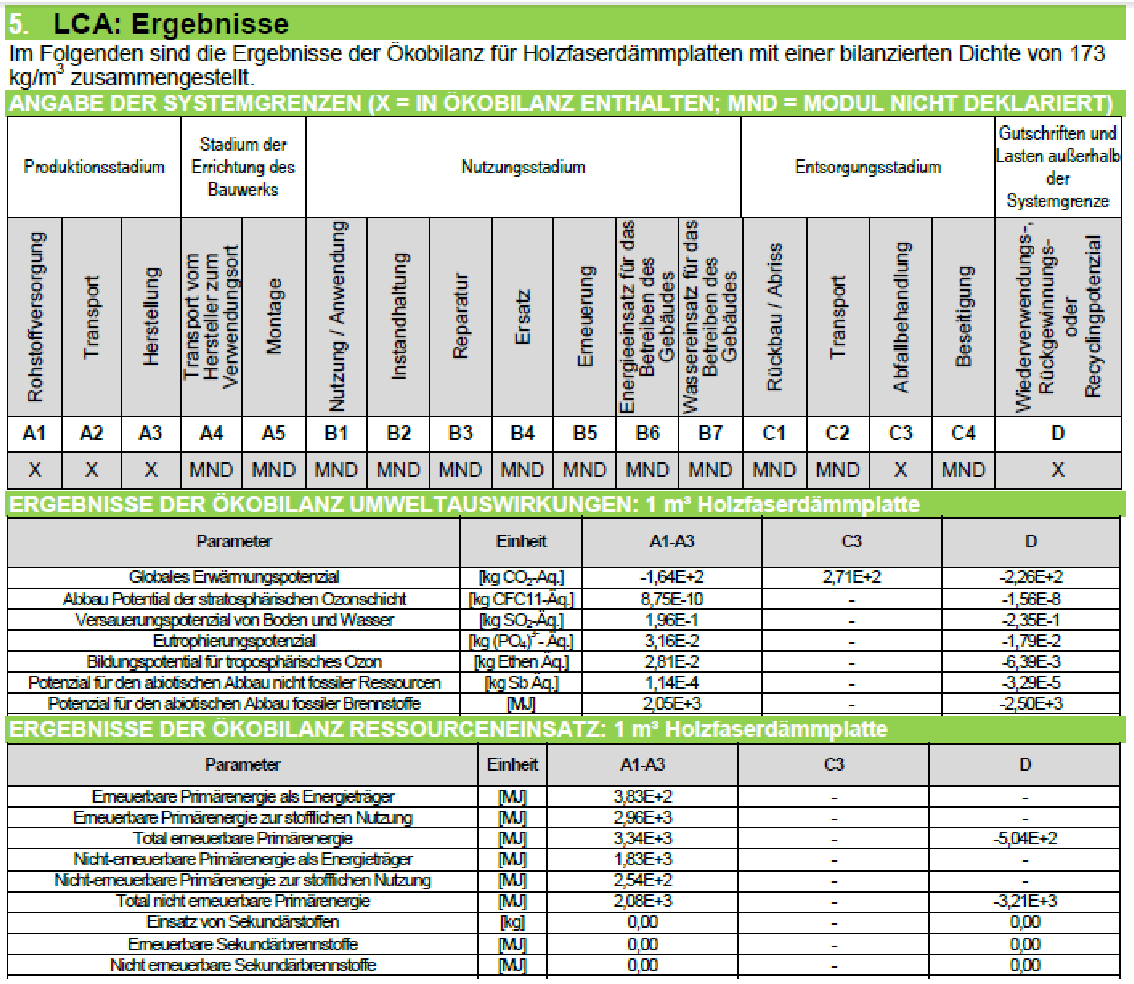
LCA RESULTS – ENVIRONMENTAL IMPACT: 1m³ stone wool, 94 kg/m³

		Production	Installation	Transport	Landfilling	Credits
Parameter	**Unit**	**A1-A3**	**A5**	**C2**	**C4**	**D**
Global Warming Potential	[kg CO_2 equiv.]	82.64	11.11	0.40	7.38	-5.92
Ozone Depletion Potential	[kg CFC11 equiv.]	3.10E-06	8.19E-09	7.03E-10	2.40E-08	-2.89E-07
Acidification Potential of Soil and Water	[kg SO_2 equiv.]	6.24E-01	2.29E-03	1.31E-03	8.16E-03	-5.83E-03
Eutrification Potential	[kg PO_4^{3} equiv.]	8.49E-02	5.64E-04	2.85E-04	2.36E-02	-7.18E-04
Photochemical Ozone Creation Potential	[kg ethene equiv.]	3.39E-02	2.02E-04	1.71E-04	2.48E-03	-6.16E-04
Abiotic Depletion Potential non-Fossil Resources	[kg Sb equiv.]	2.28E-05	4.32E-07	1.34E-08	4.07E-08	-3.59E-07
Abiotic Depletion Potential Fossil Fuels	[MJ]	1073.10	5.47	5.55	16.64	-89.20

LCA RESULTS – USE OF RESOURCES: 1m³ stone wool, 94 kg/m³

		Production	Installation	Transport	Landfilling	Credits
Parameter	**Unit**	**A1-A3**	**A5**	**C2**	**C4**	**D**
Renewable primary energy as energy carrier	[MJ]	140.51	0.04	0.01	1.06	-3.69
Renewable primary energy as material utilisation	[MJ]	13.61	n/a	n/a	n/a	n/a
Total use of renewable primary energy sources	[MJ]	154.12	0.04	0.01	1.06	-3.69
Non-renewable primary energy as energy carrier	[MJ]	1072.44	5.77	5.58	17.52	-99.43
Non-renewable primary energy as material utilisation	[MJ]	112.45	n/a	n/a	n/a	n/a

Figure 61 Environmental product declaration of Mineral Wool. Source [38].



5. LCA: Ergebnisse

Im Folgenden sind die Ergebnisse der Ökobilanz für Holzfaserdämmplatten mit einer bilanzierten Dichte von 173 kg/m^3 zusammengestellt.

ANGABE DER SYSTEMGRENZEN (X = IN ÖKOBILANZ ENTHALTEN; MND = MODUL NICHT DEKLARIERT)

Produktionsstadium			Stadium der Errichtung des Bauwerks		Nutzungsstadium							Entsorgungsstadium				Gutschriften und Lasten außerhalb der Systemgrenze
Rohstoffversorgung	Transport	Herstellung	Transport vom Hersteller zum Verwendungsort	Montage	Nutzung / Anwendung	Instandhaltung	Reparatur	Ersatz	Erneuerung	Energieeinsatz für das Betreiben des Gebäudes	Wassereinsatz für das Betreiben des Gebäudes	Rückbau / Abriss	Transport	Abfallbehandlung	Beseitigung	Wiederverwendungs-, Rückgewinnungs- oder Recyclingpotenzial
A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	X	MND	X

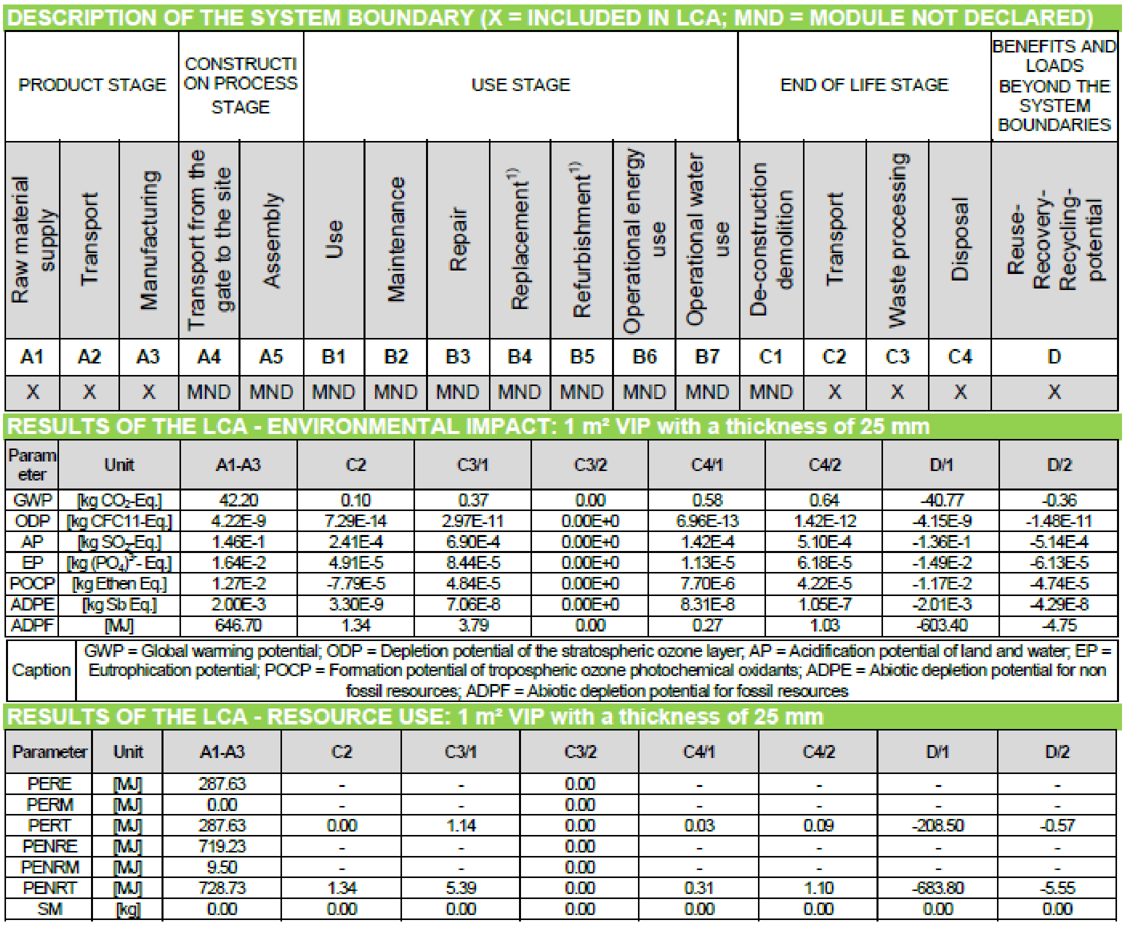
ERGEBNISSE DER ÖKOBILANZ UMWELTAUSWIRKUNGEN: 1 m³ Holzfaserdämmplatte

Parameter	Einheit	A1-A3	C3	D
Globales Erwärmungspotenzial	[kg CO_2-Aq.]	-1,64E+2	2,71E+2	-2,26E+2
Abbau Potential der stratosphärischen Ozonschicht	[kg CFC11-Äq.]	8,75E-10	-	-1,56E-8
Versauerungspotenzial von Boden und Wasser	[kg SO_2-Äq.]	1,96E-1	-	-2,35E-1
Eutrophierungspotenzial	[kg $(PO_4)^{3-}$- Äq.]	3,16E-2	-	-1,79E-2
Bildungspotential für troposphärisches Ozon	[kg Ethen Äq.]	2,81E-2	-	-6,39E-3
Potenzial für den abiotischen Abbau nicht fossiler Ressourcen	[kg Sb Äq.]	1,14E-4	-	-3,29E-5
Potenzial für den abiotischen Abbau fossiler Brennstoffe	[MJ]	2,05E+3	-	-2,50E+3

ERGEBNISSE DER ÖKOBILANZ RESSOURCENEINSATZ: 1 m³ Holzfaserdämmplatte

Parameter	Einheit	A1-A3	C3	D
Erneuerbare Primärenergie als Energieträger	[MJ]	3,83E+2	-	-
Erneuerbare Primärenergie zur stofflichen Nutzung	[MJ]	2,96E+3	-	-
Total erneuerbare Primärenergie	[MJ]	3,34E+3	-	-5,04E+2
Nicht-erneuerbare Primärenergie als Energieträger	[MJ]	1,83E+3	-	-
Nicht-erneuerbare Primärenergie zur stofflichen Nutzung	[MJ]	2,54E+2	-	-
Total nicht erneuerbare Primärenergie	[MJ]	2,08E+3	-	-3,21E+3
Einsatz von Sekundärstoffen	[kg]	0,00	-	0,00
Erneuerbare Sekundärbrennstoffe	[MJ]	0,00	-	0,00
Nicht erneuerbare Sekundärbrennstoffe	[MJ]	0,00	-	0,00

Figure 62. Environmental Product Declaration of wood fibre boards. Source [39]



DESCRIPTION OF THE SYSTEM BOUNDARY (X = INCLUDED IN LCA; MND = MODULE NOT DECLARED)

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARIES
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement$^{1)}$	Refurbishment$^{1)}$	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	X	X	X	X

RESULTS OF THE LCA - ENVIRONMENTAL IMPACT: 1 m² VIP with a thickness of 25 mm

Parameter	Unit	A1-A3	C2	C3/1	C3/2	C4/1	C4/2	D/1	D/2
GWP	[kg CO$_2$-Eq.]	42.20	0.10	0.37	0.00	0.58	0.64	-40.77	-0.36
ODP	[kg CFC11-Eq.]	4.22E-9	7.29E-14	2.97E-11	0.00E+0	6.96E-13	1.42E-12	-4.15E-9	-1.48E-11
AP	[kg SO$_2$-Eq.]	1.46E-1	2.41E-4	6.90E-4	0.00E+0	1.42E-4	5.10E-4	-1.36E-1	-5.14E-4
EP	[kg (PO$_4$)$^{3-}$- Eq.]	1.64E-2	4.91E-5	8.44E-5	0.00E+0	1.13E-5	6.18E-5	-1.49E-2	-6.13E-5
POCP	[kg Ethen Eq.]	1.27E-2	-7.79E-5	4.84E-5	0.00E+0	7.70E-6	4.22E-5	-1.17E-2	-4.74E-5
ADPE	[kg Sb Eq.]	2.00E-3	3.30E-9	7.06E-8	0.00E+0	8.31E-8	1.05E-7	-2.01E-3	-4.29E-8
ADPF	[MJ]	646.70	1.34	3.79	0.00	0.27	1.03	-603.40	-4.75

Caption	GWP = Global warming potential; ODP = Depletion potential of the stratospheric ozone layer; AP = Acidification potential of land and water; EP = Eutrophication potential; POCP = Formation potential of tropospheric ozone photochemical oxidants; ADPE = Abiotic depletion potential for non fossil resources; ADPF = Abiotic depletion potential for fossil resources

RESULTS OF THE LCA - RESOURCE USE: 1 m² VIP with a thickness of 25 mm

Parameter	Unit	A1-A3	C2	C3/1	C3/2	C4/1	C4/2	D/1	D/2
PERE	[MJ]	287.63	-	-	0.00	-	-	-	-
PERM	[MJ]	0.00	-	-	0.00	-	-	-	-
PERT	[MJ]	287.63	0.00	1.14	0.00	0.03	0.09	-208.50	-0.57
PENRE	[MJ]	719.23	-	-	0.00	-	-	-	-
PENRM	[MJ]	9.50	-	-	0.00	-	-	-	-
PENRT	[MJ]	728.73	1.34	5.39	0.00	0.31	1.10	-683.80	-5.55
SM	[kg]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 63. Environmental product declaration of Vacuum Insulation Panel. Source [41]

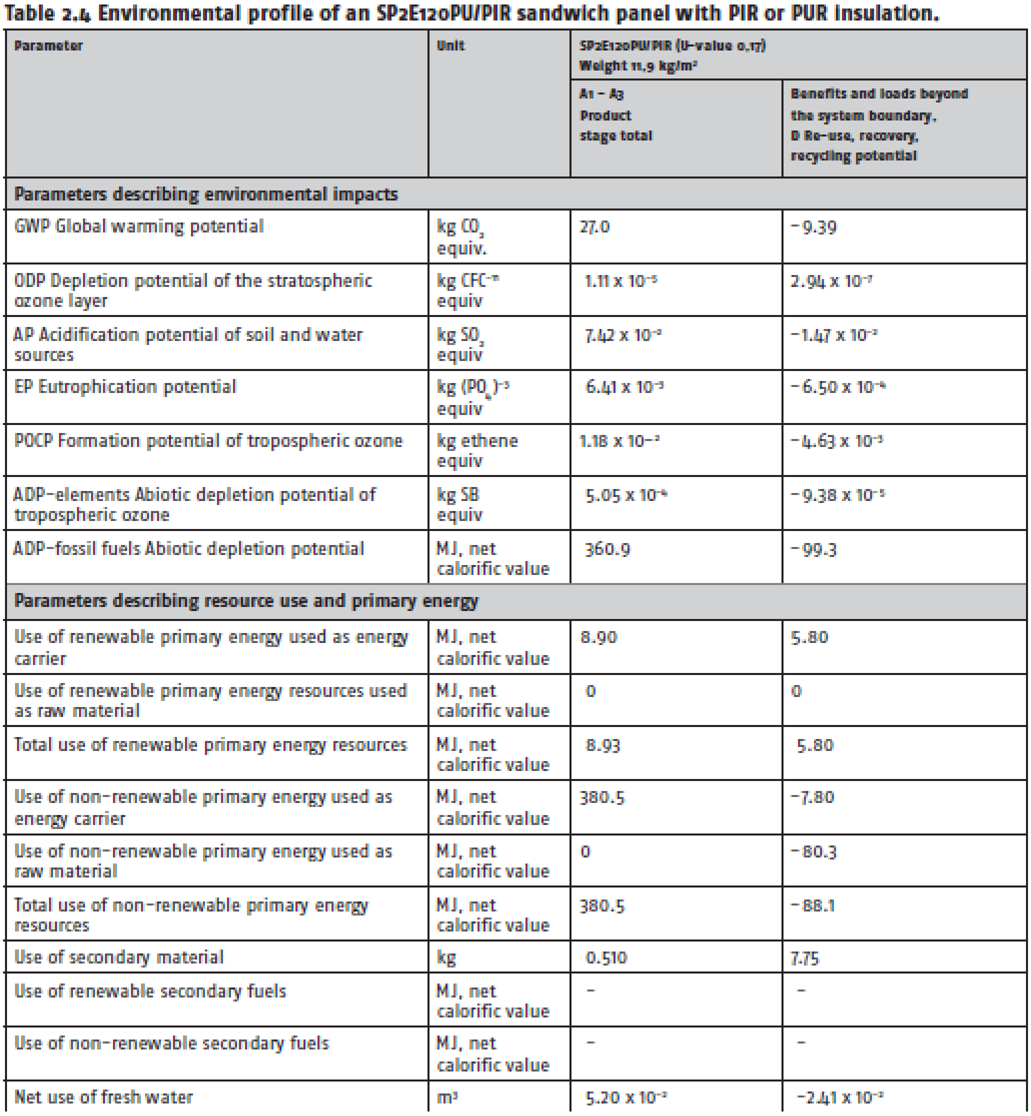
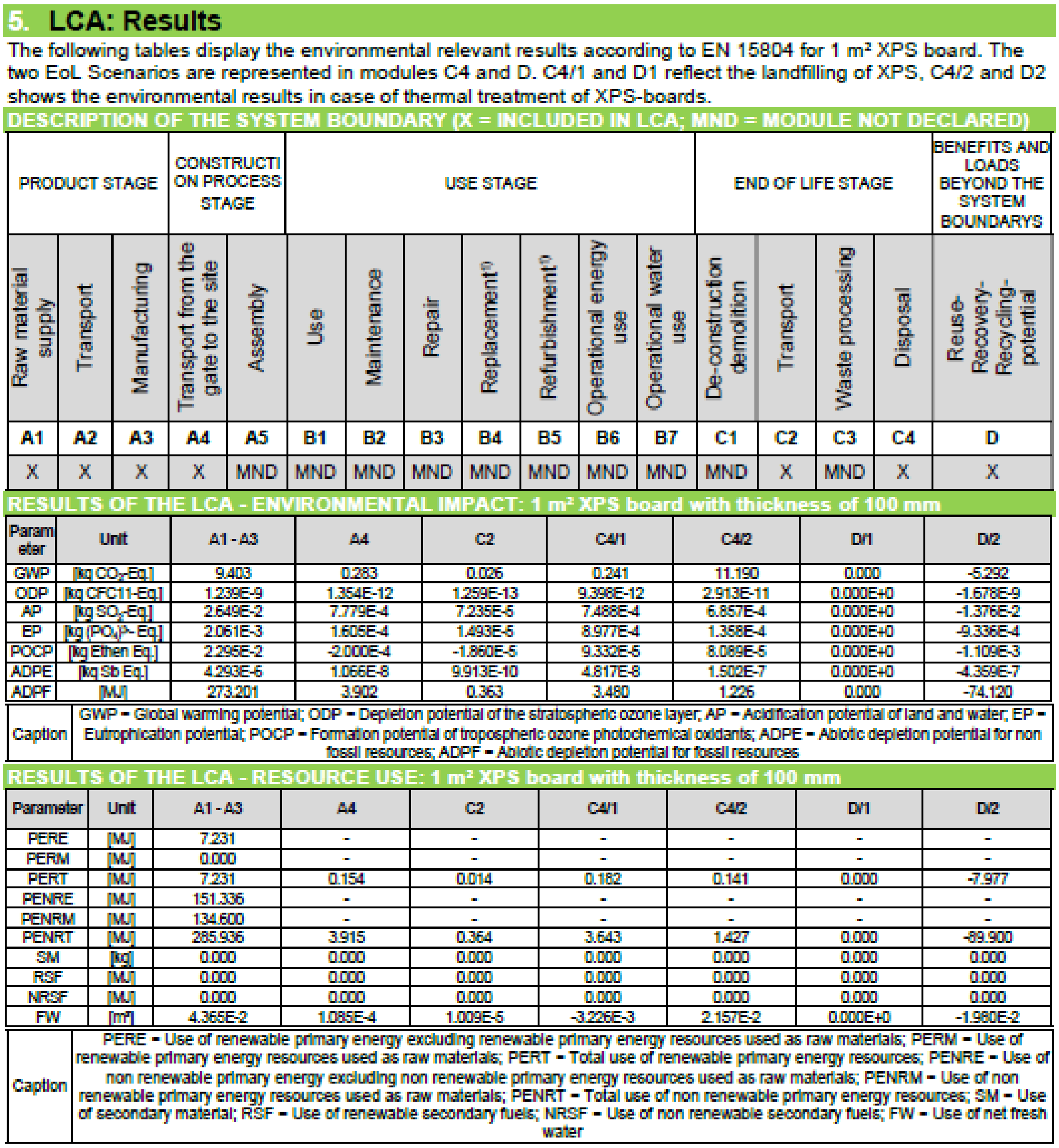


Table 2.4 Environmental profile of an SP2E120PU/PIR sandwich panel with PIR or PUR insulation.

Parameter	Unit	SP2E120PU/PIR (U-value 0,17) Weight 11,9 kg/m²	
		A1 – A3 Product stage total	Benefits and loads beyond the system boundary, D Re-use, recovery, recycling potential
Parameters describing environmental impacts			
GWP Global warming potential	kg CO_2 equiv.	27.0	−9.39
ODP Depletion potential of the stratospheric ozone layer	kg CFC-11 equiv	1.11×10^{-5}	2.94×10^{-7}
AP Acidification potential of soil and water sources	kg SO_2 equiv	7.42×10^{-2}	-1.47×10^{-2}
EP Eutrophication potential	kg $(PO_4)^{-3}$ equiv	6.41×10^{-3}	-6.50×10^{-4}
POCP Formation potential of tropospheric ozone	kg ethene equiv	1.18×10^{-2}	-4.63×10^{-3}
ADP-elements Abiotic depletion potential of tropospheric ozone	kg SB equiv	5.05×10^{-4}	-9.38×10^{-5}
ADP-fossil fuels Abiotic depletion potential	MJ, net calorific value	360.9	−99.3
Parameters describing resource use and primary energy			
Use of renewable primary energy used as energy carrier	MJ, net calorific value	8.90	5.80
Use of renewable primary energy resources used as raw material	MJ, net calorific value	0	0
Total use of renewable primary energy resources	MJ, net calorific value	8.93	5.80
Use of non-renewable primary energy used as energy carrier	MJ, net calorific value	380.5	−7.80
Use of non-renewable primary energy used as raw material	MJ, net calorific value	0	−80.3
Total use of non-renewable primary energy resources	MJ, net calorific value	380.5	−88.1
Use of secondary material	kg	0.510	7.75
Use of renewable secondary fuels	MJ, net calorific value	-	-
Use of non-renewable secondary fuels	MJ, net calorific value	-	-
Net use of fresh water	m³	5.20×10^{-2}	-2.41×10^{-2}

Figure 64. Environmental Product declaration for the PUR sandwich panel. Source [42]



5. LCA: Results

The following tables display the environmental relevant results according to EN 15804 for 1 m² XPS board. The two EoL Scenarios are represented in modules C4 and D. C4/1 and D1 reflect the landfilling of XPS, C4/2 and D2 shows the environmental results in case of thermal treatment of XPS-boards.

DESCRIPTION OF THE SYSTEM BOUNDARY (X = INCLUDED IN LCA; MND = MODULE NOT DECLARED)

PRODUCT STAGE			CONSTRUCTION PROCESS STAGE		USE STAGE							END OF LIFE STAGE				BENEFITS AND LOADS BEYOND THE SYSTEM BOUNDARYS
Raw material supply	Transport	Manufacturing	Transport from the gate to the site	Assembly	Use	Maintenance	Repair	Replacement1)	Refurbishment1)	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
A1	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
X	X	X	X	MND	MND	MND	MND	MND	MND	MND	MND	MND	X	MND	X	X

RESULTS OF THE LCA - ENVIRONMENTAL IMPACT: 1 m² XPS board with thickness of 100 mm

Parameter	Unit	A1 - A3	A4	C2	C4/1	C4/2	D/1	D/2
GWP	[kg CO_2-Eq.]	9.403	0.283	0.026	0.241	11.190	0.000	-5.292
ODP	[kg CFC11-Eq.]	1.239E-9	1.354E-12	1.259E-13	9.398E-12	2.913E-11	0.000E+0	-1.678E-9
AP	[kg SO_2-Eq.]	2.649E-2	7.779E-4	7.235E-5	7.488E-4	6.857E-4	0.000E+0	-1.376E-2
EP	[kg $(PO_4)^{3-}$- Eq.]	2.061E-3	1.605E-4	1.493E-5	8.977E-4	1.358E-4	0.000E+0	-9.336E-4
POCP	[kg Ethen Eq.]	2.295E-2	-2.000E-4	-1.860E-5	9.332E-5	8.089E-5	0.000E+0	-1.109E-3
ADPE	[kg Sb Eq.]	4.293E-6	1.066E-8	9.913E-10	4.817E-8	1.502E-7	0.000E+0	-4.359E-7
ADPF	[MJ]	273.201	3.902	0.363	3.480	1.226	0.000	-74.120
Caption	GWP = Global warming potential; ODP = Depletion potential of the stratospheric ozone layer; AP = Acidification potential of land and water; EP = Eutrophication potential; POCP = Formation potential of tropospheric ozone photochemical oxidants; ADPE = Abiotic depletion potential for non fossil resources; ADPF = Abiotic depletion potential for fossil resources							

RESULTS OF THE LCA - RESOURCE USE: 1 m² XPS board with thickness of 100 mm

Parameter	Unit	A1 - A3	A4	C2	C4/1	C4/2	D/1	D/2
PERE	[MJ]	7.231	-	-	-	-	-	-
PERM	[MJ]	0.000	-	-	-	-	-	-
PERT	[MJ]	7.231	0.154	0.014	0.182	0.141	0.000	-7.977
PENRE	[MJ]	151.336	-	-	-	-	-	-
PENRM	[MJ]	134.600	-	-	-	-	-	-
PENRT	[MJ]	285.936	3.915	0.364	3.643	1.427	0.000	-89.900
SM	[kg]	0.000	0.000	0.000	0.000	0.000	0.000	0.000
RSF	[MJ]	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NRSF	[MJ]	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FW	[m³]	4.365E-2	1.085E-4	1.009E-5	-3.226E-3	2.157E-2	0.000E+0	-1.980E-2
Caption	PERE = Use of renewable primary energy excluding renewable primary energy resources used as raw materials; PERM = Use of renewable primary energy resources used as raw materials; PERT = Total use of renewable primary energy resources; PENRE = Use of non renewable primary energy excluding non renewable primary energy resources used as raw materials; PENRM = Use of non renewable primary energy resources used as raw materials; PENRT = Total use of non renewable primary energy resources; SM = Use of secondary material; RSF = Use of renewable secondary fuels; NRSF = Use of non renewable secondary fuels; FW = Use of net fresh water							

Figure 65.Environmental Product Declaration of XPS panels. Source [40]

13 Appendix V

Solution name	EMBODIED ENERGY	
	Insulation	Windows
	$kWhy^{-1}m^{-2}$	$kWhy^{-1}m^{-2}$
Alternative 1	2,61	1,42
Alternative 2	4,70	1,42
Alternative 3	23,54	1,42
Alternative 4	3,43	1,42

Table 27. Embodied energy used to retrofit with the proposed alternatives.

Solution name	ENERGY USED		ENERGY PRODUCTION
	Embodied energy	Energy used by the refurbished building	PV panels
	kWh/m^2y	kWh/m^2y	kWh/m^2y
Alternative 1	4,03	83,44	67,59
Alternative 2	6,12	83,44	69,66
Alternative 3	24,95	83,44	88,51
Alternative 4	4,85	83,44	68,21

Table 28. The Nearly ZEB-OM balance of the building in the 4 alternative proposed. Alternative 1 uses MineralWool as insulation, Alterative 2 uses Wood fibre boards as insulation, Alternative 3 uses VIPs as insulation, Alternative 4 uses PUR sandwich panels and XPS boards. The energy use and production are presented normalized to 1 m^2 of conditioned building area and 1 year. The 4 alternatives uses different number of PV-panels in order to achieve the nZEB-OM concept.

Solution name	ENERGY USE				ENERGY PRODUCTION
	Operational energy	Embodied energy	PV embodied energy	Total energy use	PV system energy production
	kWh/m^2y	kWh/m^2y	kWh/m^2y	kWh/m^2y	kWh/m^2y
Alternative 1	83,44	4,03	14,95	102,41	67,59
Alternative 2	83,44	6,12	15,61	105,17	69,66
Alternative 3	83,44	24,95	20,08	128,47	88,51
Alternative 4	83,44	4,85	15,70	103,98	68,21

Table 29. Total energy use of the alternatives. For the PV embodied energy the Alternative 1 uses 328 PV panels, the Alternative 2 uses 338 PV panels, the Alternative 3 uses 429 PV panels and the Alternative 4 uses 331 PV panels. The energy use and energy production are normalized to 1m^2 of conditioned building surface and 1 year.

14 Appendix VI

	MINERAL WOOL (Alternative 1)						
YEAR	Energy used by the building	Embodied energy insulation	Embodied energy windows	Embodied energy PV	Energy production	NZEB-OM + PV Embodied energy	NZEB-OM building
0		130,5676699	701,7097141	269,0191008		1101,296485	832,277384
1	83,43755587				67,59326355	1117,140777	848,1216763
2	83,43755587				67,59326355	1132,985069	863,9659687
3	83,43755587				67,59326355	1148,829362	879,810261
4	83,43755587				67,59326355	1164,673654	895,6545533
5	83,43755587				67,59326355	1180,517946	911,4988456
6	83,43755587				67,59326355	1196,362239	927,3431379
7	83,43755587				67,59326355	1212,206531	943,1874303
8	83,43755587				67,59326355	1228,050823	959,0317226
9	83,43755587				67,59326355	1243,895116	974,8760149
10	83,43755587				67,59326355	1259,739408	990,7203072
11	83,43755587				67,59326355	1275,5837	1006,5646
12	83,43755587				67,59326355	1291,427993	1022,408892
13	83,43755587				67,59326355	1307,272285	1038,253184
14	83,43755587				67,59326355	1323,116577	1054,097476
15	83,43755587				67,59326355	1338,96087	1069,941769
16	83,43755587				67,59326355	1354,805162	1085,786061
17	83,43755587				67,59326355	1370,649454	1101,630353
18	83,43755587				67,59326355	1386,493747	1117,474646
19	83,43755587				67,59326355	1402,338039	1133,318938
20	83,43755587				67,59326355	1418,182331	1149,16323
21	83,43755587				67,59326355	1434,026624	1165,007523
22	83,43755587				67,59326355	1449,870916	1180,851815
23	83,43755587				67,59326355	1465,715208	1196,696107
24	83,43755587				67,59326355	1481,5595	1212,5404
25	83,43755587				67,59326355	1497,403793	1228,384692
26	83,43755587				67,59326355	1513,248085	1244,228984
27	83,43755587				67,59326355	1529,092377	1260,073277
28	83,43755587				67,59326355	1544,93667	1275,917569
29	83,43755587				67,59326355	1560,780962	1291,761861
30	83,43755587			179,3460672	67,59326355	1755,971322	1307,606154
31	83,43755587				67,59326355	1771,815614	1323,450446
32	83,43755587				67,59326355	1787,659906	1339,294738
33	83,43755587				67,59326355	1803,504199	1355,139031
34	83,43755587				67,59326355	1819,348491	1370,983323
35	83,43755587				67,59326355	1835,192783	1386,827615
36	83,43755587				67,59326355	1851,037076	1402,671908
37	83,43755587				67,59326355	1866,881368	1418,5162
38	83,43755587				67,59326355	1882,72566	1434,360492
39	83,43755587				67,59326355	1898,569952	1450,204784
40	83,43755587				67,59326355	1914,414245	1466,049077
41	83,43755587				67,59326355	1930,258537	1481,893369
42	83,43755587				67,59326355	1946,102829	1497,737661
43	83,43755587				67,59326355	1961,947122	1513,581954
44	83,43755587				67,59326355	1977,791414	1529,426246
45	83,43755587				67,59326355	1993,635706	1545,270538
46	83,43755587				67,59326355	2009,479999	1561,114831
47	83,43755587				67,59326355	2025,324291	1576,959123
48	83,43755587				67,59326355	2041,168583	1592,803415
49	83,43755587				67,59326355	2057,012876	1608,647708
50	83,43755587				67,59326355	2072,857168	1624,492

Table 30. Energy used for the Alternative 1- MINERALWOOL. The table shows the energy used by the building during the service life and the embodied energy to produce the insulation and the windows necessary for the refurbishment and the embodied energy to produce the PV system useful to reach the nZEB-OM level. The PV system is replaced after 30 year.

	WOOD FIBRE INSULATION - Alternative 2						
YEAR	Energy used	Embodied energy insulation	Embodied energy windows	Embodied energy PV	Energy production	NZEB-OM + PV Embodied energy	NZEB-OM building
0		234,9742476	701,7097141	277,2209026		1213,904864	936,6839617
1	83,43755587				69,66383923	1227,678581	950,4576784
2	83,43755587				69,66383923	1241,452298	964,231395
3	83,43755587				69,66383923	1255,226014	978,0051117
4	83,43755587				69,66383923	1268,999731	991,7788283
5	83,43755587				69,66383923	1282,773448	1005,552545
6	83,43755587				69,66383923	1296,547164	1019,326262
7	83,43755587				69,66383923	1310,320881	1033,099978
8	83,43755587				69,66383923	1324,094598	1046,873695
9	83,43755587				69,66383923	1337,868314	1060,647412
10	83,43755587				69,66383923	1351,642031	1074,421128
11	83,43755587				69,66383923	1365,415747	1088,194845
12	83,43755587				69,66383923	1379,189464	1101,968561
13	83,43755587				69,66383923	1392,963181	1115,742278
14	83,43755587				69,66383923	1406,736897	1129,515995
15	83,43755587				69,66383923	1420,510614	1143,289711
16	83,43755587				69,66383923	1434,284331	1157,063428
17	83,43755587				69,66383923	1448,058047	1170,837145
18	83,43755587				69,66383923	1461,831764	1184,610861
19	83,43755587				69,66383923	1475,605481	1198,384578
20	83,43755587				69,66383923	1489,379197	1212,158295
21	83,43755587				69,66383923	1503,152914	1225,932011
22	83,43755587				69,66383923	1516,926631	1239,705728
23	83,43755587				69,66383923	1530,700347	1253,479445
24	83,43755587				69,66383923	1544,474064	1267,253161
25	83,43755587				69,66383923	1558,24778	1281,026878
26	83,43755587				69,66383923	1572,021497	1294,800594
27	83,43755587				69,66383923	1585,795214	1308,574311
28	83,43755587				69,66383923	1599,56893	1322,348028
29	83,43755587				69,66383923	1613,342647	1336,121744
30	83,43755587			184,8139351	69,66383923	1811,930299	1349,895461
31	83,43755587				69,66383923	1825,704015	1363,669178
32	83,43755587				69,66383923	1839,477732	1377,442894
33	83,43755587				69,66383923	1853,251449	1391,216611
34	83,43755587				69,66383923	1867,025165	1404,990328
35	83,43755587				69,66383923	1880,798882	1418,764044
36	83,43755587				69,66383923	1894,572599	1432,537761
37	83,43755587				69,66383923	1908,346315	1446,311478
38	83,43755587				69,66383923	1922,120032	1460,085194
39	83,43755587				69,66383923	1935,893749	1473,858911
40	83,43755587				69,66383923	1949,667465	1487,632628
41	83,43755587				69,66383923	1963,441182	1501,406344
42	83,43755587				69,66383923	1977,214899	1515,180061
43	83,43755587				69,66383923	1990,988615	1528,953777
44	83,43755587				69,66383923	2004,762332	1542,727494
45	83,43755587				69,66383923	2018,536048	1556,501211
46	83,43755587				69,66383923	2032,309765	1570,274927
47	83,43755587				69,66383923	2046,083482	1584,048644
48	83,43755587				69,66383923	2059,857198	1597,822361
49	83,43755587				69,66383923	2073,630915	1611,596077
50	83,43755587				69,66383923	2087,404632	1625,369794

Table 31. Energy used for the Alternative 2- WOOD FIBRE INSULATION. The table shows the energy used by the building during the service life and the embodied energy to produce the insulation and the windows necessary for the refurbishment and the embodied energy to produce the PV system useful to reach the nZEB-OM level. The PV system is replaced after 30 year.

	VIP - Alternative 3						
YEAR	Energy used	Embodied energy insulation	Embodied energy windows	Embodied energy PV	Energy production	NZEB-OM + PV Embodied energy	NZEB-OM building
0		706,0560891	701,7097141	351,8572995		1759,623103	1407,765803
1	83,43755587				88,50607787	1754,554581	1402,697281
2	83,43755587				88,50607787	1749,486059	1397,628759
3	83,43755587				88,50607787	1744,417537	1392,560237
4	83,43755587				88,50607787	1739,349015	1387,491715
5	83,43755587				88,50607787	1734,280493	1382,423193
6	83,43755587				88,50607787	1729,211971	1377,354671
7	83,43755587				88,50607787	1724,143449	1372,286149
8	83,43755587				88,50607787	1719,074927	1367,217627
9	83,43755587				88,50607787	1714,006405	1362,149105
10	83,43755587				88,50607787	1708,937883	1357,080583
11	83,43755587				88,50607787	1703,869361	1352,012061
12	83,43755587				88,50607787	1698,800839	1346,943539
13	83,43755587				88,50607787	1693,732317	1341,875017
14	83,43755587				88,50607787	1688,663795	1336,806495
15	83,43755587				88,50607787	1683,595273	1331,737973
16	83,43755587				88,50607787	1678,526751	1326,669451
17	83,43755587				88,50607787	1673,458229	1321,600929
18	83,43755587				88,50607787	1668,389707	1316,532407
19	83,43755587				88,50607787	1663,321185	1311,463885
20	83,43755587				88,50607787	1658,252663	1306,395363
21	83,43755587				88,50607787	1653,184141	1301,326841
22	83,43755587				88,50607787	1648,115619	1296,258319
23	83,43755587				88,50607787	1643,047097	1291,189797
24	83,43755587				88,50607787	1637,978575	1286,121275
25	83,43755587				88,50607787	1632,910053	1281,052753
26	83,43755587				88,50607787	1627,841531	1275,984231
27	83,43755587				88,50607787	1622,773009	1270,915709
28	83,43755587				88,50607787	1617,704487	1265,847187
29	83,43755587				88,50607787	1612,635965	1260,778665
30	83,43755587	470,7040594		234,571533	88,50607787	2312,843035	1726,414203
31	83,43755587				88,50607787	2307,774513	1721,345681
32	83,43755587				88,50607787	2302,705991	1716,277159
33	83,43755587				88,50607787	2297,637469	1711,208637
34	83,43755587				88,50607787	2292,568947	1706,140115
35	83,43755587				88,50607787	2287,500425	1701,071593
36	83,43755587				88,50607787	2282,431903	1696,003071
37	83,43755587				88,50607787	2277,363381	1690,934549
38	83,43755587				88,50607787	2272,294859	1685,866027
39	83,43755587				88,50607787	2267,226337	1680,797505
40	83,43755587				88,50607787	2262,157815	1675,728983
41	83,43755587				88,50607787	2257,089293	1670,660461
42	83,43755587				88,50607787	2252,020771	1665,591939
43	83,43755587				88,50607787	2246,952249	1660,523417
44	83,43755587				88,50607787	2241,883727	1655,454895
45	83,43755587				88,50607787	2236,815205	1650,386373
46	83,43755587				88,50607787	2231,746683	1645,317851
47	83,43755587				88,50607787	2226,678161	1640,249329
48	83,43755587				88,50607787	2221,609639	1635,180807
49	83,43755587				88,50607787	2216,541117	1630,112285
50	83,43755587				88,50607787	2211,472595	1625,043763

Table 32. Energy used for the Alternative 3-VIP. The table shows the energy used by the building during the service life and the embodied energy to produce the insulation and the windows necessary for the refurbishment and the embodied energy to produce the PV system useful to reach the nZEB-OM level. The PV system is replaced after 30 year.

	XPS+PUR - Alternative 4						
YEAR	Energy used	Embodied energy insulation	Embodied energy windows	Embodied energy PV	Energy production	NZEB-OM + PV Embodied energy	NZEB-OM building
0		171,4999371	701,7097141	271,477205		1144,686856	873,2096513
1	83,43755587				68,21443625	1159,909976	888,4327709
2	83,43755587				68,21443625	1175,133096	903,6558905
3	83,43755587				68,21443625	1190,356215	918,8790101
4	83,43755587				68,21443625	1205,579335	934,1021297
5	83,43755587				68,21443625	1220,802454	949,3252493
6	83,43755587				68,21443625	1236,025574	964,548369
7	83,43755587				68,21443625	1251,248694	979,7714886
8	83,43755587				68,21443625	1266,471813	994,9946082
9	83,43755587				68,21443625	1281,694933	1010,217728
10	83,43755587				68,21443625	1296,918052	1025,440847
11	83,43755587				68,21443625	1312,141172	1040,663967
12	83,43755587				68,21443625	1327,364292	1055,887087
13	83,43755587				68,21443625	1342,587411	1071,110206
14	83,43755587				68,21443625	1357,810531	1086,333326
15	83,43755587				68,21443625	1373,033651	1101,556446
16	83,43755587				68,21443625	1388,25677	1116,779565
17	83,43755587				68,21443625	1403,47989	1132,002685
18	83,43755587				68,21443625	1418,703009	1147,225804
19	83,43755587				68,21443625	1433,926129	1162,448924
20	83,43755587				68,21443625	1449,149249	1177,672044
21	83,43755587				68,21443625	1464,372368	1192,895163
22	83,43755587				68,21443625	1479,595488	1208,118283
23	83,43755587				68,21443625	1494,818607	1223,341402
24	83,43755587				68,21443625	1510,041727	1238,564522
25	83,43755587				68,21443625	1525,264847	1253,787642
26	83,43755587				68,21443625	1540,487966	1269,010761
27	83,43755587				68,21443625	1555,711086	1284,233881
28	83,43755587				68,21443625	1570,934206	1299,457001
29	83,43755587				68,21443625	1586,157325	1314,68012
30	83,43755587			180,9848033	68,21443625	1782,365248	1329,90324
31	83,43755587				68,21443625	1797,588368	1345,126359
32	83,43755587				68,21443625	1812,811487	1360,349479
33	83,43755587				68,21443625	1828,034607	1375,572599
34	83,43755587				68,21443625	1843,257727	1390,795718
35	83,43755587				68,21443625	1858,480846	1406,018838
36	83,43755587				68,21443625	1873,703966	1421,241957
37	83,43755587				68,21443625	1888,927085	1436,465077
38	83,43755587				68,21443625	1904,150205	1451,688197
39	83,43755587				68,21443625	1919,373325	1466,911316
40	83,43755587				68,21443625	1934,596444	1482,134436
41	83,43755587				68,21443625	1949,819564	1497,357556
42	83,43755587				68,21443625	1965,042684	1512,580675
43	83,43755587				68,21443625	1980,265803	1527,803795
44	83,43755587				68,21443625	1995,488923	1543,026914
45	83,43755587				68,21443625	2010,712042	1558,250034
46	83,43755587				68,21443625	2025,935162	1573,473154
47	83,43755587				68,21443625	2041,158282	1588,696273
48	83,43755587				68,21443625	2056,381401	1603,919393
49	83,43755587				68,21443625	2071,604521	1619,142513
50	83,43755587				68,21443625	2086,82764	1634,365632

Table 33. Energy used for the Alternative 4- PUR+XPS. The table shows the energy used by the building during the service life and the embodied energy to produce the insulation and the windows necessary for the refurbishment and the embodied energy to produce the PV system useful to reach the nZEB-OM level. The PV system is replaced after 30 year.

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