NTNU – Trondheim
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Sustainability of existing buildings: costs and benefits for developers, investor and occupants

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Dedication

I would like to dedicate my thesis to my parents.

It is their unconditional love

that motivated me to set this target.

ABSTRACT

Due to the emission of greenhouse gases, the Earth's temperature is rising. Different studies show that buildings consume about 40% of all energy used: the sustainable regeneration of existing buildings is a useful way to reduce energy consumption and greenhouse gases.

The success of the use of green building practices also provides for improved productivity and user performance. The Facility Manager plays a relevant role in this contest. He knows that, considering the whole life cycle of the building, it is possible to compare the technological solutions and the related costs, to anticipate and facilitate the choice of durable materials and environmentally friendly, to allow a planned management, predict and extend the life of a building.

The building being studied is Thingvallagården, built in the 19^{th} century, in Trondheim, NTNU properties, now under renovation.

This intervention of retrofitting places the building in energy class equal to D. For this reason, it has been assumed economic-environmental solutions concerning the building envelope, identifying energy efficiency improvements, in order to make it Low Energy Building and Passive House.

The strategies have affected the variation of the thickness of insulation on the facade, in the roofing and in the bottom floor, considering the different thermal conductivity of materials.

It has been identified the effect that each different insulation material, such as wood fiber Hunton, Rockwool mineral wool, glass wool Isover

1, glass wool Glava 2, has on total costs and emissions with a view of the life cycle of building.

The initial working assumption has led to consider for each package of shell the same insulation and the resulting environmental-economic effect. Later on, it has been assumed the combination of glass wool Glava, which is more cost effective, and wood fiber, which is most environmentally advantageous, getting six additional interesting hypothesis of intervention. These six oprions advanced a right compromise between the cost and the emission of CO_2 eqv into the atmosphere.

Although it is not exhaustive, this project analysis could guide the choices made by the actors of the building process.

Keywords:

- Retrofit
- Low Energy Building
- Passive House
- Facility manager
- LCC
- LCA

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I would also like to thank my boyfriend Vito, my colleagues Valeria and Federica, all my "Norwegians" and “Italians” friends, who supported and encouraged me during these years.

In conclusion, I must also acknowledge whom I have not mentioned, but that there always been for me.

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INTRODUCTION

Construction activity has often been characterized by a considerable waste of resources and energy, however without guarantee health and comfort of users.

The depletion of non-renewable natural resources and the increasing pollution of the planet have led developed countries, including Norway and Italy, to a greater environmental awareness in the construction process, inviting to put the proper attention to the quality of materials to be used, the criteria construction and the intervention of retrofit.

The challenge of the thesis is the application of a methodology that leads to evaluate different technical solutions in terms of both economic impacts and environmental impacts.

To achieve an outcome broader it is necessary to integrate different approaches that provide a combination of total costs and emissions of greenhouse gases into the atmosphere. To obtain significant results it should be necessary to go beyond the traditional approach in order that a technical solution is sustainable both economically and environmentally.

The main result will be aimed at highlighting different total costs and emissions of CO_2 eqv in a perspective of life cycle using different technical solutions. It may provide different choices and weighted for all the actors of the building process: developers, investor and occupants.

CHAPTER I

Sustainable development

1.1 Sustainability

Sustainable development means to be is able "*to meet the needs of the present without compromising the ability of future generations to meet their own needs*"[1].

Therefore, the concept of sustainable development was defined in 1987 in the Brundtland Report.

Graphically, we can represent the concept of sustainable development with the equilateral triangle of Giaoutzi and Nijkamp[2] (Fig. 1).

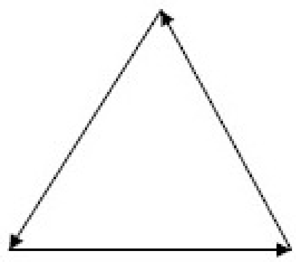

Figure 1: Equilateral triangle of sustainable development
(Source: Metodo n°21,2005)

There are three dimensions of sustainability:

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[1] Our Common Future: *Report of the World Commission on Environment and Development 1987* (A/42/427).

[2] P.L. MAFFEI: *Analisi del valore - Un metodo interdisciplinare per gestire le entità complesse nell'ottica di uno sviluppo sostenibile,* Metodo, n°21,2005

- Economic sustainability, based on the use of technological innovations to promote growth and to achieve maximum production efficiency trying to maintain employment and not to squander the wealth of natural and human;

- Social sustainability, addressed to achieve equality between and intra generational and promote confrontation, dialogue and cooperation between different cultural identities;

- Environmental sustainability, paid to environmental protection and preservation of the ecosystem, conserving natural resources and limiting the emission of pollutants, while supporting productivity.

These dimensions are not to be considered independent of each other, but interrelated, interacting and indispensable to the attainment of a common aim.

After the Brundtland report, many initiatives have been undertaken, which have implemented policies and operational tools to the environment. Such as:

- Agenda 21, result of the Second World Conference of Environment and Development convened by the United Nations also known as the Earth Summit in Rio de Janeiro in 1992;
- the climate treaty, in 1997, and Kyoto Protocol;
- The Biodiversity Convention and the creation of partnerships with the Johannesburg conference in 2002, the World Summit on Sustainable Development.

1.2 Sustainability in construction: green buildings

The current trend in political, cultural and economic believes that sustainability is now a requirement in all choices and every policy area, including the construction sector, with the result that the building like any other activity must be sustainable, in accordance with the three basic dimensions of sustainability also known as the "triple bottom line".

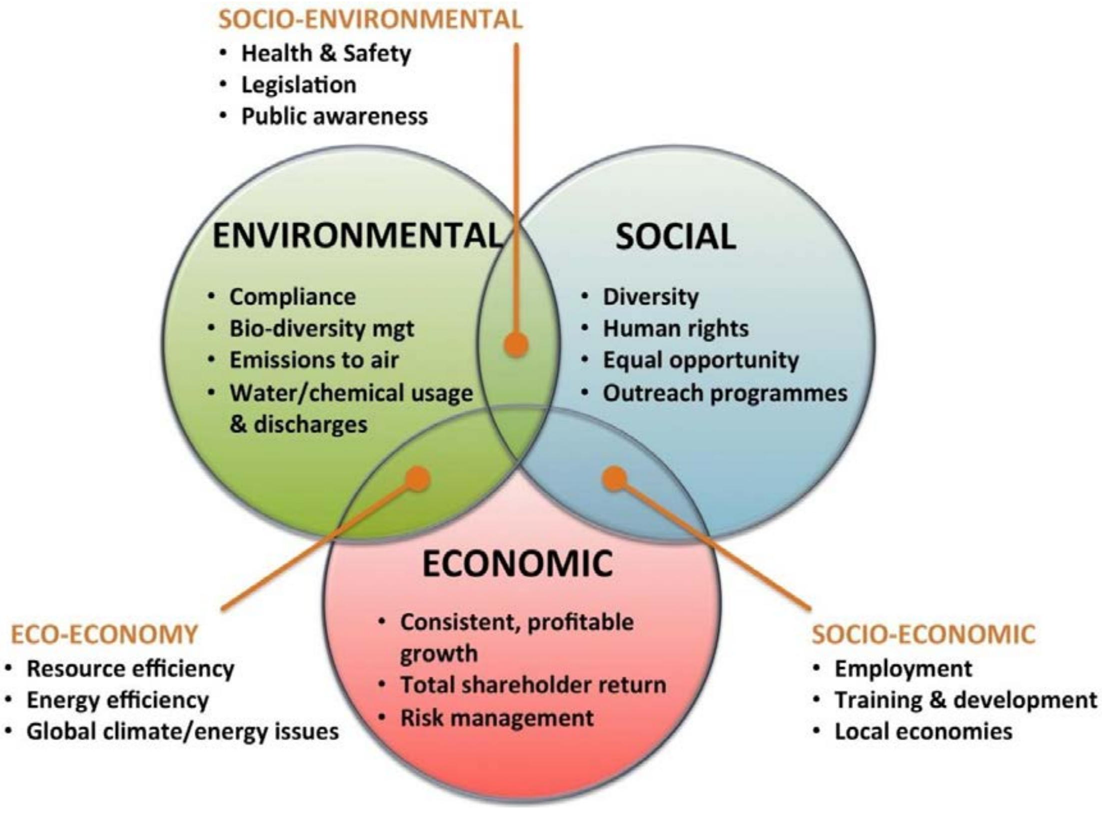

Figure 2: Triple bottom line: performance of sustainability.
(Source: http://www.sellingsustainabilitysolutions.com)

In fact, until now sustainable construction was addressed mainly to environmental sustainability; it is also called green buildings, which

should reduce the environmental impact, using non-polluting materials, limit consumption of non-renewable energy, considering the whole life cycle of the building and ensuring the health and welfare of its users.
It combines with a constructive process that seeks to rationalize both the human and material resources, always respecting the environment, the land and the man.
The green buildings through a careful design and the use of advanced technologies can reduce:
• From 24% to 50% energy consumption;
• From 33% to 39% of the carbon dioxide emissions;
• 40% of the use of drinking water;
• 70% of the production of solid waste[3].
These advantages in terms of cleaning up the environment and saving resources, however, will reveal improvements in the quality of people's lives and the economy of expenditure.
Another factor is the health of the built environment. People spend up to 90% of their time inside buildings, whose quality of the interior is in the top five risk factors for health. Designing and building healthy buildings, as committed to making green building alongside the green buildings, it can get reductions in health care costs due to the malaise of the inhabitants of the buildings as well as reduction of absenteeism with improving the performance of workers. The building structure must then be understood as a tool adaptive and interactive, as a living being able to relate to users and to changing external conditions.

[3] Source: *www.gbcitalia.org, (2011)*

Important choices in the construction process may be to prefer local raw materials (called zero kilometer) and use a bioclimatic approach, with 'common sense' which in the past were met certain rules of construction, which respect the environment, land and health and welfare of people, but also have a considerable cost reduction.

From the data of energy consumption by sector, the construction sector appears to be the biggest consumer of energy (40%)[4] both in Norway and in Europe, therefore we must encourage on one hand the savings and on the other energy efficiency of buildings.

It is therefore necessary to pursue the commitment to reduce and optimize energy consumption in buildings to achieve quick results. Despite the initial request in terms of capital investment can be significant, then it must be considered that the cost of management is reduced significantly and at the same time, it has environmental benefits and comfort of people.

Energy saving and efficiency can be achieved by acting both on the building (perimeter walls, horizontal upper and lower closures, windows, and, in general, all surfaces that involve loss of heat), and on the systems for the supply of electrical energy, air conditioning and production of hot water.

The best results are obtained with solutions that integrate different types of intervention and that assess properly the cost - benefit in the various phases of the building process:

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[4] Source: *http://www.sffe.no*
http://www.enea.it

• The planning phase, whether it is new building or refurbishment, it should test the feasibility, costs and analysis of alternative design solutions;
• In the implementation phase should be checked if the strategies and the progress made on the basis, in reference to compliance, quality and installation of materials and building components;
• In the management phase it can evaluate the results expected or unexpected, the real performance and economic benefits monitoring the actual energy consumption of the building.

It is necessary to think about the built heritage through environmental sustainability and reduce consumption. In this way, it can help families to reduce expensives and improve the livability of the buildings.

1.3 The main issues when dealing with sustainability of existing buildings

Renovate a historic building is in the logic of sustainability.

According to Peter Yost, a building science expert with 3D Building Solution, LLC, “if you double the life of a building, you halve the environmental impacts [of its construction]” (Carroon, 2010).

An old building, almost certainly, is characterized by local materials, which are suited to the climate of the area, it have fulfilled previously the low transport costs and has favored the local economy. Consequently, the historic buildings can teach sustainability in the use of building materials.

It is very important that in existing buildings should be repaired rather than replaced because this creates an economy by favoring craft people, it increases the life of products, it reduces to the minimum waste and the use of new products.
The culture of substitution is essential for reducing the environmental impact and create a company regenerative, rather than consumer.
The historic-existing buildings are characterized by a vernacular architecture, a ponderous heat capacity and a passive function. For example they often have large windows and doors, narrow passageways such as to permit a deeper light penetration.
The new technologies allow for the recovery of existing buildings, focusing on what are the most important aspects of the retrofit. They are manifold, but the most important are listed:

- Energy efficiency;
- Indoor air quality;
- The use of durable and renewable materials;
- Protection of the aesthetics of the building.

A critical aspect of the building renovation is the economic investment because investors often want an immediate gain, however it is necessary to implement a forward-looking policy to explain and convince them to invest in a long-term savings.
Users have a low perception of well-being caused by a renewal in terms of green building that is why every retrofit project should describe in detail the costs, showing in a simple and clear benefits in relation to excessive costs. For example, the retrofit linked to room lighting is an

important factor, but because of the distress related to low light is a psychophysical condition, users who have benefited from the well-being may be obtained vehicle information and training.

Another important component is user awareness in order to be aware that many energy savings can be obtained by changing their behavior and overcoming their skepticism.

1.4 The key role of the Facility manager in terms of Sustainability

The benefits of sustainability and green building practices in facility management are well established. Reduction in energy consumption, productivity increases, waste reduction, and many other beneficial effects of sustainability can be quantified and presented to an organisation's leadership in order to defend sustainable practices and their positive effect on the bottom line (Hodges, 2005).

However, the positive results are not immediate. In order to be shown it is necessary to have a long-term, carefully assessing all sustainable options rather than the traditional ones. Considering the cost of the life cycle (LCC) of the building it is possible to understand which the benefits of sustainable choices. Often these proposals are made by the facility managers who through financial and strategic planning tools "can create long-lasting value to the organization by developing, implementing and maintaining sustainable facility practices" (Hodges, 2005).

The success of the use of green building practices leads to the increase of productivity and performance. The facility manager may proceed to implement green techniques that are able to operate a building in a more efficient and reduce the negative effect on the environment.

The main driver who encourages to use green building practices is linked to the reduction of energy consumption, water, interventions of operation and maintenance, cost, pollution and increasing the productivity of those who live there and the comfort of indoor air. The economic benefits can be demonstrated by monitoring these techniques every day, while benefits connected to social and environmental well-being have already been fully documented.

Considering the whole life cycle of the building for the facility manager is clear that the major cost of a property is given by the work that can also represent 92% of the total cost. The maintenance and management of the plants absorbs 6%; the remaining 2% (Hodges, 2005) is absorbed by the design and construction.

From the above it follows that a small increase in productivity may generate a substantial saving on the main part of the cost. A similar effect cannot be achieved by operating reductions on the cost of the plants and on the design, which could have negative consequences on the realization of the work and cause an increase in energy consumption and running costs and maintenance.

To achieve an optimal result it is necessary to have a criterion balanced between the design, construction, management and maintenance, in order to optimize productivity and decrease, as much as is possible, energy consumption and the generation of waste.

Reduce energy consumption and improve the environment of the building produces a clear benefit. These two factors are often considered secondary by customers, because they would like to have lower cost services.

If you are convinced of the goodness of service planning of facilities, you have a positive influence on the productivity and profitability of the work, also performing a cultural function that might affect the project and its implementation.

The facility manager must be credible and consistent in order to push the properties and users to use green practices. He should take an equal role to others teamed need to develop sustainable practices, highlighting the advantages of the "good" practices, which need time to highlight the economic benefits.

He should achieve the confidence and know the economic policy and finance of the client, identify which are the capital, depreciation and cash flows, and create a credible relationship with the educational sector finance, which often led to prefer an economic compared to that environment.

Only a few choices of sustainable building cost less than traditional ones. It is evident that the decrease of the costs is to be programmed in the years whereas the life of the building.

The client often considers only the initial costs, regardless of operating expenses, refurbishments and disposal, total or partial, of the materials, which occur during the entire life cycle of the building.

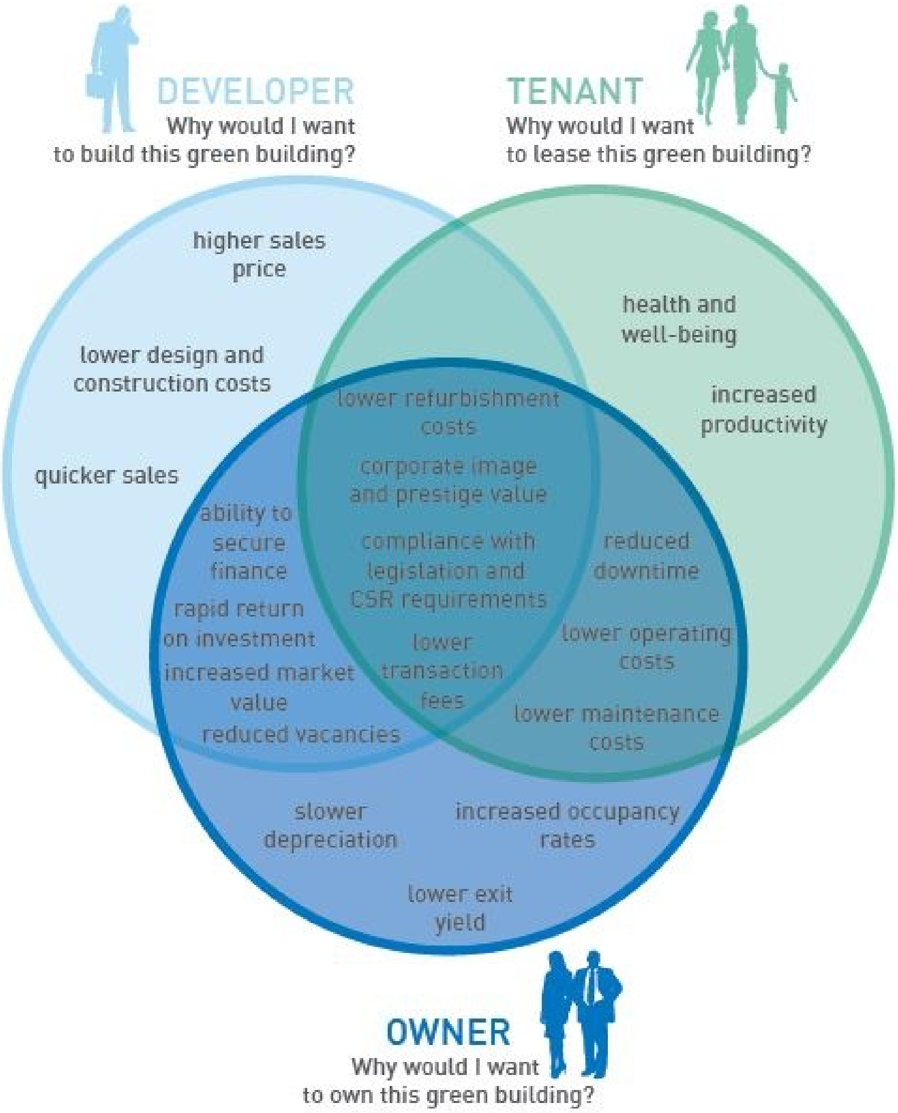

Figure 3: Stakeholder perception that affect the value of green buildings.
(Source: www.worldgbc.org (2013))

Increasing productivity and reducing energy consumption, you get a savings that go to amortize the initial investment costs. The facility manager's task is to highlight, promote and persuade you to develop good practices related to sustainability and green building, so that is no longer the option, but a common practice.

Is not well known that many sustainable materials have a long duration of life, originate from renewable sources, improve the comfort of the users and have a high possibility, in case of necessity, to be easily replaced. The facility manager should program the controls of the cyclic structure to intervene on materials, to prolong its life, for replacement, to avoid their rapid deterioration, and to regulate the disposal of the material replaced or, if necessary with the use of home automation. With a prior and proper maintenance of the building's life is extended automatically and there is a reduction of the initial cost. Improper and out of maintenance, may cause a reduction in the lifetime of the building and of course an increase in the cost of the work.

From the above, the Life cycle costing (LCC) is an indispensable method to be used to compare more technological solutions and their costs, it can anticipate and facilitate the choice of durable materials and environmentally friendly, allowing a planned management, predict and extend the life of building.

Through the LCC you can identify the necessary financial instruments. However, account must be taken of another aspect: are the actions required by a private company or a public company? It is important to identify the characteristics of the client. Private companies tend to amortize the capital employed in less time. A public company can have a repayment plan in a longer term. Knowing the available funding and the repayment plan of capital is important to promote and adopt sustainability with economic interests.

The facility manager should first of all be convinced that the green building can be made of build long-lasting manufactured goods in time. He has to demonstrate his own believes.

1.4.1 Sustainable strategies for facility

When the facility manager wants to create a structure that has sustainable solutions, he has to implement a plan leading to assess the needs, strengths and weaknesses through benchmarking and identifying the objectives to be achieved. This is possible if he is aware of the client's strategy, financial goals so you can understand the purpose of social, economic and environmental (triple bottom line) to which the work is intended. These three objectives must be equally considered without preferring one another.

The ratio of the facility manager and the client have to be trusted in order to convince it of the benefits of sustainability through the experience.

It is necessary to get social acceptance of the practices of sustainability. You can also start with small changes, to obtain the consent of the groups convinced of the "best" practices, such as the use of alternative energy sources, consumption and storage of wastewater. It is important to implement a policy of public relations publicizing the proposed solutions.

The key steps in developing a sustainability strategy involve the following:

- *Completely understand the organisation's philosophy and strategy towards handling finances.*
- *Facilitate the strategic planning process for the organisation.*
- *Develop a strategic plan for sustainability:*
    1. *Create the strategy team — involve the CFO, leadership, FM, and end-users.*
    2. *Incorporate the organisation's financial strategy.*
    3. *Evaluate the organisation's attitude towards the social, economic, and environmental attitudes of sustainability.*
    4. *Perform the SWOT analysis (strengths, weaknesses, opportunities, threats).*
    5. *Develop the sustainability mission, vision and values.*
    6. *Develop goals and objectives to support the sustainability strategy.*
    7. *Develop assessment processes that include LCC and TCO evaluation of construction, replacement and repair systems.*
    8. *Define critical success factors for the strategy.*
    9. *Publicise the strategic plan to all the stakeholders.*
- *Implement the strategy:*
    1. *Start small, with socially driven, low-cost programmes.*
    2. *Move up to the planning, design and construction phase green practices.*

3. *Implement existing facility green practices.*
4. *Develop support within the organisation.*
5. *Continually evaluate LCC of alternatives and TCO.*
6. *Measure results, revise plan, modify approach, repeat.*
7. *Celebrate and publicise successes.*

- *Become the advocate for long-lasting facilities.* (Hodges, 2005)

1.5 Existing guidelines and tool to measure sustainability

1.5.1 General

Systems assessment and certification of buildings are a valuable tool for measuring the energy performance of the building, both in terms of consumption and of CO_2 saved, and make them shareable between stakeholders.

However, the quality of a building is not only based on energy performance; it is also important to consider other factors relating to the environment and health of users, and cannot be ignored by considering all phases of the life cycle of the object construction. In recent years there have been developed systems of evaluation and environmental certification, many of which are constantly changing and updating in order to assess the quality of the built in a broader view of sustainability. All systems use the indicators, sometimes referred to as eco-tools, which are environmental, social, technical and economic factors; through the indicators, are expressed in score ratings that show different levels of environmental compatibility of the building according to the design choices adopted. Other indicators can be grouped into some captions

- Consumption of resources, materials and energy;
- Quality of the interior spaces;
- Environmental impact;
- Quality of services.

The resulting certification allows users and investors to know accurately the performance of the building and compare, quite objectively, its environmental quality with other buildings.
These tools, then stimulate the actors of the building process, to ask, propose and adopt environmentally friendly design choices and more generally sustainable.
Following the essential lines of the environmental assessment systems of the most famous buildings in the international field.

1.5.2 LCA – Life Cycle Assessment

The LCA is a process of energy and environmental assessment of a product that analyzes the entire life cycle of the same (from cradle to grave): from extraction and processing of raw materials, production, transportation, distribution, the use, reuse and recycle up to final disposal.
Born in the industry, it was later transferred to other fields of application and also in the building process, considering the effects of the built in

terms of environmental impact and consequences on the health of users. The assessment then refers to the whole life cycle of a building, from the extraction of the raw materials used in its construction, its management and maintenance to its eventual final disposal.
The application of the method is rather complex and therefore is still most often used for the certification of sustainability of materials and building components rather than entire buildings.
The LCA analysis can usefully provide to other methods, in advance, evaluation criteria for materials and built.

1.5.3 BREEAM METHOD

The method BREEAM was the first commercial system for the evaluation and environmental certification of sustainable buildings, providing a reference point for the systems which were born later.
Launched in 1990 in England, BREEAM stands for Building Research Establishment Environmental Assessment Method.
The certificate is delivered with a number of sunflowers ranging from:
• 4 = excellent sunflowers
• 3 sunflowers = very good
• 2 = good sunflowers
• 1 = pass sunflower
To assess the environmental quality of the building, considering different parameters such as:
• Energy;

• Transport;
• Water;
• Materials;
• Pollution;
• Land use;
• Health and wellness.

The certification process is accredited via an external organization with evaluators involved in each project phase, executive and management of the building as security for all actors in the process.

Originally, the system was the limit to be applied especially in England, being closely related in its approach to the reality of that geographical region, but then it was developed for use in climate zones, economic and cultural backgrounds.

1.5.4 LEED METHOD

The LEED (Leadership in Energy and Environmental Design) was born in America and subsequently developed at international level. It is promoted by GBC (Green Building Council), a non-profit organization. This method determines which are the environmental objectives and provides the criteria for evaluating and measuring the quality of the buildings. It important to use right from the design of the building to achieve maximum results.

The LEED prerequisites and credits are distributed in categories:
• Sustainability of the site (SS);

• Water Management (GA);
• Energy and Atmosphere (EA);
• Materials and Resources (MR);
• Indoor environmental quality (IQ);
• Innovation in design (IP)
• Regional priority (PR).

Loans acquired for the building are composed in a score that determines the level of certification. There are four certification levels which correspond to the minimum scores:

• Platinum (over 80 points);
• Gold (60-79 points);
• Silver (50-59 points);
• Base (40 points).

To reinforce the importance of environmental issues, the credits may have different relevance depending on the districts of the territory concerned.

The certification is conducted by an accredited and specialized person through a self-certification process.

1.5.5 GBTOOL METHOD

The GBTool born in Canada in 1996 and is sponsored by the GBC (Green Building Challenge, an international network consisting of public and private research institutions in 25 countries including Italy).

This a system evaluates the environmental performance and energy parameters of universally recognized not considering the geographic area. In this way, it is possible to promote models and exchange of information at the international level.

For evaluation requires information on the site and on the body building covering the following areas:

• Consumption of resources;
• Environmental burdens;
• Quality of the indoor environment;
• Quality of services;
• Economy and Management.

The categories are divided into subcategories and then in the criteria and sub-criteria, to which are assigned a score ranging from -2 to +5. The environmental performance indicators are measured with absolute and specific indicators.

The procedure GBTool can be summarized in the following phases:

• Definition of the building;
• Definition of the weighting system;
• Collecting data and information;
• Determination of the qualitative and quantitative performance;
• Data processing and evaluation;
• Analysis of the results.

The application of the method requires more than 1,000 answers to related questions, for which calculations require specific and extensive research.

CHAPTER II

Case study: Thingvallagården

2.1 Introduction to the case study

Figure 4: Thingvallagården.
(Source: http://www.byggogbevar.no)

Thingvallagården (Høgskoleveien 4) is located in a residential area known as the district border Elgeseter in Trondheim. Its name derives, probably, from the area which was located just beyond the city borders until 1893.

In 1889, Anders Thingvold bought two plots of Edvard Strøm: Grændsens 2 and 3, and in August 1890 Thingvalla Allegaarden. Immediately after (08/25/1890) Thingvallagården was rated as two buildings, one of which was 12.1 m long and the other was 13,1 m. In total the house would later outer dimensions 25,2 m long, 9 m deep and

7.4 m in height (Lene Marie Nommensen Kværness, 2010). The estimated year of construction is believed to be about 1890.

The houses have been described as two-story buildings, while the third floor was called "twig". The lower part of the buildings (3m) consisted of 1/2 brick with the function of masonry foundation. To north wall was made of granite. Probably, the construction was constituted with the insulating cardboard both outside and inside and in the floor. The windows and doors were made of frames. Part of the exterior facade consisted of moldings.

When the buildings were built, the roof was largely covered with slate, with the exception of the North and South side, which were covered by a table then they were covered with slate. The verandas have been described as "arcades of works post-carved with a roof height" (Lene Marie Nommensen Kværness, 2010) whose size has been 1.9m deep, 4.1m in length and 11.3m in height.

Thingvalla is located near the main building NTNU in Trondheim.

Near the building, there are many small wooden houses and in 1960, the area was acquired by NTNU preventing the future expansion of the campus. However, the expansion has not occurred in this area and this has led to a slow decay of the structure. Subsequently, Thingvalla was used for student accommodation, but in 2004 was made totally uninhabited because of the danger of this property.

2.2 Current state

Thingvalla can be divided into two buildings: the main and the secondary.

The main building is characterized by:

Figure 5: Thingvallagården – Main building - 2015

- area of the ground floor = 226,8 m^2;
- area of 1°, 2° and attic = 793,5 m^2;
- area of the roof = 360,3 m^2;
- total volume = 2.866 m^3.

The external walls are founded in part on the ground. The walls in the basement have different thickness. For this reason, it is assumed an average thickness of 700 mm. The walls of the basement are made of brick and U-value is estimated to be about 0,63 W/m^2K. The building is designed with balanced ventilation with running all day. The air flow is 1400 m^3/h and the heat exchanger temperature has an efficiency of 80%.

Figure 6: Thingvallagården – Secondary building - 2015

The secondary building is characterized by:

- area of the ground floor = 67,7 m^2;
- area of 1°, 2° and attic = 252,3 m^2;
- area of the roof = 129,8 m^2;
- total volume = 743 m^3.

The external walls are founded in part on the ground. The walls in the basement can have an average thickness of 950 mm. The walls of the basement are made of brick and U-value is estimated to about 0,54 W/m^2K.

The building is designed with a balanced ventilation. The air flow is 430 m^3/h and the heat exchanger temperature has an efficiency of 80%.

2.3 Current refurbishment

Thingvallagården has a great historical meaning for the city of Trondheim and worthy of preservation for Byantikvaren (authority). It is situated in a picturesque woodland, close to Høgskoleparken. The NTNU, the planning group and Byantikvaren, through constructive dialogue, have planned measures to preserve the building for its historical and architectural expression.

For the soil subsidence and poor maintenance, the floor of building is made of wood rot, injured parties within the same room there are floors with large height difference. Wooden structures are fungi and moulds.

The renovation work started in the second half of 2014 and it will be concluded by the end of 2016.

The refurbishment involves the reinforcement of existing wooden structures, eliminating fungi and moulds through essential ventilation, the preservation of the facade. This is achieved not by increasing the volume outside the building, not allowing to isolate it until U-values which satisfy today's requirements.

There have been new technical installations and sewer and water connection to the mains of hydronic heating inside of NTNU. The University has a surplus of district heating and this surplus is used to heat all the buildings in the campus.

Interior floors were completely demolished and they will be restored with new wooden floors. The frame and the cover are made of wood.

Vertical external walls will be realized with original wooden face with thin insulation and thicker on the outside. This limitation was imposed by the Superintendence, notwithstanding the application of the insulation on the outside of the wall would improved energy performance and improved indoor air quality.

The perimeter wall is as follows from the inside out:

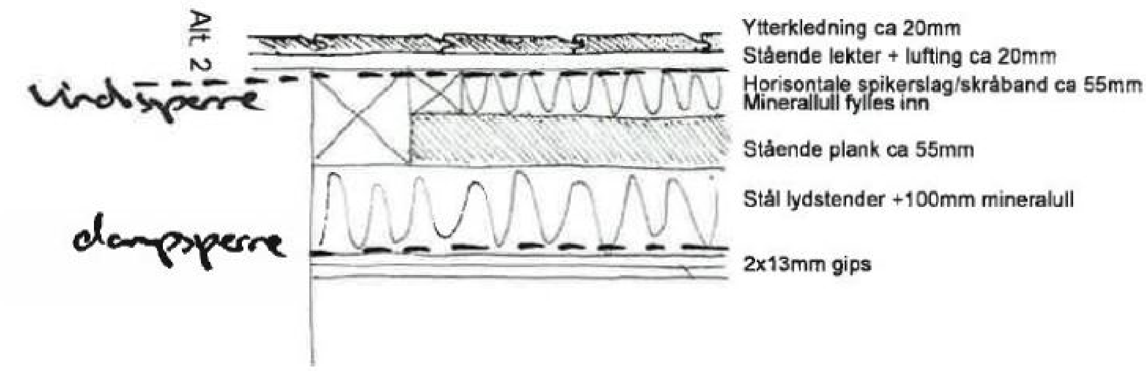

Figure 7: External walls – refurbishment NTNU

- Gypsum 2x13 mm;
- Wood axles, 36 mm;
- Vapor barrier;
- Wooden uprights with mineral wool, 100 mm;
- Existing wooden table, 50 mm;
- Wooden uprights with mineral wool, 50 mm;
- Wind barrier;
- Coating.

The roof consists of:

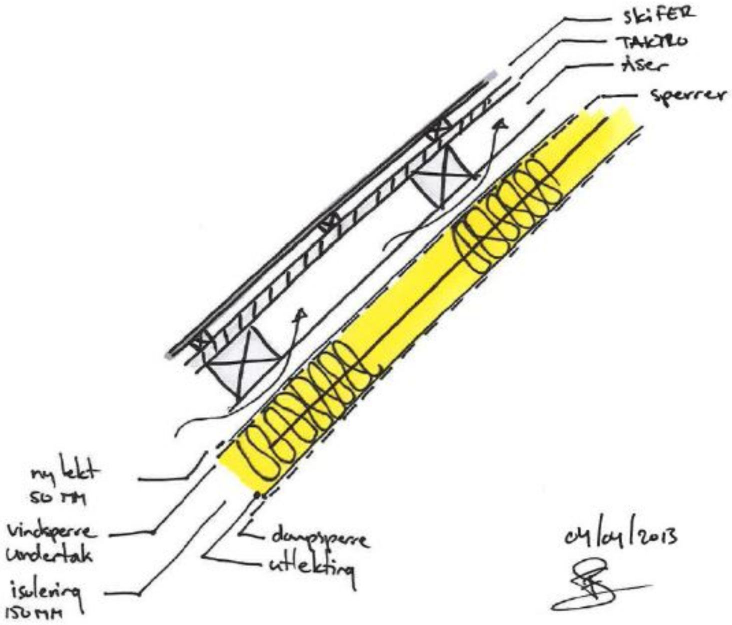

Figure 7.1: Roof – refurbishment NTNU

- Gypsum, 2 x 13 mm;
- Vapor barrier;
- Insulation with mineral wool, 100 mm;
- Barrier waterproofing;
- Floor boards;
- Cover slate, 470x470 mm.

The floor consists of:

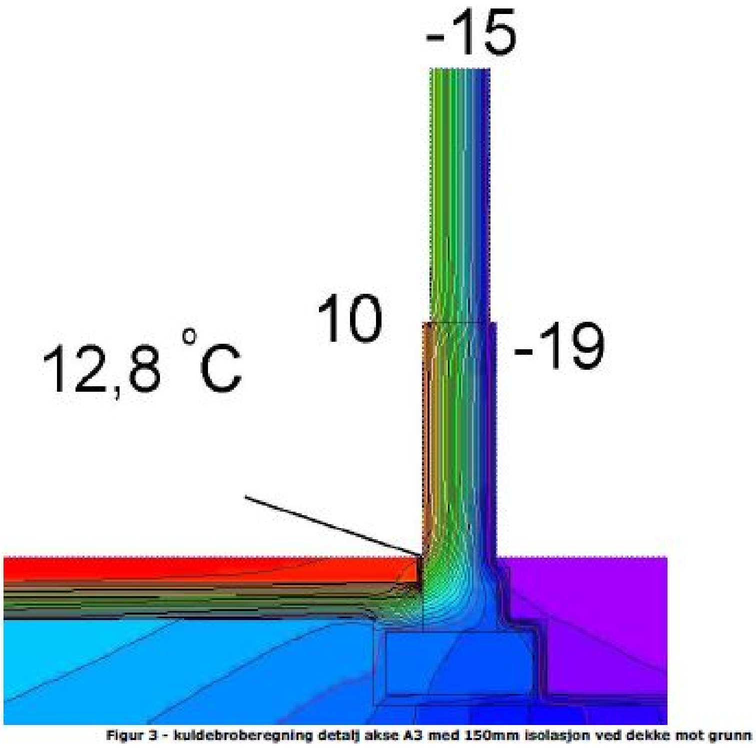

Figure 7.2: Floor – refurbishment NTNU

- Parquet, 1,5x15 mm ;
- Mortar 40 mm;
- Concrete 50 mm;
- Insulation with mineral wool, 150 mm.

2.4 Current energy consumption

Energy simulation results of the restructuring in place provide a net energy consumption of 147.4 kWh/m^2 (fig. 8), although the requirement requested by TEK10 legislation in force in Norway from 2010, is 115 kWh/m^2.

Provided energy calculated for Thingvalla is 160 kWh/m^2, which corresponds to Norwegian energy class D (Fig. 9).

Most of the demand for energy is due to heating. The 60% of heat loss is through the outer walls, the windows and doors. To save energy, it would be necessary to intervene on the thermal transmittance of the elements mentioned.

Energiramme (§14-4, samlet netto energibehov)	
Beskrivelse	Verdi
1a Beregnet energibehov romoppvarming	77,1 kWh/m^2
1b Beregnet energibehov ventilasjonsvarme (varmebatterier)	5,0 kWh/m^2
2 Beregnet energibehov varmtvann (tappevann)	29,8 kWh/m^2
3a Beregnet energibehov vifter	6,7 kWh/m^2
3b Beregnet energibehov pumper	0,0 kWh/m^2
4 Beregnet energibehov belysning	11,4 kWh/m^2
5 Beregnet energibehov teknisk utstyr	17,5 kWh/m^2
6a Beregnet energibehov romkjøling	0,0 kWh/m^2
6b Beregnet energibehov ventilasjonskjøling (kjølebatterier)	0,0 kWh/m^2
Totalt beregnet energibehov, sum 1-6	147,4 kWh/m^2
Forskriftskrav netto energibehov	115,0 kWh/m^2

Figure 8: Energy diagram – NTNU refurbishment

Transmittance values of restructuring are shown in Table 1.

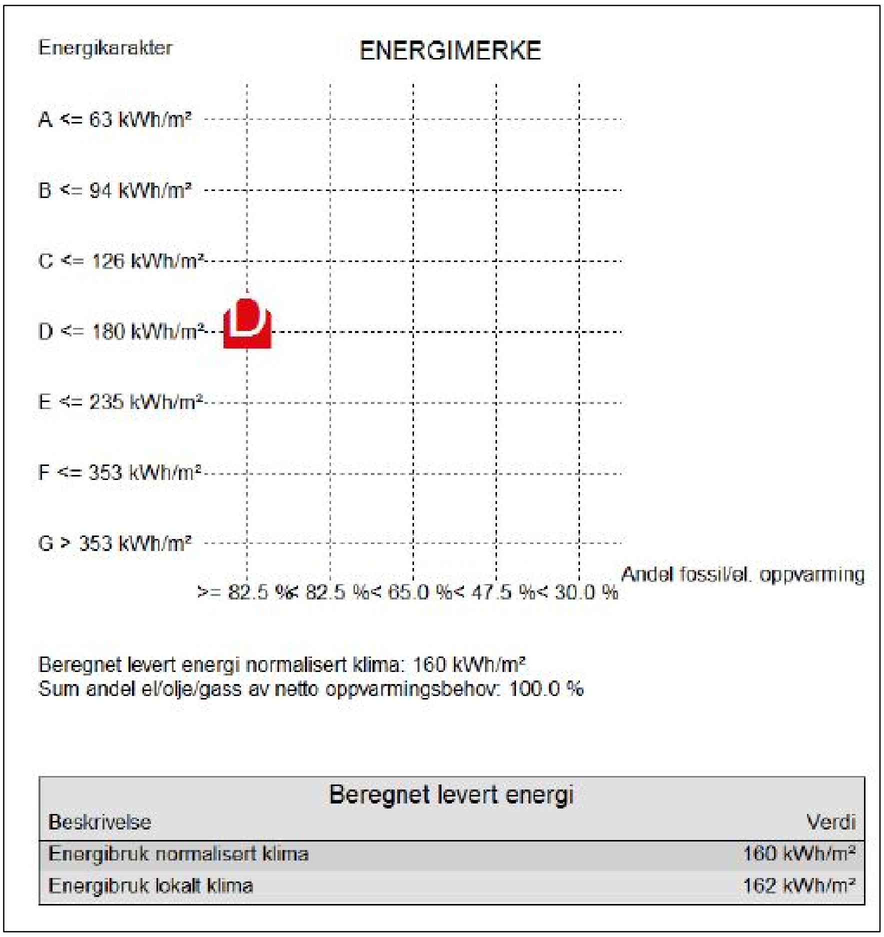

Figure 9: Energy class – NTNU refurbishment

Tab. 1 – U-values for walls, windows and doors – NTNU refurbishment

	U-values
Walls	0,320 W/m^2 K
Windows	1,20 W/m^2 K
Doors	1,20 W/m^2 K

2.5 Technical approach: project alternatives in term of sustainability

2.5.1 Method

The thesis aims to indicate the criteria project choices to propose, where possible, alternative solutions and improvement of sustainability.
The building examined, Thingvallagården, is part of a refurbishment project technology and energy efficiency proposed by Narud Stokke Wiig AS Sivilarkitekter. Despite the proposed changes, it is not totally well insulated and energy consumption remains high.
Because of constraints due to the historical value of the building and the economic component of interventions, it was not possible the implementation of existing new technological systems and the proposition of different solutions.
After careful analysis of the project, it was decided to intervene only on the building using as a reference standard Norsk Standard "PRNs 3700: 2009" (Criteria for low energy and passive houses - Residential buildings). It has used this regulations which transforms the goals of sustainability in 'standards', regulations, guidelines and support documents aimed at the development of methods necessary for planning and design of interventions in the building. This regulations indicates the environmental and economic principles, defines the 'standards' for measuring the energy performance of buildings, on the basis of environmental sustainability objectives, energy and economic.

Currently the buildings represent about 40% of all energy consumption in the world. Studies have shown that the energy efficiency of buildings produces two effects: cost savings and reductions in greenhouse gas emissions.

As intervention methodologies, there have been considered two variables: Low Energy and Passive House Building.

The maximum net energy for heating the building to Low Energy Building is estimated considering the average outside temperature annual and the heated surface according to the following table provided by the standard:

Tab. 2		
Low Energy Building	**Highest net low energy for heating** $\vartheta_{ym} \geq 5°C$	$\vartheta_{ym} < 5°C$
Residential building with $A_{fl} < 200$ m^2	$30 + 5 \times [(200 - A_{fl})/100]$	$30 + 5 \times [(200 - A_{fl})/100] + 5 \times (5 - \vartheta_{ym})$
Residential building with $A_{fl} \geq 200$ m^2	30	$30 + 5 \times (5 - \vartheta_{ym})$
N.B. ϑ_{ym} = average temperature A_{fl}= Area building		

Tab. 2 - Maximum energy consumption from Norsk standard prNS 3700:2009

Norway has the ambition that new buildings meet standards of Passive House 2020. The Passive House is a very well insulated building, which has minimal loss of heat, few or no thermal bridges and heat exchangers with high efficiency. These efforts have also a decrease in economic costs. This concept was developed by the Passive House Institute in Germany by Dr. Wolfgang Feist. The energy required by a Passive House is about 25% less of a house built according to the current regulation (SINTEF, 2010).

The maximum net energy for heating the building to Passive House is considering the estimated annual average outdoor temperature and the surface heated according to the following table provided by the standard:

Tab. 3		
Passivhus	**Highest net low energy for heating**	
	$\vartheta_{ym} \geq 5°C$	**$\vartheta_{ym} < 5°C$**
Residential building with $A_{fl} < 200\ m^2$	$15 + 3 \times [(200 - A_{fl})/100]$	$15 + 3 \times [(200 - A_{fl})/100] + 3 \times (5 - \vartheta_{ym})$
Residential building with $A_{fl} \geq 200\ m^2$	15	$15 + 3 \times (5 - \vartheta_{ym})$
N.B. ϑ_{ym} = average temperature A_{fl}= Area building		

Tab. 3 - Maximum energy consumption from Norsk standard prNS 3700:2009

Considering Thingvallagården, which has an area greater than 200 m^2, to make the building at first and second Low Energy Building Passive House, I had to calculate the average annual temperature of Trondheim from March 2014 to February 2015. The average temperature resulted of 7.4 ° C (Table 4 and Fig.10).

Tab. 4									
Months	Temperature				Precipitation			Wind	
	Average	Normal	Warmest	Coldest	Total	Normal	Highest daily value	Average	Strongest
Feb. 2015	1.7°C	-2.5°C	9.9°C Feb 19	-6.2°C Feb 5	84.4 mm	50.0 mm	30.8 mm Feb 9	3.9 m/s	12.5 m/s Feb 7
Jan. 2015	0.1°C	-3.0°C	6.2°C Jan 26	-11.6°C Jan 23	42.2 mm	60.0 mm	7.9 mm Jan 5	2.9 m/s	10.8 m/s Jan 15
Dec. 2014	-0.2°C	-2.0°C	9.4°C Dec 4	-16.7°C Dec 25	75.8 mm	80.0 mm	11.7 mm Dec 4	3.0 m/s	12.2 m/s Dec 10
Nov. 2014	3.4°C	0.5°C	11.4°C Nov 2	-6.8°C Nov 22	10.4 mm	70.0 mm	2.2 mm Nov 2	2.1 m/s	9.0 m/s Nov 8
Oct. 2014	7.4°C	5.5°C	17.4°C Oct 4	-2.3°C Oct 15	57.3 mm	100.0 mm	7.6 mm Oct 23	2.8 m/s	10.8 m/s Oct 23
Sep. 2014	11.5°C	9.0°C	22.5°C Sep 7	1.1°C Sep 23	83.1 mm	110.0 mm	22.8 mm Sep 28	2.0 m/s	13.5 m/s Sep 26
August 2014	15.0°C	12.5°C	26.7°C Aug 9	7.6°C Aug 29	134.0 mm	85.0 mm	35.9 mm Aug 19	2.2 m/s	8.4 m/s Aug 10
July 2014	19.1°C	13.0°C	31.2°C Jul 9	8.5°C Jul 2	45.5 mm	90.0 mm	9.8 mm Jul 31	2.1 m/s	7.0 m/s Jul 7
June 2014	12.0°C	12.0°C	25.0°C Jun 3	3.4°C Jun 21	74.3 mm	65.0 mm	15.0 mm Jun 12	2.5 m/s	6.5 m/s Jun 21
May 2014	9.5°C	9.0°C	23.9°C May 21	-1.4°C May 5	51.0 mm	50.0 mm	9.4 mm May 4	2.5 m/s	8.0 m/s May 16
April 2014	5.7°C	3.0°C	16.7°C Apr 24	-3.9°C Apr 2	57.1 mm	45.0 mm	9.8 mm Apr 15	2.5 m/s	9.9 m/s Apr 13
March 2014	3.4°C	0.0°C	11.5°C Mar 6	-11.5°C Mar 19	68.5 mm	50.0 mm	11.5 mm Mar 16	3.3 m/s	15.4 m/s Mar 8
Source: www.yr.no									

Tab. 4 - Tabular view for temperature and precipitation for Trondheim per month 2014-2015

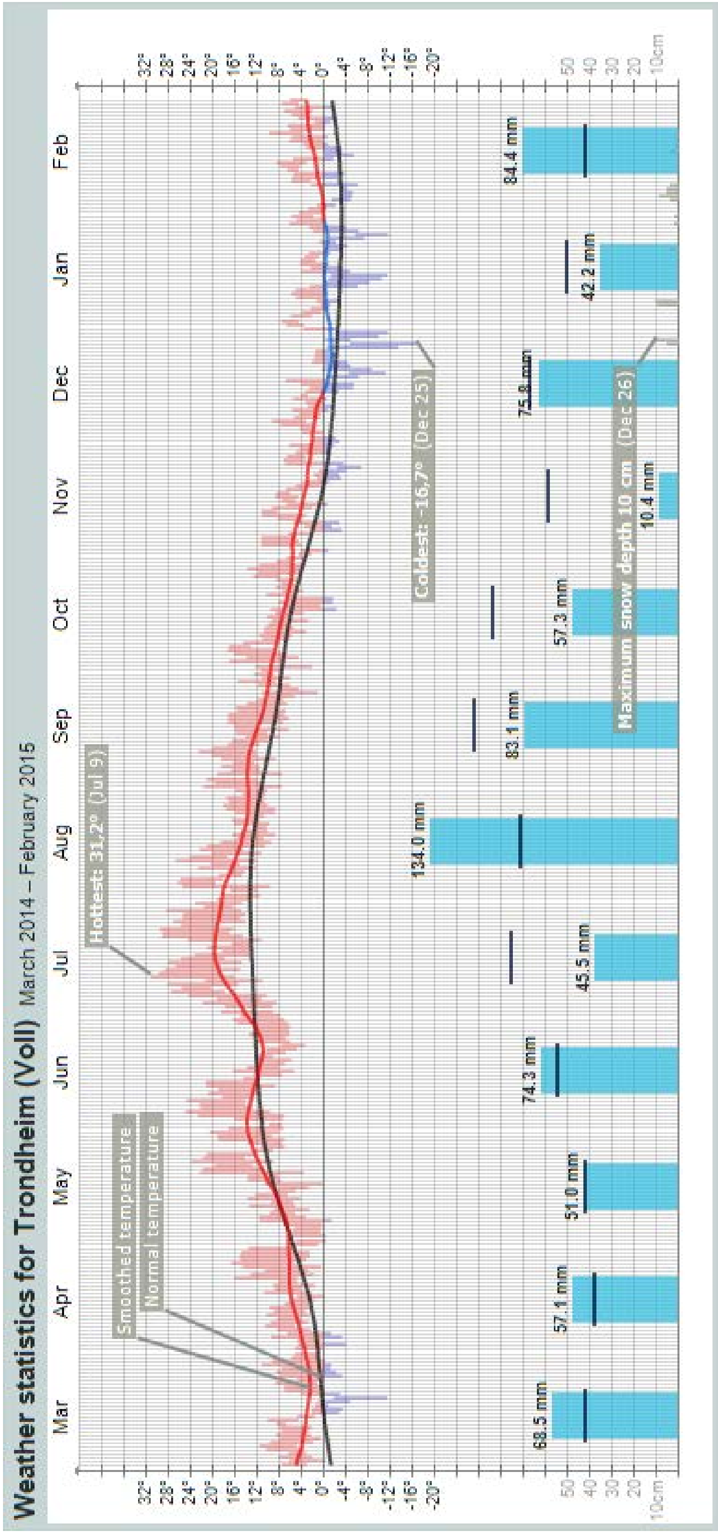

Figure 10: Weather statistics for Trondheim – March 2014 – February 2015

The black line shows mean value (both precipitation and temperature). Some stations does not have mean values, and hence no black line.
The red/blue line shows average temperature during the day (24h) (equalized for 30 days). The line is red by plus degrees, and blue by minus degrees.
The red/blue areas shows the temperature variations throughout the day (24h) with max- and min. temperature as endpoints. The area is red by plus degrees, and blue by minus degrees.
The light blue bars shows total precipitation this month. The black lines crossing is the normal (mean) value for precipitation.
The dark grey bars behind the precipitation bars shows snow depth measured day by day.
Some stations only measures precipitation, while others only measures temperature. If an area or bar is missing the station does not measure this data.

The maximum net energy for heating the building is 160 kWh/m^2, which in the variant Low Energy Building would become 30 kWh/m^2 per year (Table 5) and in Passive House of 15 kWh/m^2 per year (Table 6).

Tab. 5

Low Energy Building	Highest net low energy for heating $\vartheta_{ym} \geq 5°C$	$\vartheta_{ym} < 5°C$
Residential building with $A_{fl} < 200$ m²	$30 + 5 \times [(200 - A_{fl})/100]$	$30 + 5 \times [(200 - A_{fl})/100] + 5 \times (5 - \vartheta_{ym})$
Residential building with $A_{fl} \geq 200$ m²	30	$30 + 5 \times (5 - \vartheta_{ym})$
N.B. ϑ_{ym} = average temperature in Trondheim for year 2014-2015 A_{fl} = Area building		

Tab. 6

Passivhus	Highest net low energy for heating $\vartheta_{ym} \geq 5°C$	$\vartheta_{ym} < 5°C$
Residential building with $A_{fl} < 200$ m²	$15 + 3 \times [(200 - A_{fl})/100]$	$15 + 3 \times [(200 - A_{fl})/100] + 3 \times (5 - \vartheta_{ym})$
Residential building with $A_{fl} \geq 200$ m²	15	$15 + 3 \times (5 - \vartheta_{ym})$
N.B. ϑ_{ym} = average temperature in Trondheim for year 2014-2015 A_{fl} = Area building		

Tab. 5 - Maximum energy consumption from Norsk standard prNS 3700:2009
Tab. 6 - Maximum energy consumption from Norsk standard prNS 3700:2009

The building, with a restructuring proposal, is energy class D and indicated that:

- Scenario 1 (Low energy building): the building's energy becomes A+;
- Scenario 2 (Passive House): the building's energy becomes A++ (Table 7).

Tab. 7 - Net low energy for heating			
	[kWh/m^2]	**Average temperature [°C]**	**Energy efficiency class**
Project	160	7,4	D
Scenario 1: Low Energy building	30 max	7,4	A +
Scenario 2: Passivhus	15 max	7,4	A ++

2.5.2 Project alternatives

Considering the Norsk Standard "PRNs 3700: 2009" (Criteria for low energy and passive houses - Residential buildings) it is found that the U-value of walls, floor and roof do not reach the required limits (Table 8).

Tab. 8 – Comparison between U-values			
	Norsk Standard: prNS 3700:2009 Low Energy Building	**Norsk Standard: prNS 3700:2009 Passivhus**	**Project**
	U-values		
Walls	≤ 0,18 W/m^2 K	≤ 0,15 W/m^2 K	0,320 W/m^2 K
Floor	≤ 0,13 W/m^2 K	≤ 0,13 W/m^2 K	0,224 W/m^2 K
Roof	≤ 0,15 W/m^2 K	≤ 0,15 W/m^2 K	0,336 W/m^2 K

Those project alternatives have been acted on the walls, floor and roof, considering four different types of insulation:

- Insulation project in Rockwool Flexi A-Plate (λ = 0,037 w/mk);
- Insulating in wood fiber: Hunton Fiber (λ = 0,038 w/mk);
- Insulating in glass wool: Isover UNI-Skiva 35 (λ = 0,035 w/mk);
- Insulating glass wool: Glava Proff 35 Plate (λ = 0,035 w/mk).

Figure 12: Wood fiber – Hunton Fiber
(Source: http://www.hunton.no)

Figure 11: Mineral wool – Rockwool
(Source: http://www.rockwool.no)

Figure 14: Glass wool – Glava
(Source: http://www.glava.no)

Figure 13: Glass wool – Isover
(Source: http://www.isover.se)

Each insulation was examined considering the concept of sustainability of the "triple bottom line": environmental and economic impact.
In the calculation of U-values there were not considered thermal bridges, difficult to detect, considering the age of the building and the chance to avoid a possible error propagation (Table 9.1 and Table 9.2). The effect of thermal bridges can be assumed approximately whereas a final transmittance decreased by 10%.

Tab. 9.1								
	Hunton Fiber		Rockwool Flexi A-Plate		Isover Uni-Skiva 35		Glava Proff 35 Plate	
	Thicknes s (mm)	U - value (W/m^2 K)	Thicknes s (mm)	U - value (W/m^2 K)	Thicknes s (mm)	U - value (W/m^2 K)	Thicknes s (mm)	U - value (W/m^2 K)
Walls	50 + 150	0,184	55 + 130	0,182	50 + 130	0,183	50 + 130	0,183
Floor	280	0,132	255	0,137	250	0,132	250	0,132
Roof	240	0,151	220	0,156	210	0,154	210	0,154

Tab. 9.2								
	Hunton Fiber		Rockwool Flexi A-Plate		Isover Uni-Skiva 35		Glava Proff 35 Plate	
	Thicknes s (mm)	U - value (W/m^2 K)	Thicknes s (mm)	U - value (W/m^2 K)	Thicknes s (mm)	U - value (W/m^2 K)	Thicknes s (mm)	U - value (W/m^2 K)
Walls	50 + 200	0,148	55 + 170	0,152	50 + 170	0,151	50 + 170	0,151
Floor	280	0,132	255	0,137	250	0,132	250	0,132
Roof	240	0,151	220	0,156	210	0,154	210	0,154

Tab. 9.1 - Thickness necessary in order to get correct U-values - Low Energy Building
Tab. 9.2 - Thickness necessary in order to get correct U-values - Passivhus

2.5.3 LCA module and footprint

In 1993 during the congress of Vermount, in Canada, The Society of Environmental Toxicology and Chemistry (SETAC), defined the Life Cycle Assessment as:

"Is an objective process of evaluation of energy and environmental loads related to a process or activity, carried out by identifying energy and materials used and wastes released into the environment. The assessment includes the entire life cycle process or activity, including the extraction and processing of raw materials, manufacturing, transportation, distribution, use, reuse, recycling and final disposal."

European standards UNI EN ISO 14040:2006(Principles and framework) and the UNI EN ISO 14044:2008 (Requirements and Guidelines) are consistent with the previous definition. They define LCA as a methodology for assessing the environmental aspects and impacts of a product through a series of stages:

- Definition of the objective of the study;
- Compilation of identifying the most important inputs and outputs;
- Assessment of environmental impacts;
- Interpretation of the results of previous analyses.

An LCA can interpret the results in two ways:

1. Cradle-to-gate;
2. Cradle-to-cradle.

A cradle-to-cradle LCA considers the employees results including the entire life cycle of a product (from cradle to grave), and it compares the production phase and phrase usage.

A cradle-to-cradle LCA includes, in addition to the stages of production and use, environmental impacts in the different aspects of the disposal, recycling and reuse.

LCA can also apply to construction activity. The building is a complex system composed of several parts with different functions which influence each other. You can have technical requirements such as thermal transmittance, fire resistance or architectural requirements such as accessibility. For this reason, LCA can be applied in two ways: either to consider the building as a whole or to consider it as a sum of more technological parts connected together and assess the environmental impacts separately. Even splitting the building into several parts, the LCA will provide a complete and detailed information concerning the emissions of energy and mass in each phase of the life cycle of the product.

The data are derived from the LCA are:

- Global warming, which represents the potential global warming and hence its contribution to the greenhouse effect. It is expressed in kg CO_2 eqv emitted into the atmosphere. The latter figure represents the weighted value related to the contribution of all the climate-changing greenhouse gases emitted during the production cycle;
- Energy use, which is the use of energy in MJ.

This study focuses on the comparison of CO_2 eqv emissions in the use of various types of insulation for walls, floor and roof applied to an existing building. The study is based on certification of the Environmental Product Declaration (EPD).

The EPD is based on a Life Cycle Assessment (LCA) and complete the information available, focusing on the entire life cycle of the product. The structure of the validation of the EPD consists of three basic steps:

1. The development and approval of the Product Specific Requirements (PSR), which set out the technical and functional characteristics of a product and provide the information necessary to draw EPD;
2. The preparation of the EPD, which must include the information generated by the results from the study LCA compliance with UNI ISO 14040;
3. Verification of an independent third party, which ensures the validity and accuracy of the information contained in the EPD.

The EPD is a valuable communication tool of the environmental performance of a product, to inform and disseminate business strategies to intermediaries that can be commercial intermediaries, suppliers, consumers, citizens, organizations and associations.

For the study conducted were used for Rockwool Flexi A-Plate, Isover Uni-Skiva 35 and Glava Profs 35 Plate comes from EPD EPD-Norge, while Hunton Fiber used a report prepared by SINTEF (The Foundation for Scientific and Industrial research in Trondheim), which is the largest independent research company in Scandinavia. The information is summarized in Tab. 10.

Tab. 10								
	Hunton Fiber		Rockwool Flexi A-Plate		Isover Uni-Skiva 35		Glava Proff 35 Plate	
	Unit	Cradle to gate (A1-A3)	Unit	Cradle to gate (A1-A3)	Unit	Cradle to gate (A1-A3)	Unit	Cradle to gate (A1-A3)
Global warming	kg Co_2 eqv	-1,75	kg Co_2 eqv	1,27	kg Co_2 eqv	0,7	kg Co_2 eqv	0,76
Energy use	MJ	31,39	MJ	13,8	MJ	25	MJ	19,5
	Sources:							
	Sintef report		EPD Norge (www.epd-norge.no)		EPD Norge (www.epd-norge.no)		EPD Norge (www.epd-norge.no)	

Tab. 10 - Key environmental indicators

All proposed solutions produce improvements of the thermal resistance of the building and then examined a satisfactory solution retrofitting.
All insulation materials examined (wood fiber, mineral wool and glass wool), turn out to have different thermal transmittance, so spring from different thicknesses useful to achieve the desired final transmittance.
The density of these materials is different for each of them.
The density of a substance is a mass per unit volume, is specifically expressed in kg/m^3.
To get the kg CO_2/m^2 eqv products from each solution you must know the kg/m^2. This data obtained by dividing the thickness by the density.
The calculation is obtained by the equation (1):

$$X\ \left[\frac{kg}{m^2}\right] = \ \rho\ \left[\frac{kg}{m^3}\right]\ x\ th.\,[m] \tag{1}$$

On which:

- X represents the unknown, expressed in [kg/m^2];
- ρ is the density, expressed in [kg/m^3];
- th. represents the thickness, expressed in [m].

The data obtained for each material and for every component examined are listed in Table 11.1 and Tab. 11.2.

Tab. 11.1

	Hunton Fiber		Rockwool Flexi A-Plate		Isover Uni-Skiva 35		Glava Proff 35 Plate	
	Thickness (mm)	Kg /m²	Thickness (mm)	Kg /m²	Thickness (mm)	Kg /m²	Thickness (mm)	Kg /m²
Walls	50 + 150	10	55 + 130	5,365	50 + 130	3,06	50 + 130	2,97
Floor	280	14	255	7,395	250	4,25	250	4,125
Roof	240	12	220	6,38	210	3,57	210	3,465

Tab. 11.2

	Hunton Fiber		Rockwool Flexi A-Plate		Isover Uni-Skiva 35		Glava Proff 35 Plate	
	Thickness (mm)	Kg /m²	Thickness (mm)	Kg /m²	Thickness (mm)	Kg /m²	Thickness (mm)	Kg /m²
Walls	50 + 200	12,5	55 + 170	6,525	50 + 170	3,74	50 + 170	3,63
Floor	280	14	255	7,395	250	4,25	250	4,125
Roof	240	12	220	6,38	210	3,57	210	3,465

Tab. 11.1 - Kg/m^2 of insulation - Low Energy Building
Tab. 11.2 - Kg/m^2 of insulation - Passivhus

According to ISO 14040, a functional unit (FU) defines the quantification of the service or function performed by the material/product system under consideration. The purpose of defining the FU is to provide a reference unit, where inventory inputs and outputs are quantified in the system boundary to facilitate the conversion of the basic life cycle inventory data to provide a means of comparing different materials/products for a given function. The FU is defined as "mass (kg) of insulation material needed to cover a 1 m^2 of area at a thickness that gives a design thermal resistance R of 1 m^2K/W within an expected service life of 60 years". The FU can be expressed using equation:

$$FU = R.\lambda.\rho.A \text{ [kg] (Fufa, 2007)}$$

On which:

- R is unit thermal resistance [m^2K/W];
- λ is the thermal conductivity [W/mK];
- ρ is the density [kg/m^3];
- A is unit area [m^2].

For the analysis of the materials it is used the "Declared unit" of the certifications described above.

The unit can be declared:

- One element (example 1 brick, 1 window),
- An amount by weight (example 1 kg of cement) [kg],
- An amount in length (example 1 m of pipe) [m],
- A surface (example 1 m2 of wall) [m^2],
- A volume (eg. 1 m^3 of wood) [m^3].

It is used when the precise function of the analysis object, the building has not yet been defined, or when the LCA does not cover the entire life cycle (cradle to cradle), but stops at the gate of the factory (cradle to gate).

The Declared unit differs for each material taken according to Tab. 12.

Tab. 12 - Declared unit with R= 1 m^2 K/W				
	Hunton	**Rockwool**	**Isover**	**Glava**
Density (kg/m^3)	50	29	17	16,5
Thickness (m) of 1 m^2	0,038	0,037	0,035	0,035
Kg/m^2 ([5])	1,900	1,073	0,595	0,5775

The kg CO_2/m^2 eqv for each solution adopted were obtained by developing the proportion according to the formula (2):

$$Y_{1-i}\left[\frac{kg}{m^2}\right] : Y_{2-i}\left[CO_2\ eqv\right] = Z_{1-i}\left[\frac{kg}{m^2}\right] : Z_{2-i}\left[CO_2\ eqv\right] \tag{2}$$

[5] This data is obtained used the equation (1) :

$$X\left[\frac{kg}{m^2}\right] = \rho\left[\frac{kg}{m^3}\right] x\ th.\left[m\right]$$

On which:

- Y_{1-i} is the i-th data present in Tab. 12;
- Y_{2-i} is the i-th data present in Tab. 10;
- Z_{1-i} is the i-th data present in Tab. 11.1 and Tab. 11.2;
- Z_{2-i} is the i-th unknown.

From the formula (2) it is obtained that:

$$Z_{2-i}\ [CO_2\ eqv] = \frac{Y_{2-i}\ [CO_2\ eqv] x\ Z_{1-i}\ \left[\frac{kg}{m^2}\right]}{Y_{1-i}\ \left[\frac{kg}{m^2}\right]} \tag{3}$$

The data obtained by the formula (3) are shown in Tab. 13.1 and 13.2

Tab. 13.1

	Hunton Fiber		Rockwool Flexi A-Plate		Isover Uni-Skiva 35		Glava Proff 35 Plate	
	Thickness (mm)	Kg CO_2/m^2	Thickness (mm)	Kg CO_2/m^2	Thickness (mm)	Kg CO_2/m^2	Thickness (mm)	Kg CO_2/m^2
Walls	50 + 150	-9,2105	55 + 130	6,3500	50 + 130	3,6000	50 + 130	3,9086
Floor	280	-12,8947	255	8,7527	250	5,0000	250	5,4286
Roof	240	-11,0526	220	7,5514	210	4,2000	210	4,5600
Total		-33,1579		22,6541		12,8000		13,8971

Tab. 13.2

	Hunton Fiber		Rockwool Flexi A-Plate		Isover Uni-Skiva 35		Glava Proff 35 Plate	
	Thickness (mm)	Kg CO_2/m^2	Thickness (mm)	Kg CO_2/m^2	Thickness (mm)	Kg CO_2/m^2	Thickness (mm)	Kg CO_2/m^2
Walls	50 + 200	-11,5132	55 + 170	7,7230	50 + 170	4,4000	50 + 170	4,7771
Floor	280	-12,8947	255	8,7527	250	5,0000	250	5,4286
Roof	240	-11,0526	220	7,5514	210	4,2000	210	4,5600
Total		-35,4605		24,0270		13,6000		14,7657

Tab. 13.1 - CO_2/m^2 of insulation - Low Energy Building
Tab. 13.2 - CO_2/m^2 of insulation - Passivhus

The incidence of CO_2/m^2 eqv of each material and each building component examined shown in the tables above, was displayed in the histograms Fig. 15 and Fig.16.

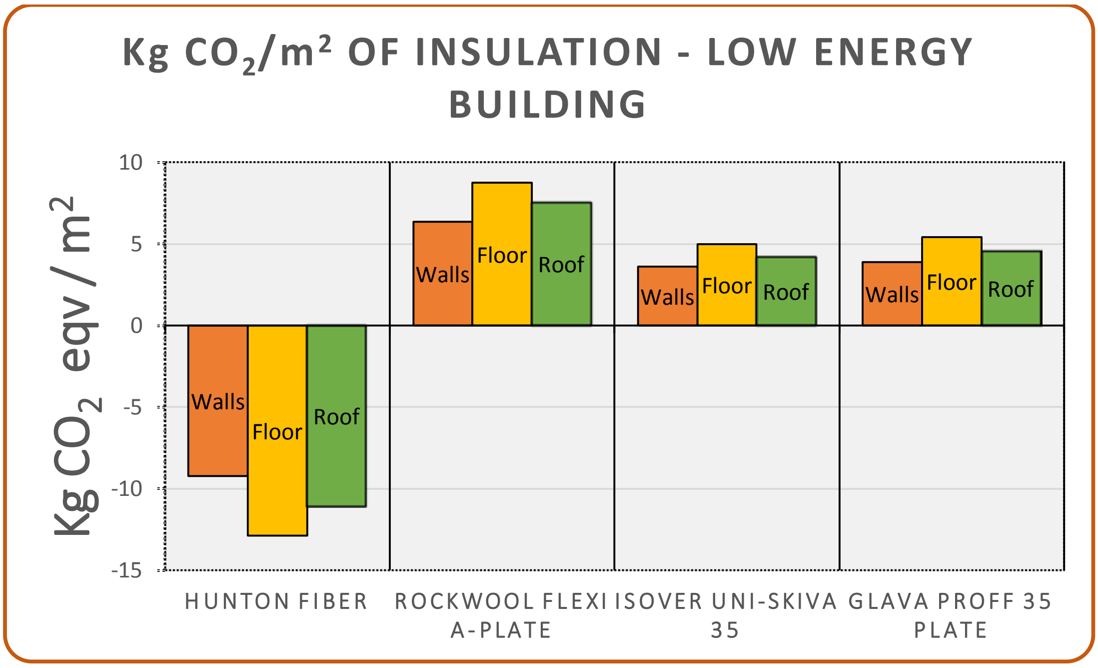

Figure 15: Kg CO_2/m^2 of insulation - Low Energy Building

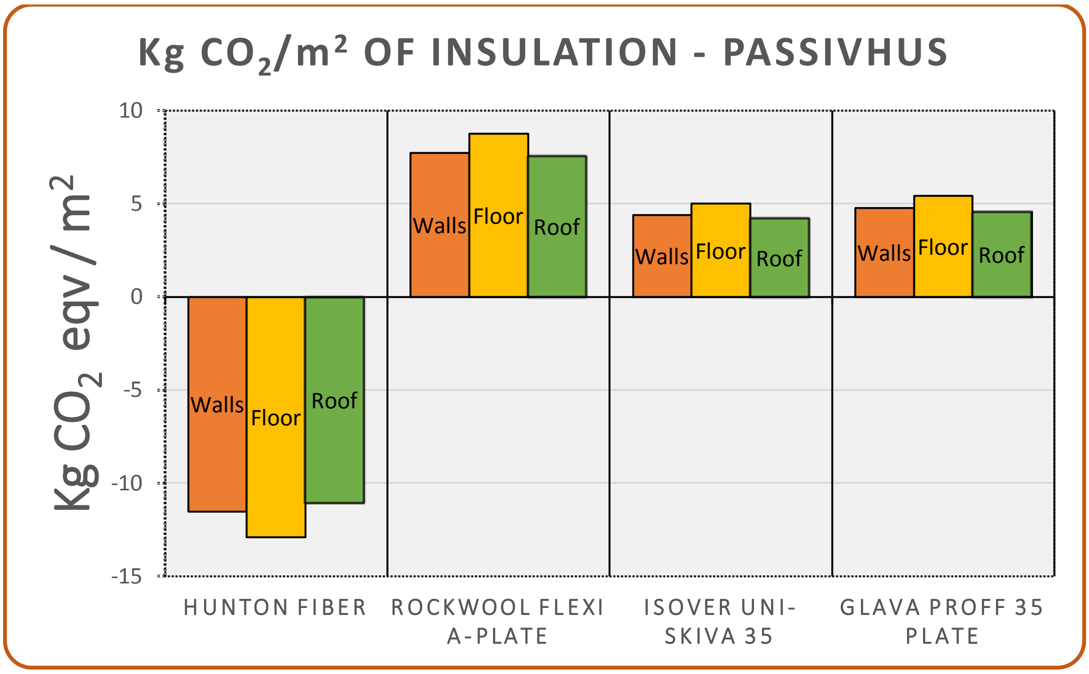

Figure 16: Kg CO_2/m^2 of insulation - Passivhus

After analysis of the parts, it has proceeded to the evaluation of climate-changing power of the materials on the building. The data of this evaluation, are deduced from Tables 14.1 and 14.2, and were obtained by multiplying the area of each individual component considered for the incidence of emission of CO_2/m^2 eqv.

Tab. 14.1 - kg CO_2 total - Low energy building					
	Area	**Hunton Fiber**	**Rockwool Flexi A-Plate**	**Isover Uni-Skiva 35**	**Glava Proff 35 Plate**
	(m^2)	**kg CO_2**	**kg CO_2**	**kg CO_2**	**kg CO_2**
Walls	1203	-11080,26316	7639,05	4330,8	4702,011429
Floor	316,2803	-4078,351237	2768,307437	1581,4015	1716,9502
Roof	404,6129	-4472,037316	3055,374169	1699,37418	1845,034824

Tab. 14.2 - kg CO_2 total - Passivhus					
	Area	**Hunton Fiber**	**Rockwool Flexi A-Plate**	**Isover Uni-Skiva 35**	**Glava Proff 35 Plate**
	(m^2)	**kg CO_2**	**kg CO_2**	**kg CO_2**	**kg CO_2**
Walls	1203	-13850,32895	9290,736486	5293,2	5746,902857
Floor	316,2803	-4078,351237	2768,307437	1581,4015	1716,9502
Roof	404,6129	-4472,037316	3055,374169	1699,37418	1845,034824

The data obtained in Tables 14.1 and 14.2 have been represented in the histograms in Figure 17 and Figure 18 shown below.

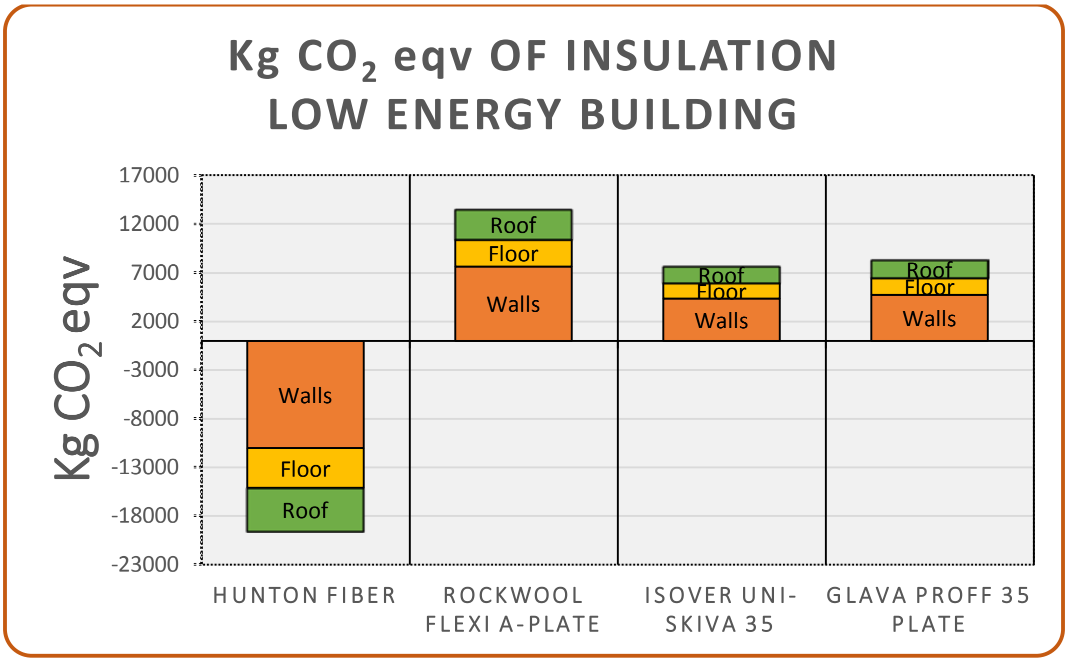

Figure 17: Kg CO_2 eqv of insulation – Low Energy Building

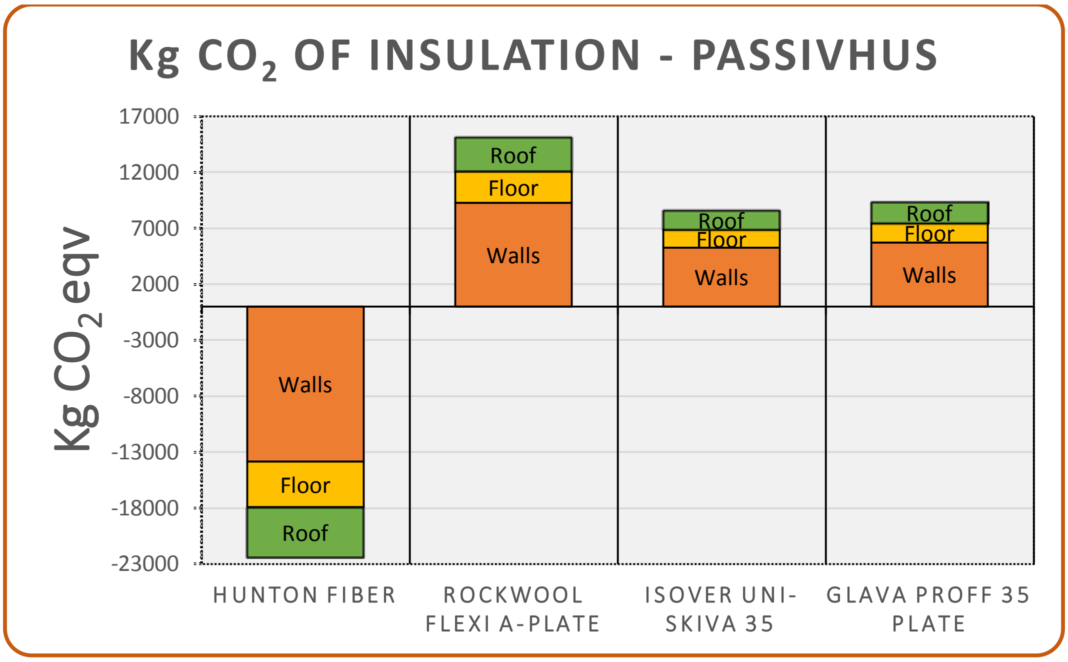

Figure 18: Kg CO_2 eqv of insulation – Passivhus

2.5.3.1 Consideration

Their analysis, emissions of CO_2 eqv of the four alternatives designed to upgrade the energy, materials, rock wool (Rockwool Flexi A-Plate), glass wool 1 (Isover Uni-Skiva 35) and glass wool 2 (Glava Profs Plate 35) have different effects. These effects can also double with each other, but all have a high environmental impact.

Rock wool has a total of emissions of greenhouse gases:

- scenario Low Energy Building equal to 13462,73 Kg CO_2 eqv;
- scenario Passive House equal to 15114,42 Kg CO_2 eqv.

Glass wool Isover has a total of emissions of greenhouse gases:

- scenario Low Energy Building equal to 7611,58 Kg CO_2 eqv;
- scenario Passive House equal to 8573,98 Kg CO_2 eqv.

Glass wool Glava has a total of emissions of greenhouse gases:

- scenario Low Energy Building equal to 8263,99 Kg CO_2 eqv;
- scenario Passive House equal to 9308,89 Kg CO_2 eqv.

The only material with the beneficial effects on the greenhouse, which indeed tends to decrease, is the wood fiber. This has a storage capacity of heat equal to double compared to conventional mineral wool.

The wood fiber, given its density, will provide a better thermal protection for the building capacity, which is the propensity of a component casing of the accumulation of heat. For this reason, the wood fiber tends to accumulate heat and to release it with a certain time interval. This feature is functional in cold climates, where there is the need for the housing in winter retain the heat in the environment confined. The wood fiber for its thermal inertia will work well by heat shield making it more stable the internal temperature.

The wood fiber is produced from wood waste, without significant pollutant loads because taken from the material in excess of other products of wood which were previously intended for combustion.

In this, also, are added additives which increase the fire resistance making them almost fireproof.

The wood fiber also has other qualities, including good sound absorption.

The wood fiber Hunton has a total of emissions of greenhouse gases:

- scenario Low Energy Building equal to -19630,65 Kg CO_2 eqv;
- scenario Passive House equal to -22400,72 Kg CO_2 eqv.

2.5.4 Life Cycle Costing (LCC) module

The ISO 14040:2006 and ISO 15686:2008, European regulations concerning the recent economic and environmental sustainability of the interventions in the construction field, identify potential approaches of Life Cycle Assessment (LCA) and Life Cycle Costing (LCC). In these regulations it shows that the central component of "cost" has an important role in sustainable project.

The cost is a key element for the implementation of decisions from the early stages of the construction process until the end in view of the life cycle. Its role is essential to assess the feasibility of the projects and supports the building blocks of an intervention. This consists of the following elements:

- Construction process, global expression of planning;
- As management control of the life of the building and its use;
- Life cycle of the building, expressed in the articulation of the process in phases.

The LCC (Life-Cycle Cost) is a method of economic evaluation, in which the costs of owning, use, maintain, and ultimately dispose of a certain project, are considered potentially important to take decisions. The LCC is used to determine the 'total cost' of a product, considering its entire life cycle, useful to evaluate design alternatives that meet a certain level of performance (comfort, architectural quality, construction standards, etc.) They have, however, different investment costs, management, maintenance and refurbishment and life cycles.

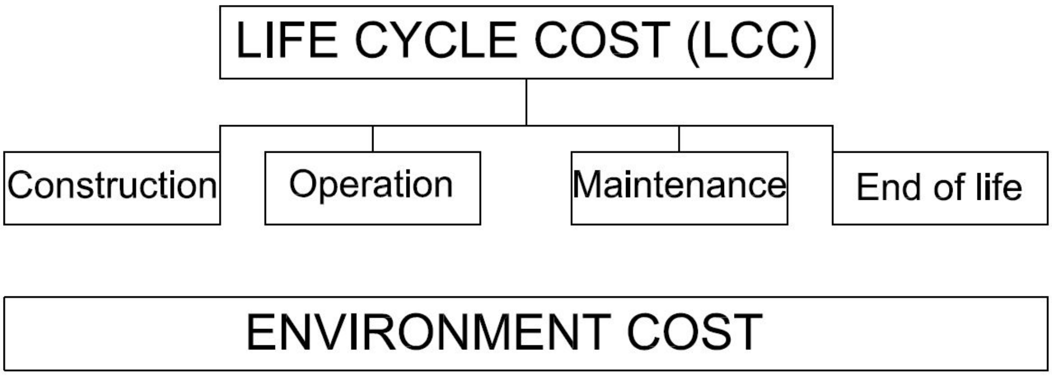

Figure 19: Cost analysis

The LCC is also useful in evaluating projects with high upfront investment, functional to reduce operating costs thereafter. It identifies relevant issues in terms of costs, specifying the constraints of physical, functional or legal involving the a priori exclusion of certain alternatives, and identifies valid design alternatives that meet specific performance techniques.

This study considers the activities of a period during which the costs and benefits related to some investment, have repercussions on the interests of the investor who must make the decision.

The design alternatives to be comparable to each other must have the same study period. This:

- Start at the time 0;
- Includes the period of planning and construction;
- Includes management period;
- It concludes the year ‘n’ established at the time of evaluation.

In the perspective of sustainability it is necessary to open the analysis of the feasibility of the project to technical aspects - technological, related to building systems for the realization of the same ones and economic - financial.

In construction there are different stages of the life cycle and supply chain evaluation as shown in Figure 20.

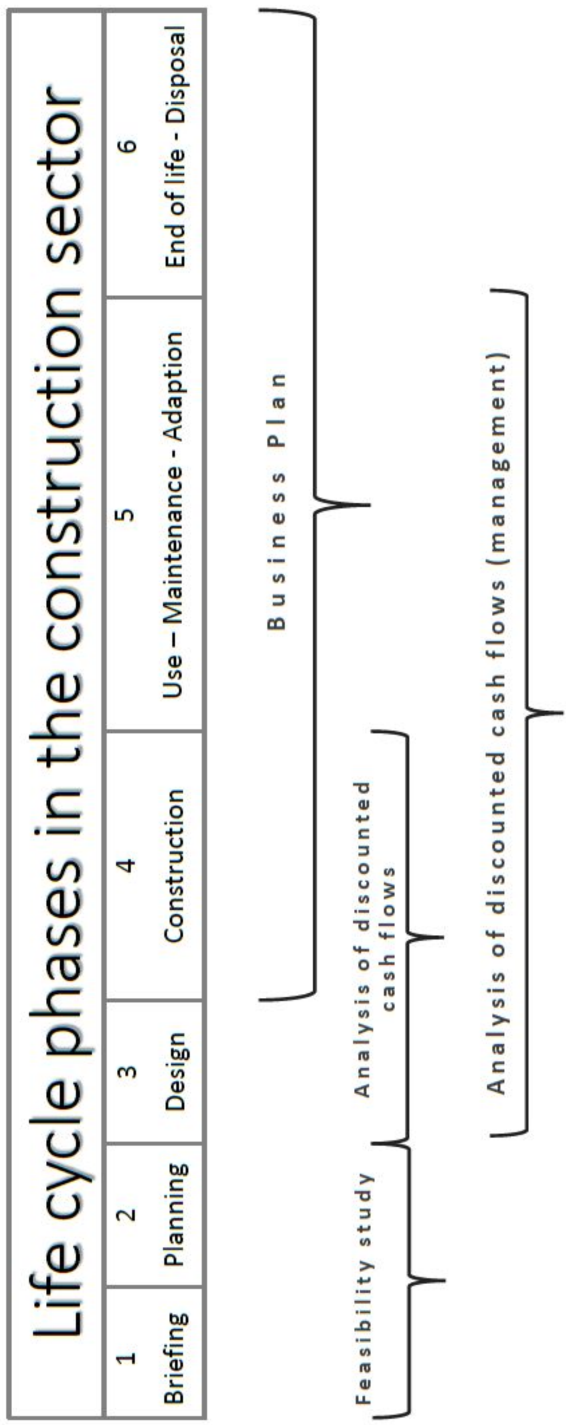

Figure 20: Life cycle phases

The *Feasibility study* architecture - technology involves the identification and analysis of the objectives of the client involved, followed by an analysis of the functionality over time focusing on the identification of materials and technology solutions best performing in terms of performance, site preparation and the economic impact.

The *Discounted cash flow* analysis is carried out during the design / construction. The cost is related to the project, treated as output of an application of LCC.

The *Business plan* covers the entire supply chain including evaluation of the simulation of the budget related to the activities of the enterprise as a whole.

From an operational point of view, after setting up a project idea for which were defined aims, the scale and the initial capital, it can defined a methodology LCC, which consists of 15 steps:

1. Identification of the main purpose of the analysis LCC;
2. Identification of the initial scope of the analysis:
3. Identification of the relationships between sustainability analysis and LCC;
4. Identification of the period of analysis and the methods of economic evaluation;
5. Identification of the need for additional analyzes, such as analysis of risk / uncertainty and sensitivity;
6. Identification of the requirements of the well and the project;
7. Identification of the options to be included in the analysis LCC and cost items to be considered;

8. Collection of data of cost and time for your analysis LCC;
9. Check the values of the financial metrics and analysis of the period;
10. Review of the risk strategy and the production of a preliminary analysis of risk / uncertainty;
11. Production of economic evaluation;
12. Application of risk / uncertainty detailed, if necessary;
13. Application of sensitivity analysis, if necessary;
14. Interpretation and presentation of initial results;
15. Presentation of the results and preparation of final reports.

The correlation between the cost categories and each phase of the life cycle of the building with its approaches to the treatment of costs are highlighted in Figure 21.

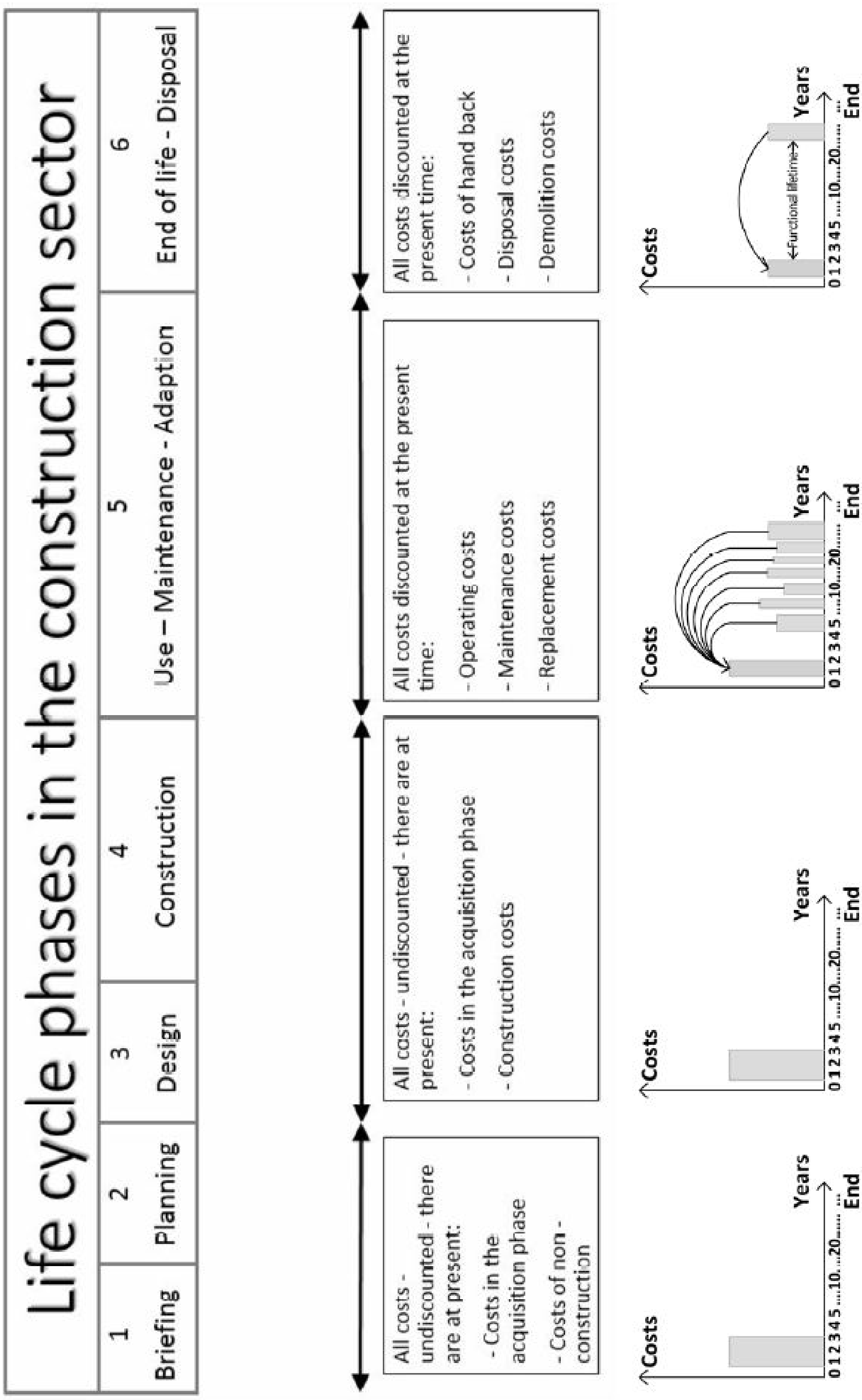

Figure 21: Life cycle phases: correlation between cost and phase.

In this case study related to Thingvallagården, it has been taken in consideration a *Business plan*: the construction phase, the operation, maintenance, replacement, the end of life and disposal of the four types of insulation already considered previously.

Following estimates made in Trondheim have evaluated various items: price insulation including transport; price for the installation of the insulation; price for the maintenance; price for disposal.

PRICE FOR INSULATION WITH TRASPORT

It has been considered either units or pack, net and gross inclusive of VAT at 25% (current VAT). It has been analyzed for each insulating material, considering in condition both of Low Energy Building (Tables 15 - 16 - 17 - 18) and in Passive House (Tables 19 - 20 – 21 - 22).

Tab. 15					
	Unit	Net price [nok]	Gross price with VAT 25% [nok]	Total price with VAT 25% [nok]	
Walls	Pack	300,00 + 255,00	375,00 + 318,75	NOK	287.700,00
Floor	Pack	250,00 + 250,00	312,50 + 312,50	NOK	107.500,00
Roof	Pack	250,00 + 280,00	312,50 + 350,00	NOK	114.312,50
Source: Byggmakker - Fossegrenda 3 - 7038 Trondheim (Norway)					

Tab. 16					
	Unit	Net price [nok]	Gross price with VAT 25% [nok]	Total price with VAT 25% [nok]	
Walls	Pack	207,20 + 215,20	259,00 + 269,00	NOK	155.616,00
Floor	Pack	207,20 + 207,20	259,00 + 259,00	NOK	49.728,00
Roof	Pack	207,20 + 207,21	259,00 + 259,01	NOK	63.455,00
Source: Byggmakker - Fossegrenda 3 - 7038 Trondheim (Norway)					

Tab. 15 - Prices for insulation - Low energy building - Hunton Fiber
Tab. 16 - Prices for insulation - Low energy building - Rockwool A-Plate

Tab.17

	Unit	Net price [nok]	Gross price with VAT 25% [nok]	Total price with VAT 25% [nok]
Walls	Piece	34,32 + 67,20	42,90 + 84,00	NOK 212.049,90
Floor	Piece	67,20 + 34,32	84,00 + 42,90	NOK 92.796,00
Roof	Piece /Pack	62,20 479,20	84,00 599,00	NOK 99.986,70
Source: Byggmakker - Fossegrenda 3 - 7038 Trondheim (Norway)				

Tab.18

	Unit	Net price [nok]	Gross price with VAT 25% [nok]	Total price with VAT 25% [nok]
Walls	Pack	279,20 + 255,20	349,00 + 319,00	NOK 133.681,00
Floor	Pack	287,20 + 279,20	359,00 + 349,00	NOK 43.508,00
Roof	Pack	287,20 + 279,20	359,00 + 349,00	NOK 54.926,00
Source: Byggmakker - Fossegrenda 3 - 7038 Trondheim (Norway)				

Tab. 17 -Prices for insulation - Low energy building - Isover Uni-Skiva 35
Tab. 18 - Prices for insulation - Low energy building - Glava Proff 35 Plate

Tab.19

	Unit	Net price [nok]	Gross price with VAT 25% [nok]	Total price with VAT 25% [nok]
Walls	Pack	300,00 + 255,00	375,00 + 318,75	NOK 214.612,50
Floor	Pack	250,00 + 250,00	312,50 + 312,50	NOK 107.500,00
Roof	Pack	250,00 + 280,00	312,50 + 350,00	NOK 114.312,50

Source: Byggmakker - Fossegrenda 3 - 7038 Trondheim (Norway)

Tab.20

	Unit	Net price [nok]	Gross price with VAT 25% [nok]	Total price with VAT 25% [nok]
Walls	Pack	207,20 + 207,20	259,00 + 259,00	NOK 188.811,00
Floor	Pack	207,20 + 207,20	259,00 + 259,00	NOK 49.728,00
Roof	Pack	207,20 + 207,21	259,00 + 259,01	NOK 63.455,00

Source: Byggmakker - Fossegrenda 3 - 7038 Trondheim (Norway)

Tab. 19- Prices for insulation – Passivhus - Hunton Fiber
Tab. 20 - Prices for insulation – Passivhus - Rockwool A-Plate

Tab.21

	Unit	Net price [nok]	Gross price with VAT 25% [nok]	Total price with VAT 25% [nok]	
Walls	Piece	34,32 + 67,20	42,90 + 84,00	NOK	352.413,90
Floor	Piece	67,20 + 34,32	84,00 + 42,90	NOK	92.796,00
Roof	Piece /Pack	62,20 479,20	84,00 599,00	NOK	99.986,70
Source: Byggmakker - Fossegrenda 3 - 7038 Trondheim (Norway)					

Tab.22

	Unit	Net price [nok]	Gross price with VAT 25% [nok]	Total price with VAT 25% [nok]	
Walls	Pack	279,20 + 287,20	349,00 + 359,00	NOK	163.352,00
Floor	Pack	287,20 + 279,20	359,00 + 349,00	NOK	43.508,00
Roof	Pack	287,20 + 279,20	359,00 + 349,00	NOK	54.926,00
Source: Byggmakker - Fossegrenda 3 - 7038 Trondheim (Norway)					

Tab. 21 - Prices for insulation – Passivhus - Isover Uni-Skiva 35
Tab. 22 - Prices for insulation – Passivhus - Glava Proff 35 Plate

The tables above have been obtained in accordance with the assessments made by the company Byggmakker.

PRICE FOR INSTALLATION OF INSULATION

It has been considered to m^2, net and inclusive of VAT at 25% (current VAT).

The price for installing insulation, implemented by qualified personnel, was calculated based on the price list FDV-nøkkelen (version 2014).

It has been analyzed for each insulating material considering in condition of both Low Energy Building (Table 23) and in Passive House (Tables 24).

Tab.23 - Prices for installation of insulation - Low energy building					
	Hunton Fiber - Rockwool A-Plate - Isover Uni-Skiva 35 - Glava Proff 35 Plate				
	Unit	**Net price [nok]**	**Gross price with VAT 25% [nok]**	**Total price with VAT 25%**	**[nok]**
Walls	m^2	32,00	40,00	NOK	48.120,00
Floor	m^2	40,00	50,00	NOK	15.814,02
Roof	m^2	36,00	45,00	NOK	18.207,58
Source: FDV-nøkkelen - 2014					

Tab.24 - Prices for installation of insulation - Passivhus					
	Hunton Fiber - Rockwool A-Plate - Isover Uni-Skiva 35 - Glava Proff 35 Plate				
	Unit	**Net price [nok]**	**Gross price with VAT 25% [nok]**	**Total price with VAT 25%**	**[nok]**
Walls	m^2	36,00	45,00	NOK	54.135,00
Floor	m^2	40,00	50,00	NOK	15.814,02
Roof	m^2	36,00	45,00	NOK	18.207,58
Source: FDV-nøkkelen - 2014					

PRICE FOR DISPOSAL OF INSULATION

It has been considered a ton, net and inclusive of VAT at 25% (current VAT).

The price for disposal of the insulation has been calculated according to the directions of the company Franzefoss AS, specializing in sale of building materials.

It has been analyzed for each insulating material, considering in condition of both Low Energy Building (Table 25 - 26 - 27 -28) and in Passive House (Table 29 - 30 - 31 -32).

Tab. 25 - Prices for disposal - Low energy building - Hunton Fiber				
	Weight (ton)	**Net price [nok/ton]**	**Gross price with VAT 25% [nok/ton]**	**K_d = Total price with VAT 25% [nok]**
Walls	12030,00	1800	NOK 2.250,00	NOK 27.067.500,00
Floor	4427,92	1800	NOK 2.250,00	NOK 9.962.829,45
Roof	4855,35	1800	NOK 2.250,00	NOK 10.924.548,30
Source: Franzefoss AS, Olav Ingstads vei 5, Postboks 53, 1309 Rud (Norway)				

Tab. 26 - Prices for disposal - Low energy building - Rockwool A-Plate				
	Weight (ton)	**Net price [nok/ton]**	**Gross price with VAT 25% [nok/ton]**	**K_d =Total price with VAT 25% [nok]**
Walls	6454,10	1800	NOK 2.250,00	NOK 14.521.713,75
Floor	2338,89	1800	NOK 2.250,00	NOK 5.262.508,84
Roof	2581,43	1800	NOK 2.250,00	NOK 5.808.218,18
Source: Franzefoss AS, Olav Ingstads vei 5, Postboks 53, 1309 Rud (Norway)				

Tab. 27 - Prices for disposal - Low energy building - Isover Uni-Skiva 35				
	Weight (ton)	**Net price [nok/ton]**	**Gross price with VAT 25% [nok/ton]**	**K_d =Total price with VAT 25% [nok]**
Walls	3681,18	1800	NOK 2.250,00	NOK 8.282.655,00
Floor	1344,19	1800	NOK 2.250,00	NOK 3.024.430,37
Roof	1444,47	1800	NOK 2.250,00	NOK 3.250.053,12
Source: Franzefoss AS, Olav Ingstads vei 5, Postboks 53, 1309 Rud (Norway)				

Tab. 28 - Prices for disposal - Low energy building - Glava Proff 35 Plate				
	Weight (ton)	**Net price [nok/ton]**	**Gross price with VAT 25% [nok/ton]**	**K_d =Total price with VAT 25% [nok]**
Walls	3572,91	1800	NOK 2.250,00	NOK 8.039.047,50
Floor	1304,66	1800	NOK 2.250,00	NOK 2.935.476,53
Roof	1401,98	1800	NOK 2.250,00	NOK 3.154.463,32
Source: Franzefoss AS, Olav Ingstads vei 5, Postboks 53, 1309 Rud (Norway)				

Tab. 29 - Prices for disposal – Passivhus - Hunton Fiber				
	Weight (ton)	**Net price [nok/ton]**	**Gross price with VAT 25% [nok/ton]**	**K_d =Total price with VAT 25% [nok]**
Walls	15037,50	1800	NOK 2.250,00	NOK 33.834.375,00
Floor	4427,92	1800	NOK 2.250,00	NOK 9.962.829,45
Roof	4855,35	1800	NOK 2.250,00	NOK 10.924.548,30
Source: Franzefoss AS, Olav Ingstads vei 5, Postboks 53, 1309 Rud (Norway)				

Tab. 30 - Prices for disposal – Passivhus - Rockwool A-Plate				
	Weight (ton)	**Net price [nok/ton]**	**Gross price with VAT 25% [nok/ton]**	**K_d =Total price with VAT 25% [nok]**
Walls	7849,58	1800	NOK 2.250,00	NOK 17.661.543,75
Floor	2338,89	1800	NOK 2.250,00	NOK 5.262.508,84
Roof	2581,43	1800	NOK 2.250,00	NOK 5.808.218,18
Source: Franzefoss AS, Olav Ingstads vei 5, Postboks 53, 1309 Rud (Norway)				

Tab. 31 - Prices for disposal – Passivhus - Isover Uni-Skiva 35				
	Weight (ton)	**Net price [nok/ton]**	**Gross price with VAT 25% [nok/ton]**	**K_d =Total price with VAT 25% [nok]**
Walls	4499,22	1800	NOK 2.250,00	NOK 10.123.245,00
Floor	1344,19	1800	NOK 2.250,00	NOK 3.024.430,37
Roof	1444,47	1800	NOK 2.250,00	NOK 3.250.053,12
Source: Franzefoss AS, Olav Ingstads vei 5, Postboks 53, 1309 Rud (Norway)				

Tab. 32 - Prices for disposal – Passivhus - Glava Proff 35 Plate				
	Weight (ton)	**Net price [nok/ton]**	**Gross price with VAT 25% [nok/ton]**	**K_d =Total price with VAT 25% [nok]**
Walls	4366,89	1800	NOK 2.250,00	NOK 9.825.502,50
Floor	1304,66	1800	NOK 2.250,00	NOK 2.935.476,53
Roof	1401,98	1800	NOK 2.250,00	NOK 3.154.463,32
Source: Franzefoss AS, Olav Ingstads vei 5, Postboks 53, 1309 Rud (Norway)				

Prices of disposal calculated, however, are not the ones to be considered in the LCC. The value to be used is the Net Present Value (NPV), which is the sum of all future cash flows "discounted" to their present value.

According to the scheme depicted in Figure 22, the expense of disposal, will be made in the sixtieth year, but it is updated at the time of the current estimate (year 0 = 2015).

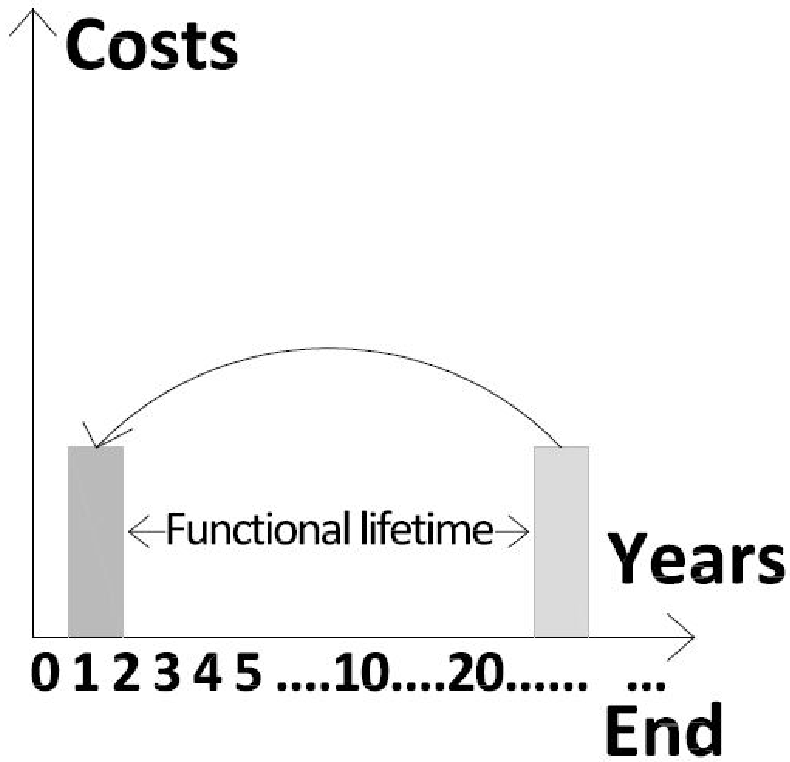

Figure 22: Costs discounted at the present time.

NPV is a financial technique to actualize future cash flows of an investment project at the moment of valuation of worth. It is widely used as a way to estimate the worth of a project as well as the value of a property. The general formula can be considered as:

$$NPV = \sum_{t=1}^{n} \frac{F_t}{(1+i)^t}$$

On which:

- F_t= estimated cash flow;
- i = discount rate;
- t = period of analysis.

The technique can be used to estimate the present value of all the expenditure according to a specific hypothesis of construction:

$$NPV = \sum_{t=0}^{T} \frac{K_d}{(1+i)^n} \tag{4}$$

In this case we have

- Kd = estimated cost in the current year (2015);
- i = interest referred to 3%;
- n = period of analysis considered 60 years.

The prices obtained for each insulating material considered are reported in Table 33 for the scenario Low Energy and in Table 34 for Passive House.

Tab. 33

	K_{di} =Total price with VAT 25% [nok]	Interest [%]	Lifetime of insulation [years]	NPV [nok]
Hunton Fiber	NOK 47.954.877,75	3,0%	60	NOK 40.066.075,68
Rockwool A-Plate	NOK 25.592.440,77	3,0%	60	NOK 21.382.364,36
Isover Uni-Skiva 35	NOK 14.557.138,49	3,0%	60	NOK 12.162.421,00
Glava Proff 35 Plate	NOK 14.128.987,36	3,0%	60	NOK 11.804.702,74

Tab.34

	K_{di} =Total price with VAT 25% [nok]	Interest [%]	Lifetime of insulation [years]	NPV [nok]
Hunton Fiber	NOK 43.797.204,45	3,0%	60	NOK 36.592.359,11
Rockwool A-Plate	NOK 22.924.052,59	3,0%	60	NOK 19.152.938,53
Isover Uni-Skiva 35	NOK 13.147.675,37	3,0%	60	NOK 10.984.821,17
Glava Proff 35 Plate	NOK 12.760.979,03	3,0%	60	NOK 10.661.738,19

Tab. 33 - Total cost for disposal e Net Present Value - Low energy building
Tab.34 - Total cost for disposal e Net Present Value – Passivhus

TOTAL COST

It is the sum of each costs: price for insulation with transport, the price for the installation of insulation, price for maintenance, price for disposal.

It is evalueted that the price for the maintenance in this case is equal to 0 nok, because the insulation does not need maintenance throughout its life cycle, because it remains inside the packages (walls, roof, floor), until to disposal.

The total price obtained for any insulating material analyzed is shown in table 35 for the scenario Low Energy and in Table 36 for Passive House.

Tab. 35 - Total cost - Low energy building	
	Total with VAT 25%
Hunton Fiber	NOK 40.657.729,77
Rockwool A-Plate	NOK 21.733.304,95
Isover Uni-Skiva 35	NOK 12.649.395,20
Glava Proff 35 Plate	NOK 12.118.959,33

Tab. 36 - Total cost - Passivhus	
	Total with VAT 25%
Hunton Fiber	NOK 37.116.940,71
Rockwool A-Plate	NOK 19.543.089,13
Isover Uni-Skiva 35	NOK 11.618.174,36
Glava Proff 35 Plate	NOK 11.011.680,79

The data obtained from Tab. 35 and Tab. 36 have been represented in the histograms in Figure 23 and Figure 24 below.

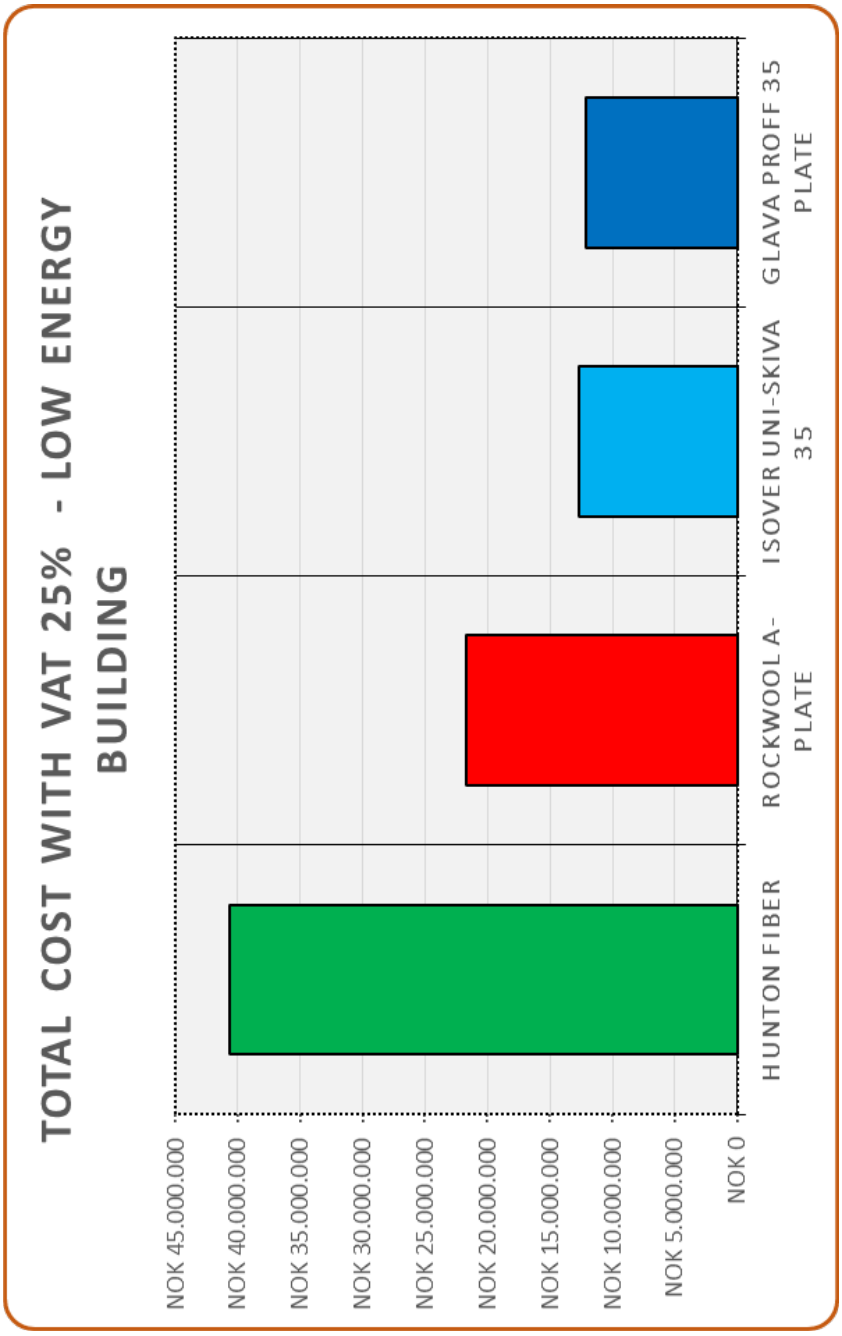

Figure 23: Total cost – Low Energy Building.

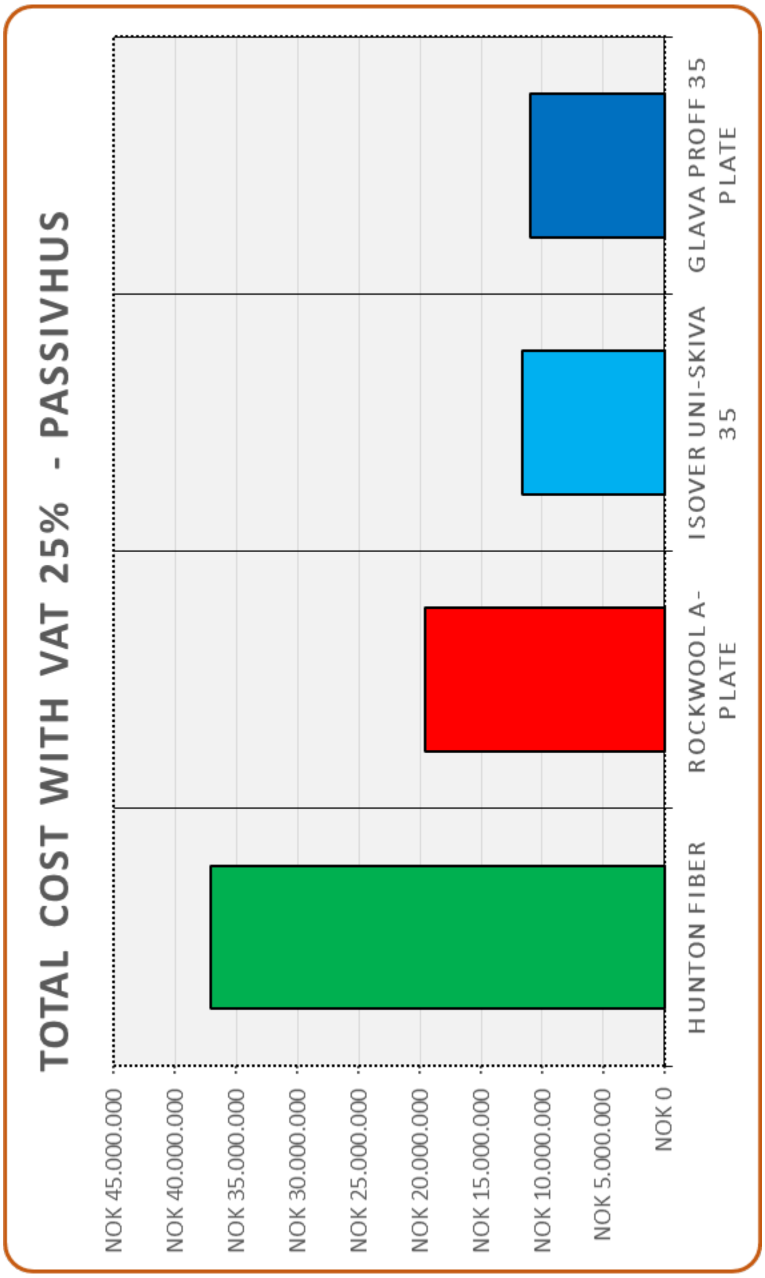

Figure 24: Total cost – Passive House

2.5.5 Reflections on total cost and CO_2 eqv emissions

Analysing data on emissions of CO_2 eqv (Fig. 17-18) and data relating to the total costs (Fig. 23-24), it is clear that the building Passive House total costs are reduced compared to the Low Energy Building.

These data are obtained using only the same material for each package casing proposed (all wood, the entire mineral fiber, whole glass wool). Combining the different materials in the condition of Passive House, there have been obtained countless different solutions, with reduced costs, although some environmentally are not optimal.

If you combine the material more sustainable (Hunton Fiber) and the most cost-effective (Glava Profs 35), it will have interesting scenarios.

2.5.6 Combination of project alternatives

The combination of wood fiber of Hunton and glass wool Glava have been obtained these six additional design alternatives:

E. Walls paneled in wood fiber Hunton and floors and roof panels with glass wool;
F. Floor panels wood fiber Hunton and walls and roof panels with glass wool;
G. Roof panels of wood fiber and the walls and floor panels in glass wool;

H. Walls panels in glass wool and floors and roof panels with wood fiber Hunton;
I. Floor panels with glass wool and the walls and roof panels with wood fiber Hunton;
L. Roof panels and walls of glass wool and floor panels of wood fiber.

These combinations are conceptually represented in Figure 25.

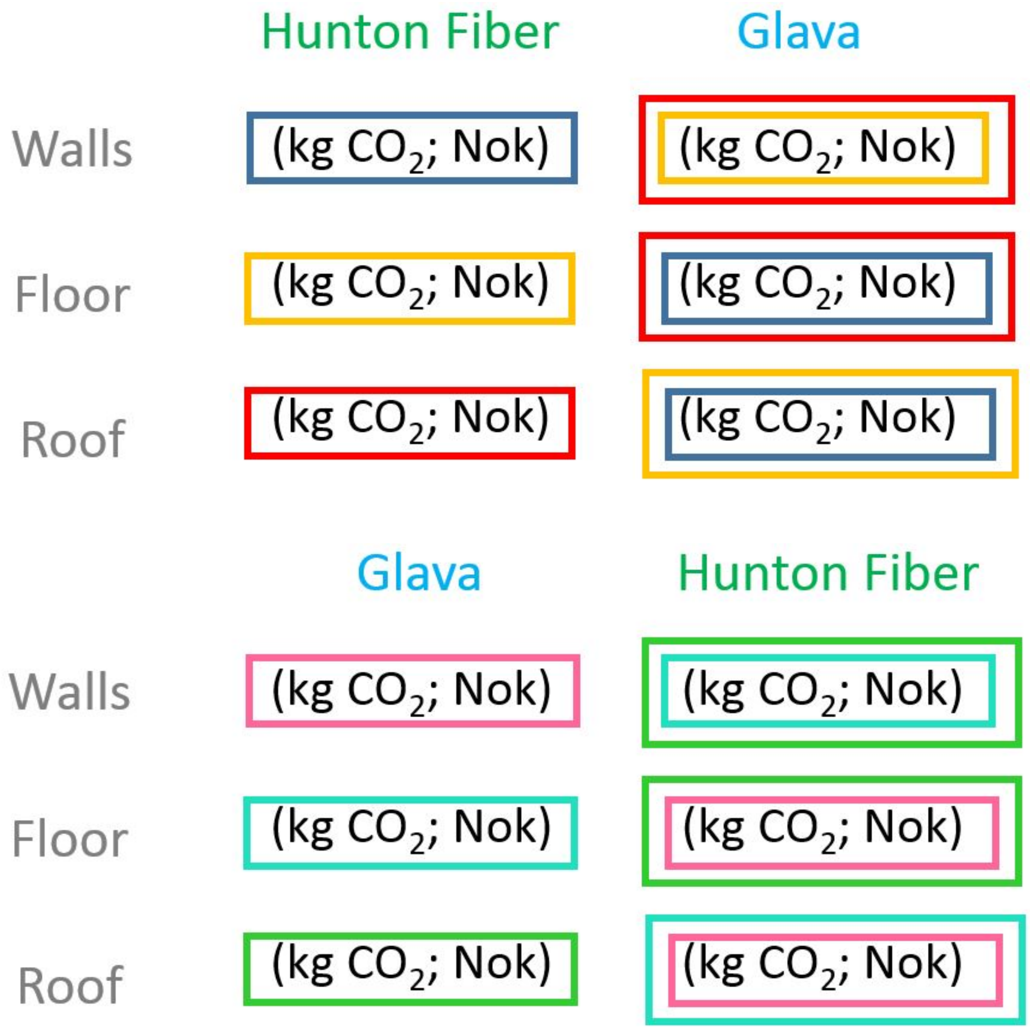

Figure 25: Combination of project alternatives

The initial combinations are indicated with A, B, C, D:

A. Walls, floors and roof of wood fiber Hunton;
B. Walls, floors and roof of mineral wool Rockwool;
C. Walls, floors and roof of glass wool Isover;
D. Walls, floors and roof of glass wool Glava.

The results of the combinations between the two materials show a decrease in emissions of CO_2 eqv respect to the solution D and a reduction of the total costs compared to the solution A.

The analytical data of the ten solutions are highlighted in a graph which presents the environmental impacts on the ordinate axis (Increasing CO_2 eqv) and the economic impacts on the abscissa axis (Increasing the LCC) (Fig. 26).

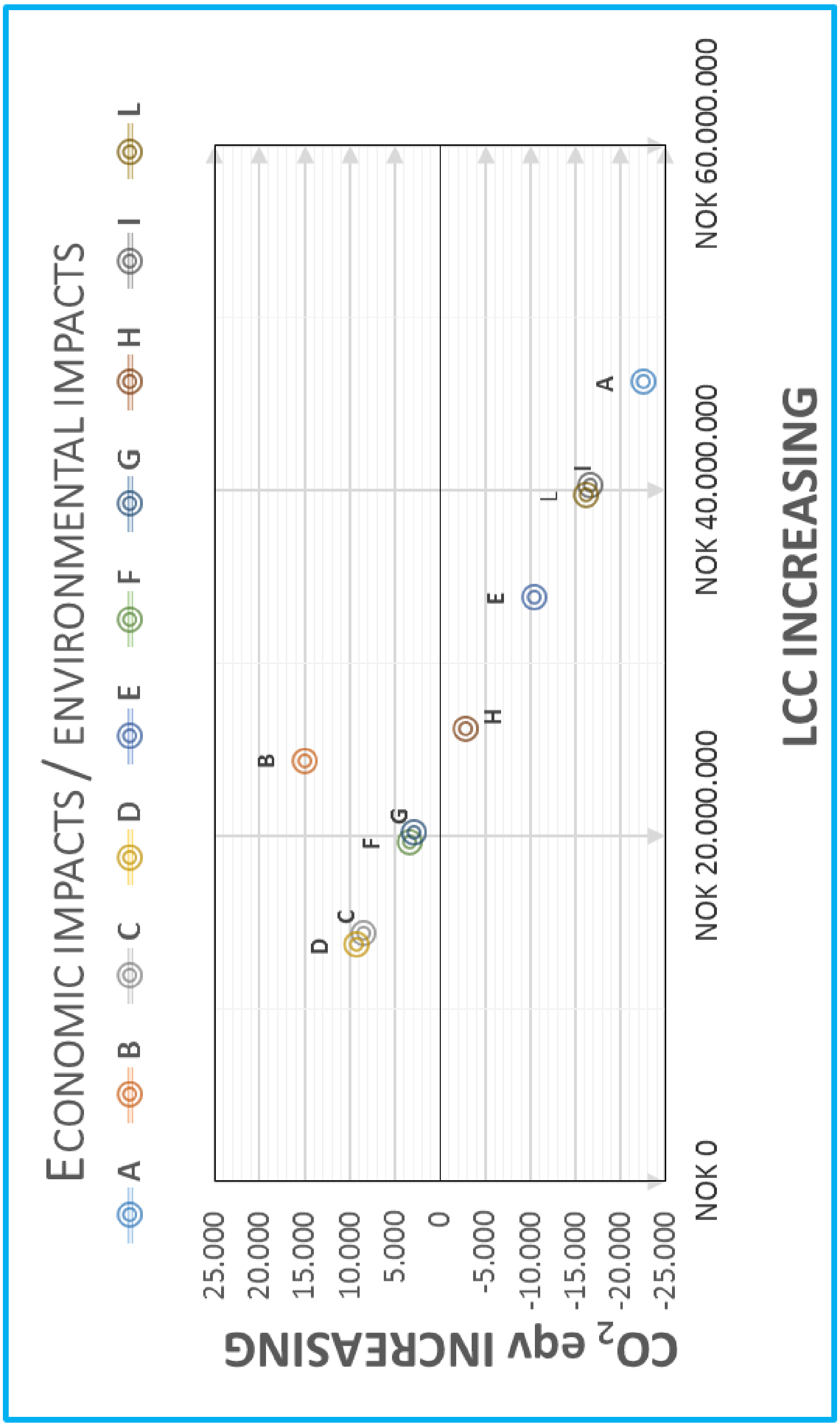

Figure 26: Probabilistic approach: economic impacts and environmental impacts of ten project alternatives

All solutions have an uncertainty evaluation. These uncertainties illustred in Figure 26 are represented by circles to indicate the potential dispersion of the values, that is the range within which it can vary both the economic and environmental impacts.

From the data in Figure 26 it was converted into a function F (x) that intercepts the ten solutions (Figure 27).

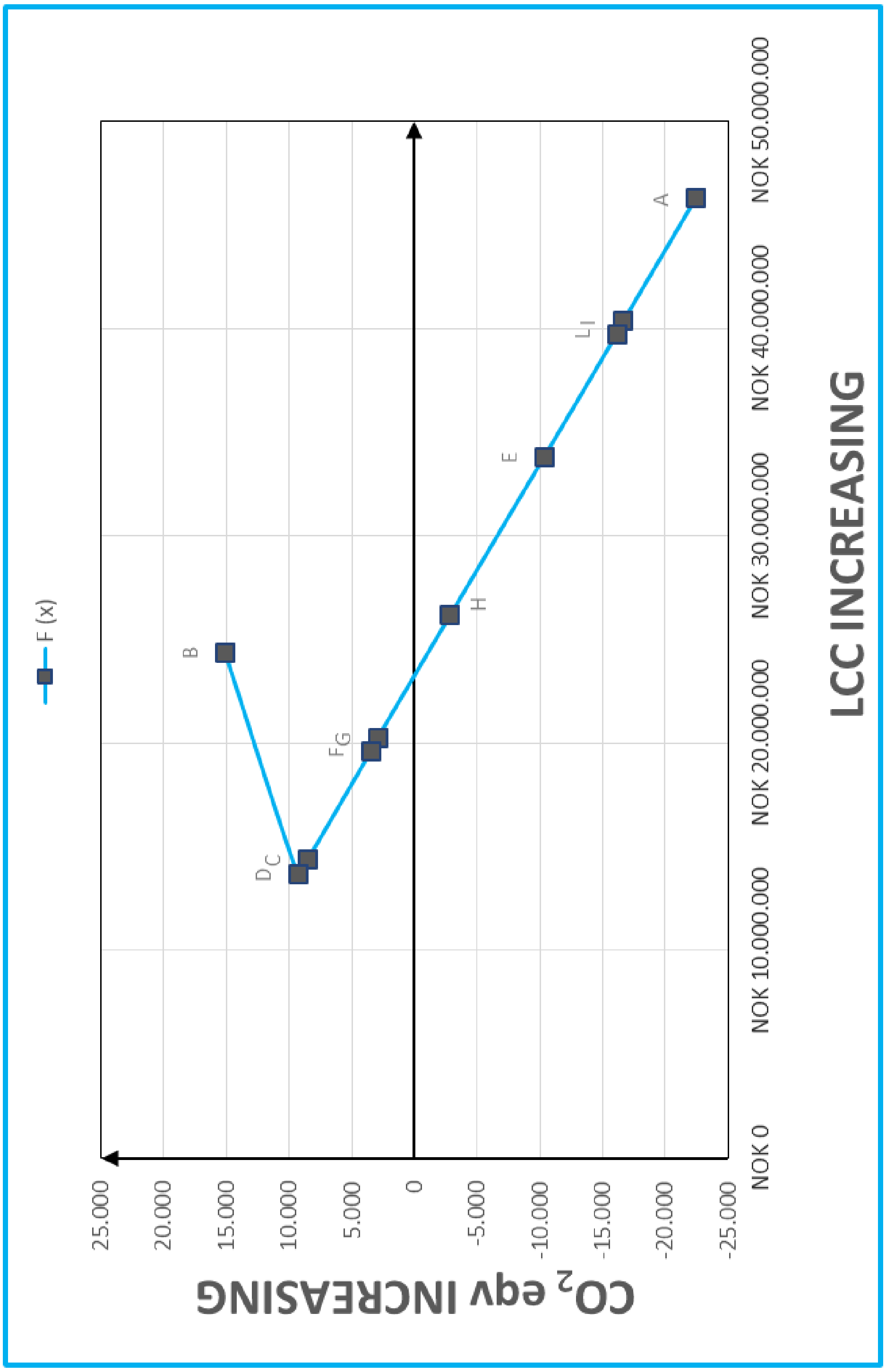

Figure 27: Function relationship of the ten solutions

The total cost of each solution provided can be divided into annual installments (AC) for the entire lifecycle of manufactured housing.

The total cost current i-th (PV) will be equal to:

$$PV = AC \frac{(1+i)^{60} - 1}{(1+i)^{60}\, x\, i} \tag{5}$$

On which:

PV = total cost [nok];

AC = prorated costs [nok];

i = interest calculated at 3%;

60 = years of life cycle analysis.

From the formula (5) it is obtained that:

$$AC = PV \frac{(1+i)^{60}\, x\, i}{(1+i)^{60} - 1} \tag{6}$$

In the processing of data relating to the proposed solutions is obtained the following table 37 explicative:

Tab. 37 : Annual cost and kg CO_2 eqv for each solution			
	PV	**AC**	**kg CO_2 eqv**
A	NOK 46.244.350	NOK 843.338	-22400,72
B	NOK 24.341.693	NOK 443.909	15114,42
C	NOK 14.333.579	NOK 261.395	8573,98
D	NOK 13.647.220	NOK 248.878	9308,89
E	NOK 33.757.781	NOK 615.626	-10288,34
F	NOK 19.582.533	NOK 357.118	3513,59
G	NOK 20.198.476	NOK 368.351	2991,82
H	NOK 26.133.789	NOK 476.590	-2803,49
I	NOK 40.309.037	NOK 735.098	-16605,42
L	NOK 39.693.094	NOK 723.866	-16083,65

The graph relating to the above table is the following Fig. 28.

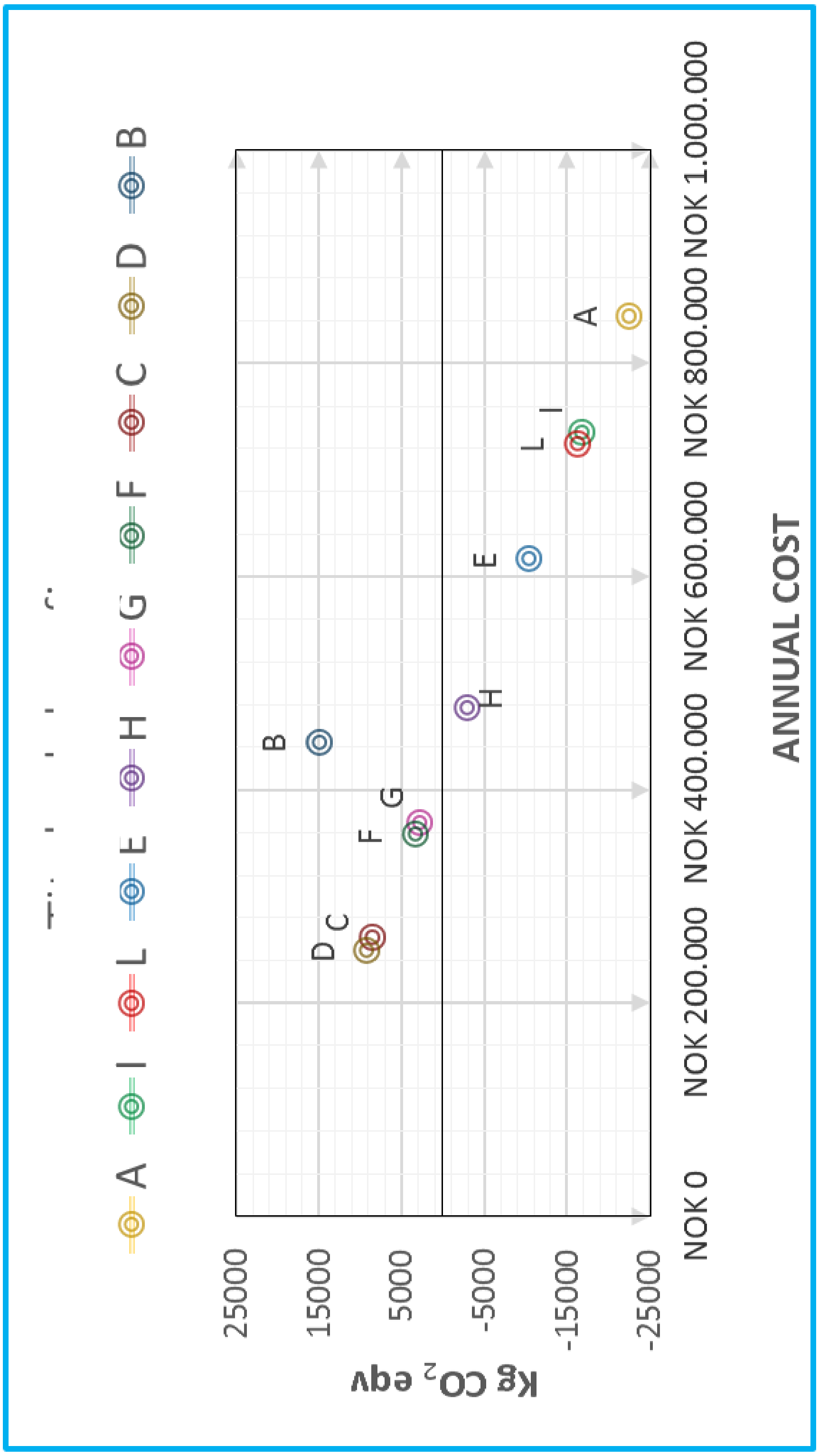

Figure 28: Probabilistic approach: annual cost and environmental impacts of ten project alternatives

CHAPTER III

Conclusion

3.1 Summary

This thesis work focused on the analysis of the total costs and emissions of greenhouse gases of various types of insulating alternative applied to an existing historic building in Trondheim, Norway, whose name is Thingvallagården.

The choice of alternative retrofit was based on the comparison between the current most widely used insulation material (mineral wool) and other types, equally performing.

When making a renovation of an existing building efficiency by implementing a technical approach, it can be considered various insulation materials to subsequently install. The strategies concern the variation of the thickness of insulation on the facade, in the shall and in the bottom floor, considering the different thermal conductivity of materials.

The aim was to identify the effect that each different insulation material examined, has on the total costs and emissions with a view of life cycle.

The combination of the total costs and greenhouse gas emissions is not a common practice if you want to assess the economic and environmental impacts. For this reason it analyzed four types of insulation, which would make the building Low Energy Building or, in the best condition, Passive House.

The research questions have been:

- Is it possible to implement sustainable interventions in the renovation of an existing building in Norway?

- Is it possible achieve limiting the costs and emissions of greenhouse gases retrofitting an existing building?

- Is it possible to use various insulating materials containing costs and CO_2 emissions with a view of the life cycle of an existing building?

For the first question it has been considered the norm Norsk PrnS standard 3700:2009. Following that, the interventions to be proposed are aimed at increasing the level of insulation in order to obtain a lower consumption of annual net energy for heating. In this perspective, adding the use of components windowed and doors with specific characteristics of transmittance, it could change the building from class D to class A+ or A++.

The second and third questions have led us to consider four different types of insulation commercialized in Norway, evaluating CO_2 eqv in the atmosphere and total costs considering the whole life cycle of the building considered.

The insulating materials examined were panels of wood fiber of Hunton, mineral wool of Rockwool, glass wool 1 of Isover and glass wool 2 of Glava.

The analysis of the greenhouse gas emissions of each material examined has shown that each of them has contributed in a different way one from each other: the wood fiber provides a positive contribution to the environment; the same can not be said for the two types of glass wool and mainly for mineral wool, as shown in Figure 29.

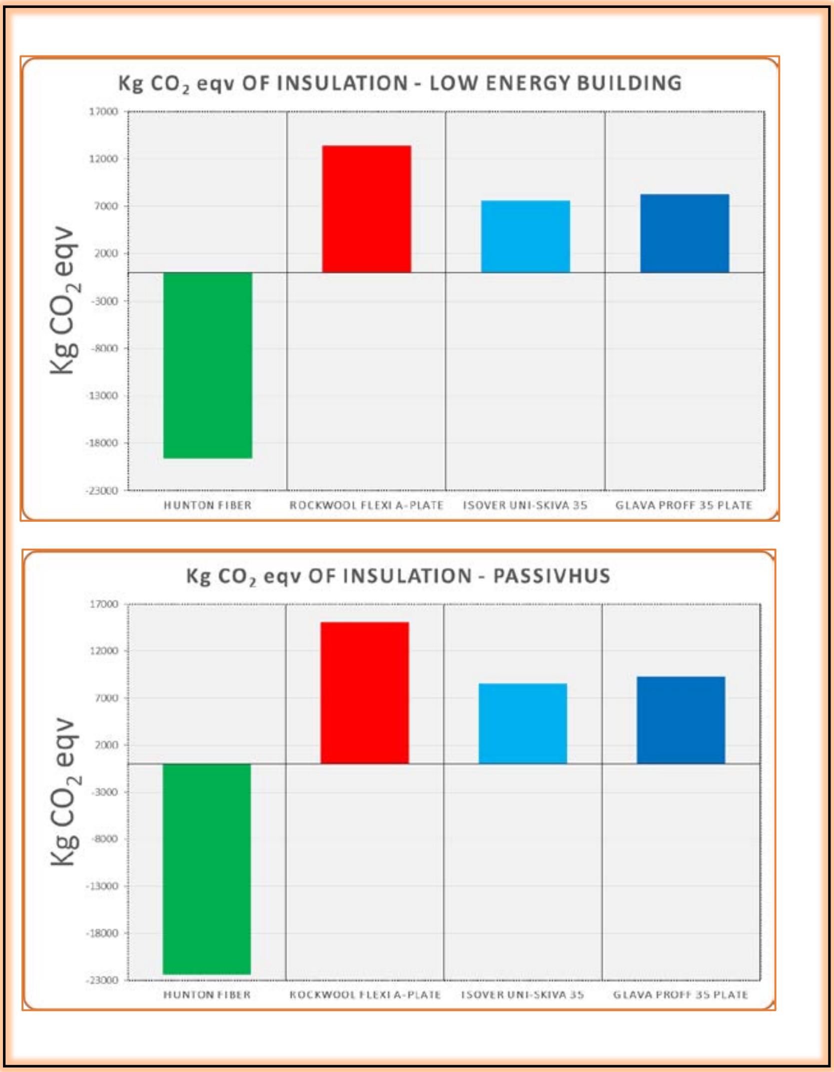

Figure 29: Results analysis of emissions of greenhouse gases

The analysis of the total costs of each material examined showed, in contrast, that the wood fiber, being a more sustainable material, is more expensive. The most cheaper is glass wool 2 as shown in Figure 30.

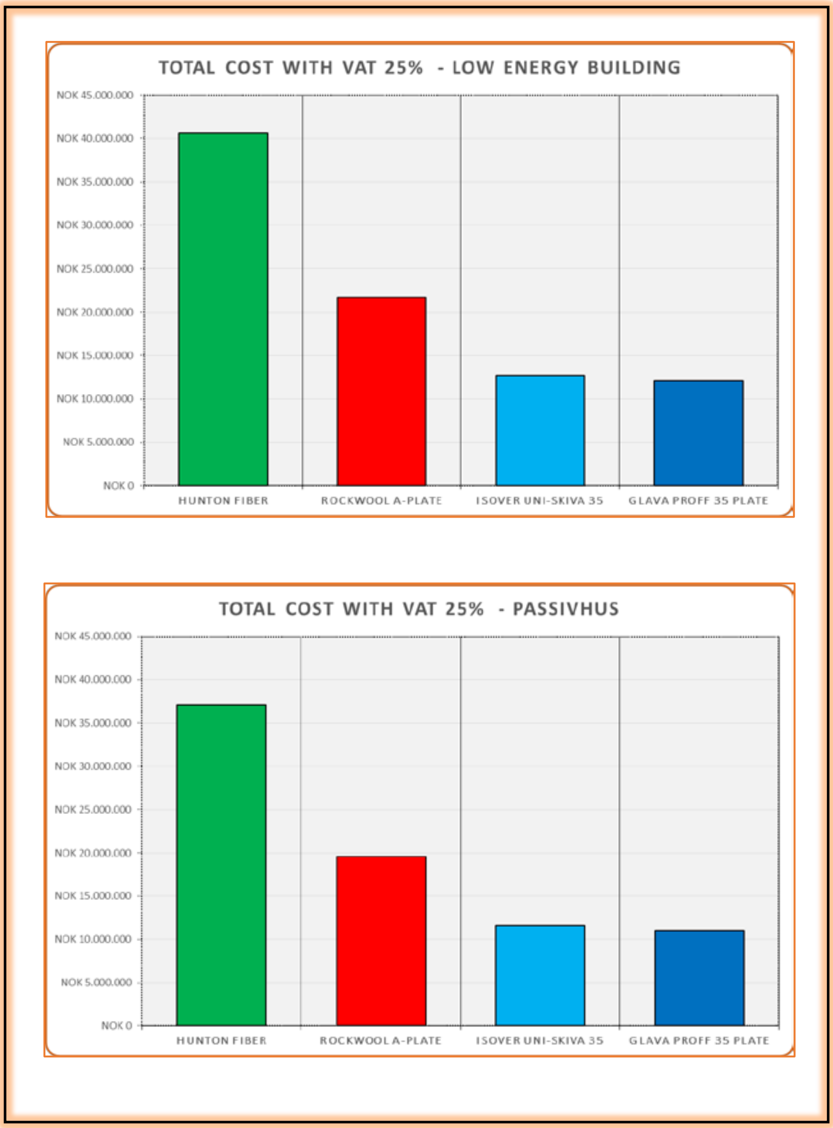

Figure 30: Results analysis of total costs

This work has shown that it is difficult to define an optimal and univocal solution for the sustainable retrofit of an existing building, using a single insulating material for each element of the casing, because of their own different emissions and costs. The high cost of wood fiber certainly is due from being produced in Poland. If the company Hunton, as it already aims, would produce the same product in Norway, certainly it would have a dampening of investment and trasportation costs that would affect significantly the total cost.

It can obtain interesting results from an economic-environmental, in condition of Passive House retrofit, if you use a combination of two types of insulating material (wood and fiber glass wool Glava), getting six additional cases of intervention, as shown in Figure 31.

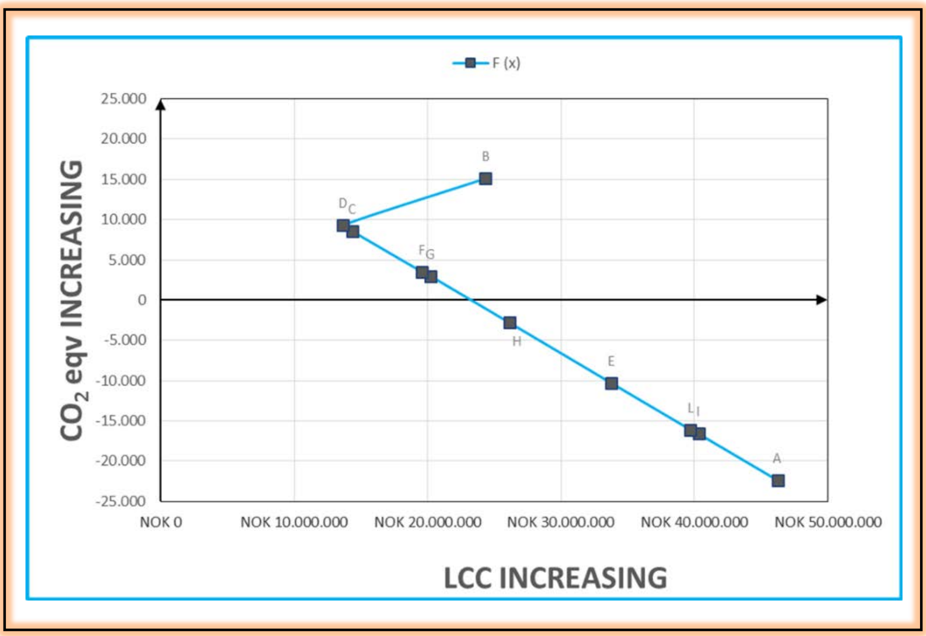

Figure 31: Results of the analysis of additional combinations of materials.

3.2 Final consideration and conclusions

In building interventions, both new construction and retrofit of existing, it is always difficult to make univocal assessments. Using LCC (Life Cycle Cost) methodology economic evaluation is privileged, LCA (Life Cycle Assessment) tends to highlight the environmental impact.

When you are making building interventions are often evaluated immediate costs, ignoring the costs of maintenance, replacement, re-use and disposal operations required during the life cycle of the property. Environmental aspects are considered as secondary (The CILECCTA patners, 2013).

A complex assessments is required for specific analysis, integrating economic considerations with environmental ones, considering the life cycle of the property.

These two evaluation types can be:

- Parallel;
- Simultaneously;
- Partially of a number of interventions concerning or the entire project or individual components.

Using economic and environmental interventions it has been shown an impartial methos, *Life Cycle Thinking*.

This complex approach theorized in the project CILECCTA (www.cileccta.eu) which is proposed as an applicative methodology for verification of sustainability in the construction industry, through the approach known as *Life Cycle Assessment and Costing* (LCC + A). It is an important tool and decision support to sustainable planning.

The different technical solutions proposed in this work have attempted to integrate economic considerations with environmental ones. It does not affect the building as a whole, but it has affected interventions on the shell building.

The result of the intervantions in this work are assumed to be related to a period of 60 years, during which the factors considered are subject to possible, uncertain, changes: the price of fuel and energy, the price of building materials, the service life of products, means of transport, the use of the building. For this reason the results are not deterministic, but probabilistic. There are potential dispersions of values, in other words ranges within which it can vary both in terms of economic impacts and environmental impacts.

However, this work, even if suggests a partial picture, it wants to suggest project ideas for those are responsible of final decisions: the finance manager, the environment manager, the manager of the company's environmental policy and, last but not least, the user final / investor. They may be inclined to choose the economic aspect or the environmental aspect or to mediate between these two, but the choice could be made easier by the scenarios shown.

Future directions of research may be based on the increasing quality of input data.

More data may allow a further refinement of analysis. The data can be analysed using a probability distribution or a possibilty distribution (fuzzy logic). In this way it is possible to replace each point of the combination with a distribution of value based in empirical observation or possibilty distrubution using fuzzy number.

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