NTNU – Trondheim
Norwegian University of
Science and Technology

Life Cycle Assessment of an Active House

Sustainability concepts by integrating energy, environment and well-being

Agneta Ghose

Master in Industrial Ecology
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Supervisor: Rolf André Bohne, BAT

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

Abstract

An emerging interest in constructing ultra low energy buildings, with low impact materials and maximizing the potential of using renewable energy reflects the potential in building industry to significantly contribute towards reducing environmental impacts. Life cycle assessments of the different green building prototypes provide a means to estimate the impacts of such buildings as well as provide suggestive improvements. The Active house in Stjørdal, Norway is one such prototype of a green building. This is a single family residence which is built with a concept of solar architecture in ultra low-energy buildings. It is challenging to harness solar energy at high latitudes. The Active house uses the fundamental construction details for a Passive house as mentioned in Norwegian regulatory standard, with specific changes in increasing the glazed surface to promote passive solar heat gain as well as increase daylighting , but also making it vulnerable to heat loss.

The house is based on timber framework. Apart from electricity the house uses solar collectors which are connected to the hot water storage and hydronic floor heating. Space heating is also compensated by use of wood stoves. In the LCA results suggest that, based on the construction the Active house requires ten percent more energy than an equivalent Passive house which uses only electricity and wood. However, due to the effectivity of the solar collectors, it compensates for the need of the extra energy and in a lifetime of 60 years, it performs 15 % better , contributing to lesser environmental impacts than an equivalent Passive house.

It is understood that extra embodied energy does not affect the environmental performance of a building if it results in better environmental performance (1). However, it is important to create demonstrable value of the building for the end user. Lifecycle assessment results from simulated operational use carries considerable error with respect to how the building actually performs. The results in this study have also been estimated with an approximate error factor derived from previous studies (2). There is a necessity to make every stakeholder of the building participative in the functioning of the building, inclusive of the end user, and maintaining the well-being. The case has also been scored in the basic categories of a sustainibility certification, with the results available from the lifecycle assessment and energy simulation.

Contents

List of Tables

List of Graphs

List of Figures

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1 Introduction

The building industry is often referred to as the 40 percent impact industry. It is recorded to account for 40 percent use of energy intensive manufactured materials such as steel and concrete as well as 40 percent energy use for the operational needs. Residential buildings account for 22 percent of the energy use in the Norwegian building stock (3; 4). Recent trends in innovating energy efficient buildings which follow low and ultra-low energy standards for the operational phase are fast evolving. The Norwegian building standard wants to develop a strategy for low energy and passive houses. Moreover, the Norwegian government is also stressing on energy conservation and increased awareness on energy consumption by installation of automated measurement systems by allowing users to customize their power usage (5).

The sector is stressing on construction methodology which inculcates good thermal insulation, air-tightness, and design without thermal bridges, use of triple paned low e-glazing windows and a ventilation system with highly efficient heat recovery. In addition, added renewable energy source within the building such as use of heat pumps, solar collectors and solar panels to substitute the energy use of the building is an added advantage. These new standards influence on the component manufacture industry. It is necessary to investigate on the impact trade off due to increased material investment and how intelligent design solutions are more advantageous.

However, such improvements require an initially high material and cost investment. Studies on passive house constructions in Kronsberg, Germany and Stord, Norway have suggested that initial material investment in the house saves 25-30 percent of the energy use over the lifetime (6) (4). A typical Passive house is focused on the reduction of space heating loads, leaving the lightening, hot water, cooling, appliance and misc., which fall under the "total primary energy requirement". All passive houses rely on very heavy insulation, avoidance of thermal bridges, ultra-tight construction- which result in designers to choose simpler shapes, passive solar gain by the window orientation to the south, heat recovery with 80-90 percent efficiency and heating of the ventilation air to provide space heating (7). Passive houses often use supplementary energy producers such as gas boilers, solar collectors or PV and wood stoves to further reduce the direct demand on commercial electricity supply. Apart from reducing the energy consumption for space heating, further research is towards decreasing the energy requirements for hot water, energy efficient lightening and appliance use, resident's interaction with the installed appliance system. There is an increasing diversity in solutions emphasizing on energy and environment performances as well as livability experience.

The Active house prototype analyzed here is a solar building design which uses concepts of active and passive solar gain. The building uses a combination of the passive house requirements with certain modifications, as well as added technological benefits conditioning it to resident's use. An LCA calculation combined with energy simulation of the house can reflect on the probable performance of the house. Adding on the qualitative measures for increased daylight and view has been included in a particular building sustainability module to understand the effect of the building.

1.1 Objective

The Active house envisions a step towards integrating the three main principles of energy, indoor climate and environment.It is designed as a solar low-energy building its design is based on gaining passive heat from the sun and also actively converting solar energy to supplement energy needs for domestic hot water and space heating. The building is built keeping in consideration the minimal requirement standards for a Passive house, and adding on technologies to alter the energy performance of the house as well as focusing on the livability and aesthetics. Based on the design flexibility, the Framtidens Aktivhus is a collaborative project between the Ligaard Group (construction manager, Stjørdal) and the Velux Group (major supplier of roof windows, sun screens and solar collectors). The goal of this study is to evaluate the possible benefit of this house with the given construction structure, the use structure of primary energy and Indoor climate

The objectives of this study are:

- Identify the Active elements in the building design and how it is simulated to influence the primary energy performance of the building.
- Life cycle Assessment of the Active house
- Compare the environmental performance of the Active house with an equivalent Passive house
- A short selective analysis based prevalent sustainable building standard BREEAM on three specific key indicators- Energy, Environment and Indoor Environment.

1.2 Study structure

This thesis is divided into 8 chapters. Chapter 1 introduces the objective of the project, guidelines and standard for recent building designs and previous studies carried out in the same area. Chapter 2 further defines the case more elaborately with its key components. Chapter 3 covers the methodology of life cycle assessment and the software used in this study, as well as the system boundary and inventory description for this study. Chapter 4 elaborates on the results. Chapter 5 discusses possible scenarios and the sensitivity of the impact results with each scenario. Chapter 6 is based on a brief sustainability scoring for the case. Chapter 7 is the discussion chapter and Chapter 8 concludes with suggestive further work. References and relevant appendices follow.

1.3 Guidelines on Building Environment Design

Building industry has potential to be the most energy saving industry in the future. Emphasis towards sustainable buildings in recent years has developed many buildings technicality concepts. Though, the primary idea is to reduce the operational energy use. This would add on to reducing environmental impacts related to excessive energy use from the grid. Yet, green building designs further require use of excessive material for insulation, triple glazed windows, heat pumps, solar collectors, etc which add to the embodied emission. The concept of green building is an environmental initiative towards responsible and efficient building materials used to develop buildings which use lesser energy over an entire life-cycle. It is necessary to understand the different concepts of green buildings existing today and their basic technical design. The different housing concepts are:

Low-energy building- A low-energy building focuses on design and technology, which help the building use lesser energy from the main source of power than the contemporary building. The idea of low energy building is constantly changing, but it generally refers to a building built around the low-energy standards for Germany and Switzerland for space heating. The German Standard limits low-energy to 50 kWh/m^2/yr , while the Swiss low energy standard limits space heating to 42kWh/m^2/yr. Norwegian standard for low-energy buildings space heating limit is 43,2 kWh/m^2/yr.

Passive house/building- Passive house is a development to further increase the energy efficiency and often termed as an ultra-low energy building. The passive house standard steps up the concepts revolving around low-energy building standards with super insulation and use of mechanical ventilation with heat recovery. The German standard for passive houses limits energy required for space heating to 15kWh/m^2/yr. However, the Norwegian standard for passive houses limits energy required for space heating to 23,9 kWh/m^2/yr. The flexibility for space heating in the Norwegian standard is owing to the harsher climatic conditions. However, the NS 3700 further emphasizes on use of renewable energy. The standard requirements are further elaborated in this chapter.

Solar building- Solar architecture aims towards maximizing the potential of using sunlight and solar energy towards reducing energy requirements of the house for space heating, hot water and even passive cooling. Use of solar architecture in higher latitudes is a challenge and requires significant understanding of climatology, thermodynamics and fluid mechanism.

Zero energy building- Zero energy building's also covers a broad range of green building ideas within it. But is particularly focuses on buildings producing on-site renewable energy and independent of the energy grid supply. Low dependence on grid energy also reduces the impact towards green house gases on other environmental impact since grid energy mix is often dependent on several fossil or nuclear sources. Building's that produce surplus energy are called energy plus buildings.

Eco-building- These buildings are a small scale initiative focusing on use of natural material which are available locally. This also focuses on traditional building methods with straw bales, mud bricks, timber and stone.

1.3.1 Norwegian Passive house standard

Since the Active house is built based on the Passive house standard, the technical requirements for the standard have been further elaborated here.

The Norwegian standard for low and passive house standard (NS 3700) is based on the German standard made by Passivhaus Institutt. The Passive House standard provides guidance for planning; construction and evaluation of residential buildings with low energy need (8). In addition, the energy requirements in technical regulations in the Planning and Building Act and energy labelling of buildings, NS 3031 is used as the reference standard (9).

The standard criteria for Passive House and Low energy house in Norway NS 3700 was established in April, 2010 and is under consideration whether to introduce it for all new buildings by 2020. It is based on the German standard and concept developed by Dr Wolfgang Feist and Prof Bo Adamson. The unique focus of passive house is on prevention of heat loss by conduction and air leakage through the building envelop. It needs to be emphasized that though the Passive house standard does not deviate much from the standard used in Europe, it does take into account special Norwegian conditions, especially that a large number of houses are built in very cold climate due to a higher latitude.

The primary Passive House Target criteria are:

- A total heating and cooling demand of ≤80 kWh/m^2/yr
- Total primary energy of ≤ 60 kWh/m^2/yr (energy requirements regarding lighting , technical equipment and hot water)
- Air tightness- 0,6 air change/hour@ 50 Pascal

The recommended measures for construction include:

Table 1 U- values (thermal transmittance) for the building envelope

Properties	U-value (W/m^{2}K)	Insulation Requirements
External Wall	≤0,12	300-400mm mineral wool / glasswool
Roof	≤0,10	450-550mm mineral wool / glasswool
Floor (ground)	≤0,10	300-350mm exp polystyrene
Window	≤0,80	
Door	≤0,80	
Thermal Bridge	≤0,03	

The total area for glass, windows and doors is a maximum of 20 percent of the heated floor area (10).

The recommended measures for ventilation include:

Table 2 Requirements for mechanical ventilation

Properties	Passive House Standard
SFP Factor	1,5 kW/(m^3/s)
Heat Recovery	80% balanced
Air change rate	1,2 m^3/ (h m^2)
Energy Use	4 kWh/ m^2 yr

It is assumed that the house uses energy-efficient lightening and technical equipment, giving low internal heat gains.

Table 3 The recommended energy for lightening, technical equipment, hot water demand and heat gains

	Operation time (hr/days/weeks)	Annual Net energy (kWh/ m^2/yr)	Heat Gains (W/m^2)
Lightening	16/7/52	11,4	1,95
Technical Equipment	16/7/52	17,5	1,80
Hot Water	16/7/52	29,8	0,00
Occupants	24/7/52	-	1,50
Total		58,7	

1.3.2 Heating Requirement for houses

The current technical standard requirement for buildings TEK10 states the minimum of 40 percent of estimated net energy for space heating (including heating ventilation air) and hot water in new residential buildings and the refurbishment should be met by other energy than electricity or fossil fuels.

The obligation ceases if one of the following criteria are met (reference):

a) if the net heating of the building is less than 17 000 kWh / year.

b) if the developer can show that heat the solutions involves extra costs over the building life cycle, compared with the use of electricity or fossil fuels.

In such cases, the homes of over 50 m² UFA still needs to have a closed chimney and fireplace for use of biofuels such as wood stove or pellets.The International Standard Organization has been further referred for more guidelines to assess Building environment design with respect to energy efficiency and Indoor climate requirement.

According to the ISO 23045 which gives guidelines on Energy efficiency of building environment design, emphasizing the integration of Active solar systems into the building to achieve the target value for the energy efficiency of the building. It also considers day lighting and direct solar heat gains or passive solar heat gain through windows to reduce space heating. However, hourly solar radiation and electricity demand are necessary to identify the real amount of energy produced.

Apart from the focus on increasing the energy efficiency of Sustainable building design, standards also emphasize on guidelines on Indoor climate (Air Quality and Day lighting) and Hot water consumption.

Based on ISO 15316-3-1, the average hot water use in a single family residence is estimated to be 1,49 litres/ m^2. Average daily tapping for a single person estimates 36 litre of daily hot water use provided at 60 °C (11).
Indoor environmental parameters such as indoor air quality, thermal environment, lightening contributes significantly to the building energy performance as well as productivity, health and performance of occupants. ISO 16814 focuses on expressing the quality of indoor air for human occupancy and EN 15193 on the energy requirements for lightening. These recommendations have been adopted by the passive house standard NS3700 and NS 3031 (calculation of energy performance of building).

These standards provide the recommended as well as the upper value of estimated energy utilization, providing flexibility of the building design to maintain the required criteria or perform better.

1.4 Energy labelling of buildings

Energy labelling is a regulatory system to reduce energy use as well as energy source in buildings while making the user aware. Energy labelling has been mandatory for all residential and commercial property since 1 July 2010 available for sale or rent. The goal is to increase awareness energy and various heating solutions. Energy marking consists of an energy character and a warm character. Heating grade is given by a 5 level colour code, while heating requirement of each house based the useful area. Energy ratings are from A to G (12).

There is no relationship between energy and heating character grade. A building with a high calculated energy consumption and associated energy-poor character, you get a good warm-character example a bio-based heating system. Conversely, a low energy building a good energy rating, while warming the character will be poor if the building only has electric heating (12). Energy grade is a result of the calculated delivered energy for your home or building during normal use. However, the calculation is provided in the standard NS 3031 (12). A table in the Appendix () provides the delivered energy per m^2 of heated useful floor area (UFA\BRA- kWh\m^2).The residence energy requirement based on TEK07 and Passive house based on NS3031 (12). The required energimerking for TEK 07/10 is **C**, for Passive and low- energy houses it is **A** and **B** respectively. Heating grade given by a calculation based on the systems that are installed for heating rooms and hot water in the home / building. Green is the best grade and given where the dwelling or building systems where one can use a high proportion of other energy commodities other than electricity, oil or gas, while using only fossil fuels and the direct use of electricity produces red character (12). This character is independent of the building's energy needs. It stresses only on the source of energy. For example it is taken for granted that the district grid can cover close to the heating requirements. A system based on biomass is assumed to cover approximately 80% of the heating requirements, while remaining is covered by electricity. Solar collectors are assumed to cover 20% of heating requirements and 30-50% of the hot water demand. (12)

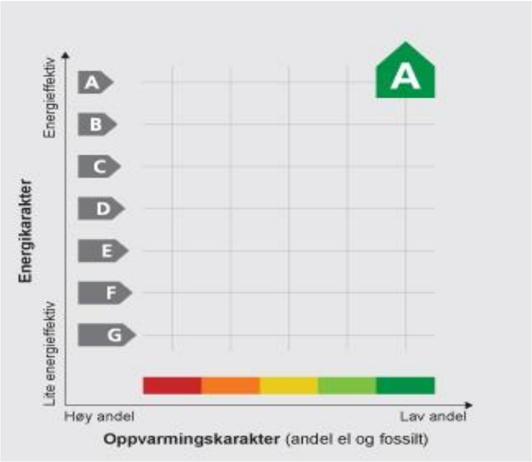

Figure 1 Typical energy marking graph (Source: Energimerking.no)

The Active house has an A energimerking with a green label as it is able to substitute its energy supply with other renewable sources. This has been simulated by SIMIEN 2.0. Given in the Appendix D

1.5 Review:

Life Cycle Assessment of buildings is of rising interest, in the last decade with equal focus on operational energy as well as material use. Research towards developing zero emission buildings has led to rising interest in energy systems implemented to minimize energy use from direct electricity supply and performing lowest environmental impact as possible. Most Scandinavian countries are focussing on reducing energy use by 20% before 2020 compared to 1995 (13). Life Cycle Assessment is recognized as innovative methodology which improves sustainability in the construction industry (14). Fast developing projects all over Norway, is stirring further interest and future prospects of passive houses performance in higher latitudes. Recent material flow study suggests that additional embodied energy on buildings in Norway can essentially reduce impacts to climate change, if they can also reduce consumption pattern (15). The greatest reported challenges are related to finding appropriate energy systems based on renewable energy. There is still a lack of standardized detail with respect to minimizing thermal bridges of the exterior wall (16).

A comparative study by Brunklaus et al., between conventional and passive residential buildings in Sweden, illustrates the limitations of energy studies of buildings suggests that although passive houses have a low energy use over lifetime, it does not automatically lower the environmental burden. Lowering the environmental burden requires setting requirements for source of energy, possibly in the whole life chain, for material production, space heating and household electricity (17). The study stresses on the role of actors in the supply chain and end –users (residents) to be more aware of their green choices that influence the building’s total environmental impact (17). Popularly life cycle studies on buildings are limited to energy use (18); however a few comprehensive studies illustrate similarities between energy and environmental impacts (19; 20; 21; 1; 4). Very few studies reflect the social nature of energy use, the effect of user behaviour on total energy use of a building, though with the implementation of Passive houses, the energy responsibility is shifting from district grid supply to residents, and this includes several communicative gaps (17).

Drawing conclusions from, previous LCA studies done on various energy systems implemented in buildings indicates a positive performance of the system substituting the need from the district grid (22; 1). However, both these studies are based on energy simulation models and the results are based on assumed scenarios. According to Sørens, a single residential house, installed with a solar collector system has lower CO_2-eq output over a lifetime as well as present value cost rather than a house with an air-water heat pump attached (1). A study in Germany by Kohler et al., on various energy systems on conventional and passive houses reflects use of photovoltaics as the best option to reduce electricity demand, however the results might not be realistic in large scale (23; 17). Implementation of solar heating systems are gaining popularity in Nordic countries to provide heating for domestic water use and are designed to provide 40-60% of the energy required for hot water (24). Life cycle performance of wood stove using modern technology is preferred over older technology as the products of incomplete combustion in the latter have a high contribution to all impact categories (25). Strong emphasis is also given to shorter transport for the source of wood (25).

Apart from energy system and material use, Indoor climate is a relevant focus for houses built on ultra low energy specifications. There are conflicting reasoning between indoor air quality and user behaviour. Based on a Sintef study, there is little evidence to suggest that indoor climate of passive houses is worse than conventional houses. Installation of balanced ventilation system with sufficient air change is an essential key for maintenance of desired thermal comfort and indoor climate especially in the winter months (26) . LCA study on ventilation units are few, however a case study by Nyman and Simonson analyzing two types of ventilation units suggest that a good ventilation system with an efficient heat recovery has a positive impact on the environment (1; 27).

Daylighting and integrated control strategies can reduce the energy use for lighting in buildings, and it is a natural resource that should be harvested to obtain energy savings. Studies by Sintef, consider it as a fundamental requirement for zero emission buildings and possibly lower investment compared to electrical equipment (28). Athienitis reports that rooms with shadings, daylighting and dimming control increase energy saving for lighting to 75% for overcast sky and 90 % for clear skyø the control system adjust the sloping of shading blinds to control the light flux penetrating into the room creating a high quality indoor environment as well (29; 28). Daylighting involves postioning of windows and characteristic design of fasades. LCA of windows have been carried out by Dahlstrøm, O., results of which have been used in this study as well (30).

Several efforts are focussed on working on the perfect blend of appropriate construction modelling and design of buildings along with assimilation of energy systems to make maximal use of renewable energy and reduce auxillary energy needs. Several Demo houses have been established by VELUX[1] on several latitudes based on latest know-how in sustainable construction. The model houses developed have particular focus on active facade design, with larger window area and giving in more inclusion of solar passive heat gain from windows (window area over 28% of the HFA[2]), as well as maximise use of daylighting. The houses also have installed heat pumps as well as photo-voltaics to further substitute energy need. The use of balanced ventilation during winters and natural ventilation during summer is the element of hybrid innovativeness in these houses. Equipment automation is also focussed upon involve essential user behavior. Projects such as SOLTAG, Modern homes 2020 and Active house have been developed in Austria, Germany, Denmark, France, UK and Norway (31; 32).

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[1] Multinational building material and home improvement company, also the chief partner of Active House development at Stjørdal.

[2] Under Passive house recommendation, window area should be under 20 percent of the total heated floor area.

2 Case Description

As defined in the objective, the model case available for this study is an Active house (Framtidens Aktivhus AS), developed by Velux A/S and Ligaard-gruppen in association with several other building material producers. The Active house development is typically similar to a Passive house construction with marginal construction difference and additional technological integration. The same case is considered passive, excluding the additional properties of the Active house.

This chapter further defines the case.

2.1 Geographic location:

The Active house has been constructed in Stjørdal; situated 32 kms North of Trondheim, it is located in Midt-Norge. The climatic conditions are recorded at Værnes and slightly similar to Trondheim. However, areas far from the coast have higher differences than the annual average mean. The table below gives further detail on the geographic location and annual mean temperature. The figure 2 and 3 provide the geographic location and the annual weather statistics for Værnes (Stjørdal) for 2011-2012.

Table 4 Geographical details

Location and Climate		**Unit**
Place	Stjørdal	
Latitude	63°15'	North
Longtitude	10°33'	East
Annual Mean temperature	5,3°	Celsius
Annual precipitation	892	mm/yr
Average solar radiation, horizontal plate	108	W/m^2
Average Wind Speed	3,5	m/s

Figure 2 Geographic position of Stjørdal (close proximity to Trondheim) (25)

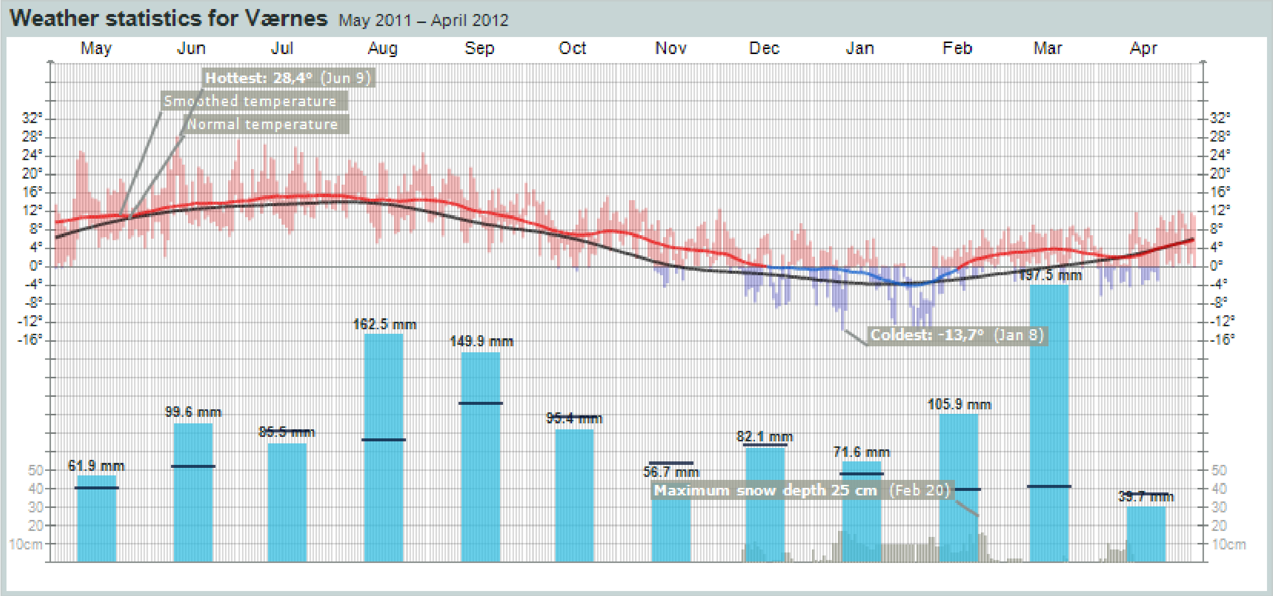

Figure 3 Annual Mean temperatures at Værnes (Stjørdal) inclusive of precipitation (Source: yr.no)[3]

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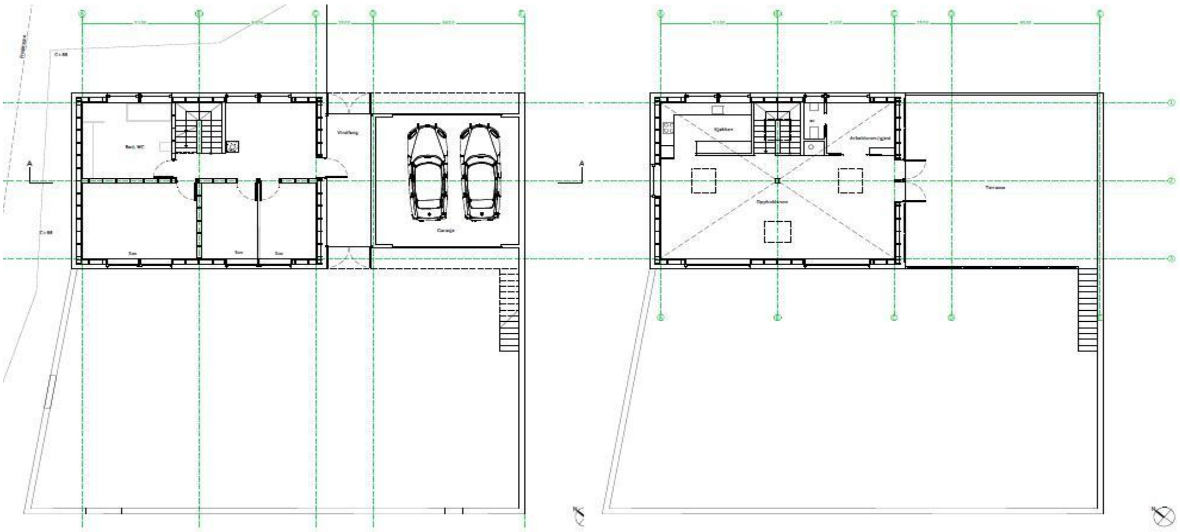
[3] The black line shows the mean value for both temperature and precipitation. The red/blue line shows the average temperature. The light blue bars represent the total precipitation each month.

2.1 Building Characteristics:

2.1.1 Active House, Stjørdal:

The Aktivhus building is designed as a single-family residence. It is a timber framed construction. The cladding is also wooden.

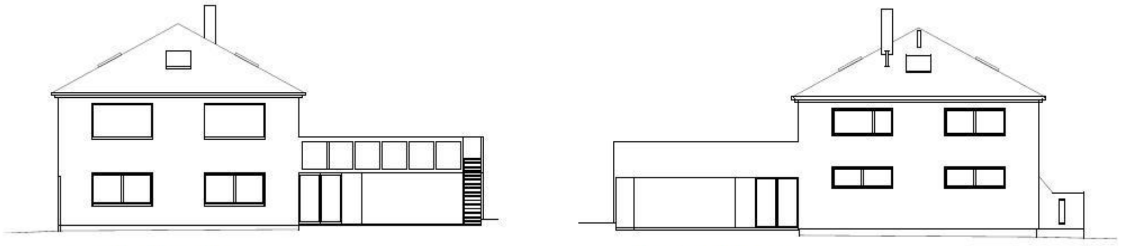
The total useable living area is 136 m^2 (This is also the total heated floor area). The building consists of two floors and a basement. The figure 4 below gives the schematic overview of each of the floor plans. The total plot area is 408 m^2. The auxillary area includes terrace, hall, garage, basement and garden.



1 etasje **2 etasje**

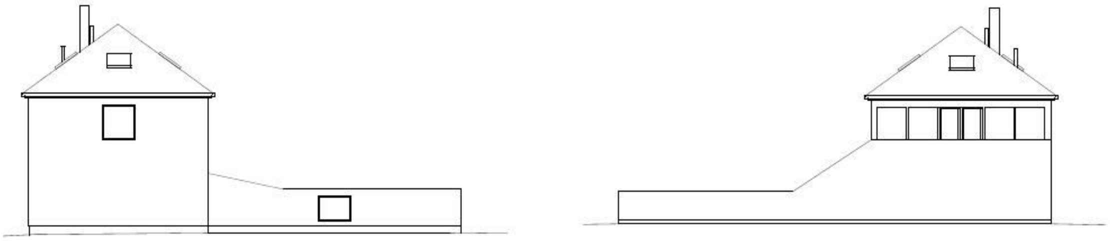
Figure 4 Floor plan- Active House, Stjørdal

The figure 5 below represents the building facade. There is evidence of extensive glazed surface in the south west and north east fasades. In addition, each face of the tetrahydral pyramid roof has a roof window. The south west and south east facades have solar panels, covering 18,5 m^2 of the cladding area.



sør vest fasade

nord øst fasade



nord vest fasade

sør øst fasade

Figure 5 Active House Facade, Stjørdal

The building construction is characteristic of NS 3700 Passive and low energy house standard. The basement is constructed of Leca blocks with extra 10 cm of insulation in the centre of the blocks. The basement walls have a U-value of 0,14. The basement floor is insulated with 20 cm of expanded polystyrene. The exterior walls have a U-value of 0,12 with 350mm insulation. The pyramidal roof has an insulation of 500mm and an U-value of 0,10. The insulation material used is glasswool. The facade windows and doors are triple-glazed and have a U-value of 0,7. The roof windows are also three layered with a U-value of 0,1. All the windows on the south facade as well as the roof windows are equipped with solar screens.

The total glazed area is 38 m^2, which is 28 percent of the total heated floor area. The recommended passive house standard suggests the glazed surface to be ≤ 20 percent of the total heated floor area. The table 5 gives summary of the basic construction details of the Active house.

Table 5 Summary of building characteristics- Active house

Active House		
	Area (m^2)	U-value (W/m^2K)
External Walls	191,1	0,12
Glazed Area (Walls)	34,5	0,7
Glazed Area (Roof)	3,7	1
Roof	61	0,1
Basement	35,95	0,14
Thermal Bridge		0,03
Natural ventilation:	May-August (4 months)	
Balanced mechanical Ventilation:	September- April (8 months)	
Ventilation Air load- 430 m3/h, efficiency- 80%		
Specific Fan Capacity- 1,5kW/(m3/s)		
Heating sources- Electricity, Flat plate solar collectors, hydronic heating wood stoves		

2.1.2 Passive house, Stjørdal:

To compare the As mentioned before, the model house constructed follows all the requirements of a Passive house with marginal construction differences particularly with reference to glazed area.

To make a valid comparision between added benefits or flaws of the model house, a Passive house with the exact same construction detail is assumed. Based on the definition by Feist.W., " a *building in which thermal comfort [EN ISO 7730] can be guaranteed by post-heating or post-cooling the fresh-air mass flow required for a good indoor air quality."* (6; 4).

Hence, in the control case: the passive house has identical construction details the house has the glazed area reduced to 20 percent of the total heated floor area. The glazed surface is removed from the roof and reduced on the north facade and marginally on the south facade to provide the desired change. It is also assumed that the Passive house uses balanced mechanical ventialtion throughout the year, this system utilizes a heat recovery system during the winter months. The passive house does not include the secondary heating sources, such as solar collectors and wood stoves. It's chief heating source is based on electricity. Electric cables are connected to the hydronic water heating system, to provide additional floor heating during the colder months.

Table 6 Summary of building characteristics- Passive house

	Passive House	
	Area (m^2)	U-value (W/m^2K)
External Walls	191,1	0,12
Glazed Area (Walls)	27,2	0,7
Glazed Area (Roof)	NA	NA
Roof	61	0,1
Basement	35,95	0,14
Thermal Bridge		0,03
Natural ventilation:	NA	
Balanced mechanical Ventilation:	12 months	
Ventilation Air load- 430 m3/h, efficiency- 80%		
Specific Fan Capacity- 1,5kW/(m3/s)		
Heating Source- Electricity, wood stove		

2.2 Active Components:

The Active house uses possibilities of passive solar building design to provide necessary energy consumption reduction. The aim of an Active house is to harvest available energy to meet electricity, heating or cooling demands as well as provide good indoor air quality, ensuring minimal impact on the environmental and cultural resources.

The model house as approached this process by certain installations as defined in the following chapter.

2.2.1 Heating Systems:

The house aims to keep its annual consumption below 80 kWh/m2. Apart from specific construction detailing ,the house uses several heating sources.

2.2.2 Modern wood stoves

The house essentialy depends on biofuel for most of the space heating, covering almost 72 percent of the total heated area of the house. The house has 2 modern stoves installed in each floor. The maximum utilization of the stoves is assumed to be in the coldest winter months to substitute the electrical heating requirement.

Based on energy standards, sources of heating from biofuel can provide 80 percent of the heating requirement (12). Wood is an essential source of household heating in Norway. Burning wood in the use phase of the stove contributes to 60 percent in all the impact categories.However, it is necessary to use a modern wood stove as it increases the efficiency of the stove and decreases the impacts in all categories by 28-80 percent (25). The greenhouse gas emissions from wood stoves are about 80g CO$_2$/kWh compared to 210g CO$_2$/kWh of the Nordic electricity mix (25).

2.2.3 Flat-plate solar collectors:

Solar collectors are installed on the south-east facade and a part on the balcony railings of the south-west facade, covering 18,5 m^2 of the outer cladded area. The collectors are meant to fulfill approximately 50% of the requirement for domestic hot water. The solar collector system is also connected to the hydronic system to provide floor heating on the tiled surface of the entrance and bathroom area on the ground floor.

Active solar heating is a supplement to main heating, the heat is collected centrally on the hotwater storage tank, which is otherwise connected to electric sources during the unavailability of solar heat. The system operates automatically throughout the year. During the summer the the house is enitirely self-sufficient in hotwater, but in cold winter months it requires additional electrically heated hot water. The main application of the solar collector is to completely substitute the energy cost for hotwater use during the favourable seasons.

Investment of solar energy to substitute energy for hot water is recommended in Passive houses, particularly in the temperate latitudes (33). However, in Norway solar radiation varies greatly with seasons. Variations in a day can be from 8,5 kWh/m^2 on a sunny cloudless summer day to 0,02 kWh/m^2 on an overcast winter day (34).Hence, it is necessary to intelligently harness the energy. The figure and the table below further summarize the amount of solar radiation available annually at 63°North latitude.

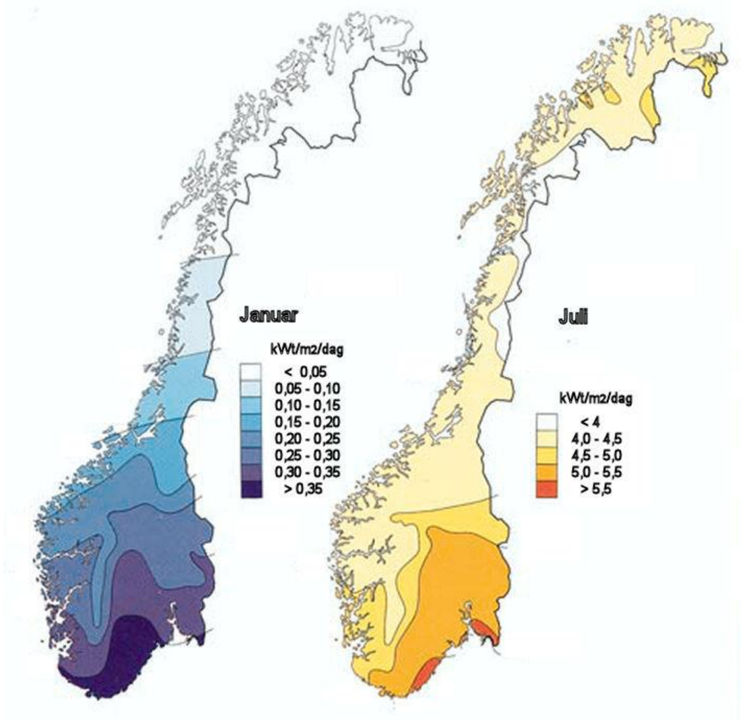


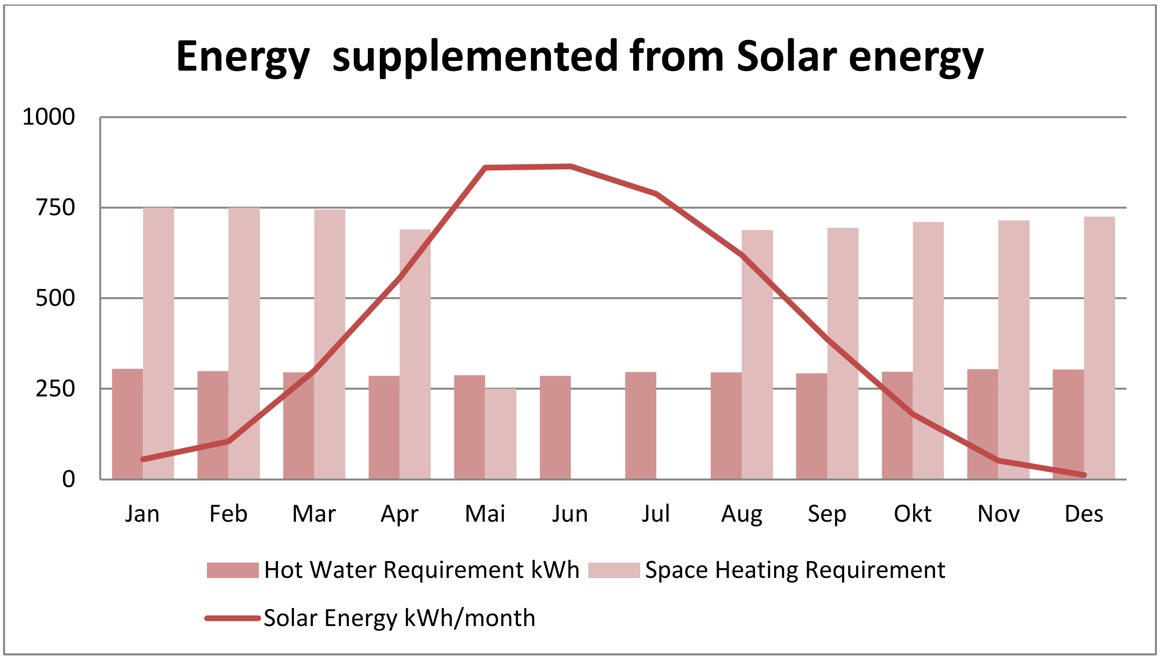
Figure 6 Solar radiation in Norway (30)

Based on estimated solar radiation data based on sunrise and sunset from NASA, assumed insolation values have been used to calculate the available solar energy annually in Stjørdal (35).

Table 7 Solar Insolation at Stjørdal (31)

		Jan	Feb	Mar	Apr	Mai	Jun	Jul	Aug	Sep	Okt	Nov	Des	Mean
per day	**kWh/m2**	0,16	0,65	1,74	3,34	5	5,19	4,58	3,6	2,32	1,08	0,31	0,07	**2,34**
Month		4,96	18,85	53,94	100,2	155	155,7	141,98	111,6	69,6	32,4	9,3	2,17	**71,31**

One of the major drawbacks of relying on solar collectors is that it's effectivity is heavily dependent on the presence of the sun. However, the average number of wet, overcast days at this latitude is nearly 64% (35). Assuming a 64 percent efficiency loss, the annual energy from solar radiation is about 3900 kWh. This helps in covering 51% of the building's hot water consumption and 2% of the space heating. The graph 1 below shows that most of the energy from solar collectors is available when the need is quite low, especially for space heating for the Active house.



Graph 1 Annual solar energy vs. required energy

2.2.4 Electrical Heating:

The house uses a combination of biomass, electricity and solar energy for space heating. It has installed electrical heating cables connected to the hydronic system to provide floor heating in the coldest months. Apart from two of the bedrooms are installed with 600W panel heaters to substitute any extra heating requirement. Electrical heating will be used to provide 25-50 percent of the space heating, depending on use of biofuel in stoves or available solar energy.

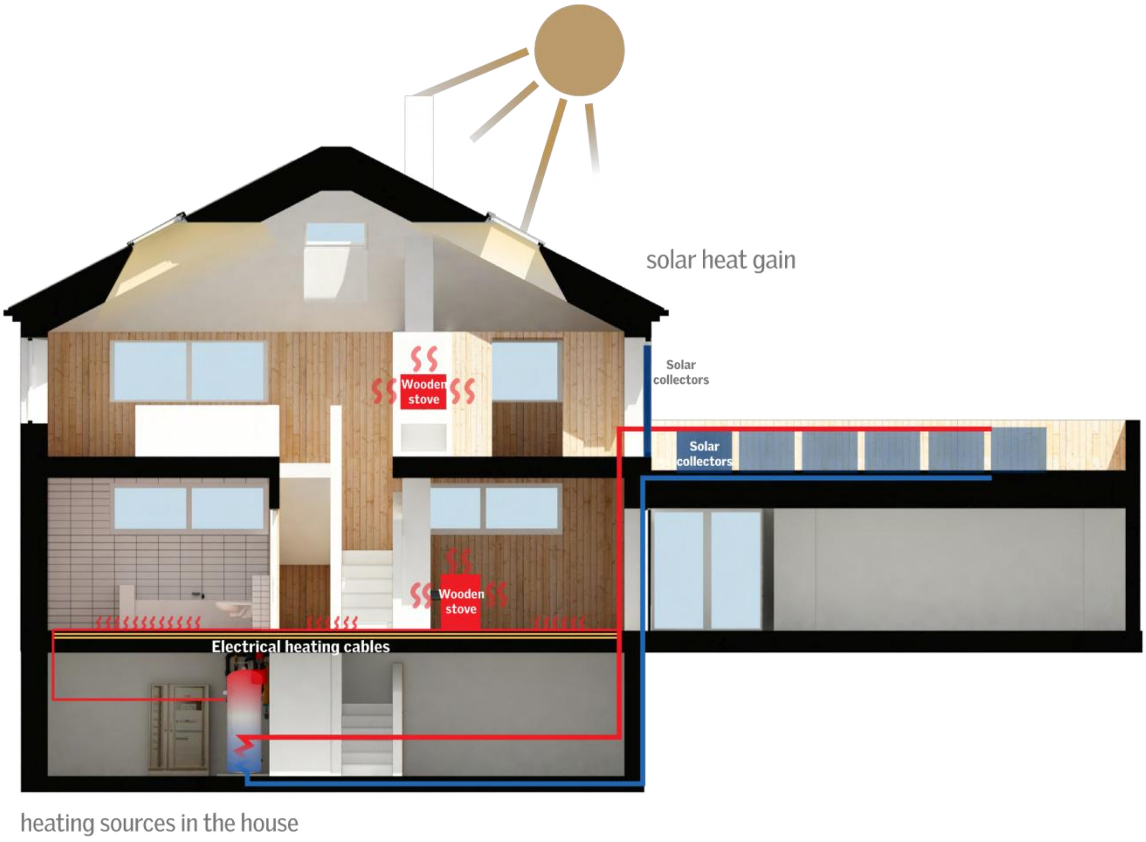


Figure 7 Heating sources of the Active house

2.2.5 Ventilation System

Maintaining good indoor air quality is an essential component of a passive house beside retaining thermal comfort. The Active house uses a combination of natural and mechanical ventilation, in order to achieve good indoor climate.

2.2.5.1 Mechanical Ventilation:

The building uses mechanical ventilation in the winter which introduces fresh outdoor air into the house which is pre-heated using an heat as well as recovers the heat from the air which is expelled out. Thus avoiding excessive need for heating the incoming fresh air.

The ventilation and heat recovery sytem is installed by Swegon and Aas Luftbehandling (36). The ventilation system is connected to control systems. It ensures that when the firplace is lit, the air input is compensated for the given time, reducing negative air pressure and preventing smoke from the chimney coming indoors. Low pressure compensator is installed on the external outlets. When the ventilator is switched on during cooking activities, the air input aggregate is increased. A switch at the entrance allows residents to turn ventilation to minimum when the house is not occupied. The ventilation system is fixed with two air exhausters to ensure quicker and controlled cooling of the house. However, the second exhausters might be removed if it is not effectively required (36). The characteristics of the ventilation unit installed are: maximum air flow of is 120l/s and it recovers 80% of the exhaust heat.

The house is designed to use mechanical ventilation during the winter months. Since the house is at a high latitude, it is assumed that it uses mechanical ventilation for a period of 6-8 months each year.

2.2.5.2 Natural Ventilation:

The idea supporting the use of natural ventilation for the summer months was to significantly reduce the demand for electric fans. The active house uses the principle of stack effect or the ”chimney effect”i.e., during the summer months the the warm air will rise upwards, reducing the pressure indoors. The warm air escapes from the openable roof windows, while fresh air infiltrates through the facade windows. The house still stays warm as the thermal energy is stored within the building materials (36).

The natural ventilation is effectively used in the summer months ranging from 4-6 months.

Figure 8 Mechanical ventilation and Natural Ventilation

2.2.6 Active Windows

The extensive installation of glazed area in the house requires necessary mention. Windows have a substantial effect on building’s thermal performance as well as indoor environment . Windows have both positve and negative effects on the energy performance of a building.

The U-value; heat transfer from the inside to the outside by thermal conduction or convection is very relevant for windows of low-energy or passive houses. The facade windows of this house have a U-value of 0,7 Wm^2/K and the sloped windows of the roof have higher U-value 1,0 Wm^2/K. Heat loss through the roof windows is increased due to higher U-value. Windows also increase the amount of solar gain. The g-value of a window is the measure of solar gain transmitted through the glazing.

The effective way of using windows on a building facade is to find the energy balance, with optimal solar gain and heat loss. Energy balance is measured in $kWh/\ m^2$. The energy balance depends on where the window is installed, orientation , slope of the window as well as the geographical location. If the energy balance is positive then the window adds to the energy demand of the building. Energy balance for south-oriented windows are positve and much higher than other facades.

The Active house has about 16,7 m^2 and 16,3 m^2 of glazed area on the south-west facade and north east facade respectively, inclusive of roof windows. Each of the windows are triple-glazed with very low U-values. This minimizes heat loss to a large extent. Passive solar gain from the windows, especially during the spring and autumn months provide additional energy to supplement room heating. However, it also adds the problem of overheating during summer months.

2.2.6.1 Solar screening:

The Active house, has installed automated solar screens to prevent the effect of overheating as well as heat loss. Each of the windows on the south facade are installed with automated solar screens on the exterior, these keep out almost 90% of the solar heat on hot days. The roof windows are equipped with exterior screening to avoid overheating in summer and interior screening to avoid heat loss.

Solar screens donot influence the U-value of the window but have certain benefits as mentioned below (37):

Benefits with Solar Screen

- **Cools the home or other living space**
- **Reduce cooling energy costs –** independent studies have shown that solar screen installed on exposed windows can reduce the cooling portion of electric energy costs as much as 30-35 % on a typical home in a warm climate. In many cases the "payback" period can be as short as 1-2 years
- **Protection from fading –** the UV rays blocked by solar screen can help protect home furnishings such as furniture, drapes, floors and paintings
- **Daytime privacy –** it is harder for people to see into the building during the daylight hours.
- **Reduces glare –** it helps reduce the glare coming in through the windows

A house with screening has a higher need of energy, but the temperature is about 10 degrees lower on warm days (37) as shown in the figure() below.

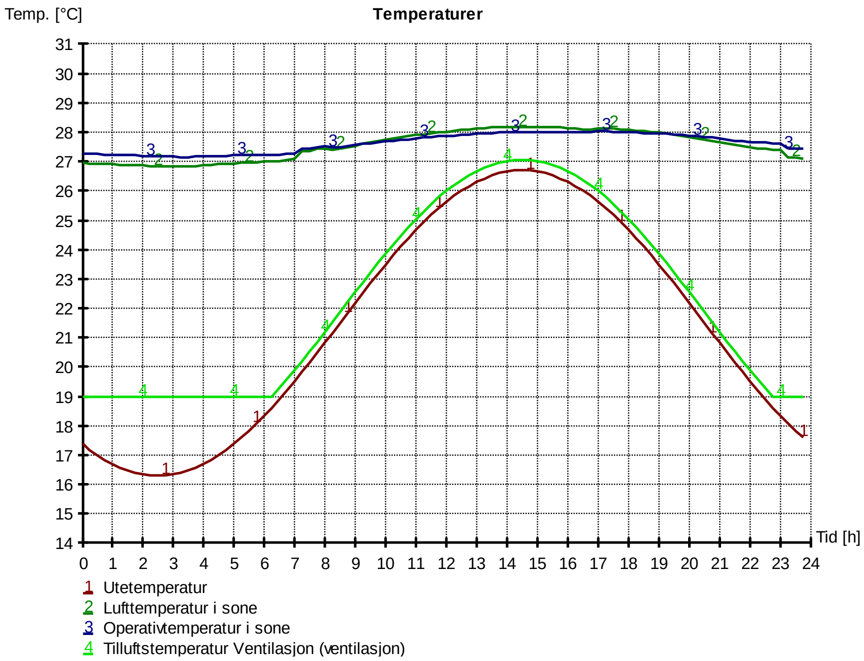


Figure 9 Temperature simulation on a warm day in a house with solar screening (30)

The additional benefits of the window to daylighting and view has been given emphasis relative to the building design.

2.2.6.2 Daylighting and view

The trends towards sustainable low energy architecture contribute negatively with respect to daylight utilization (38):

- Reduction of window size, causing reduction of daylight transmission
- Better window U-value- lower transmission of the glazing
- Denser areas- outdoor obstruction of the sky vault
- Thicker walls- poorer penetration of daylight.

One of the primary aims of the Active house is to provide a ‘day lit’ building meeting the standards of a low energy building at high latitudes. Daylight illumination of a space is dynamic, constantly changing in intensity and spatial distribution (39). The sources of daylight are – the sun and the sky which interact with the geometry and physical properties of the space. However, the evaluated ‘Daylight Factor’ (DF) includes contribution only from skylight. Though there is proof that day-lighting has positive physiological and psychological effects of occupants, harnessing resourcefully, while maintaining the sustainability of a building is challenging (39) (40).

The daylight factor is calculated as a ratio, in percent, of work plane illuminance (at a given point) to the outdoor illuminance on the horizontal plane. It is evaluated under overcast conditions only. The daylight factor is defined as (41):

$$\boldsymbol{DF} = \left(\frac{\boldsymbol{Ei}}{\boldsymbol{Eo}}\right) \boldsymbol{x}\ \mathbf{100\%}$$

Where,

Ei = illuminance due to daylight at a point on the indoor’s working plane.
Eo= simultaneous outdoor illuminance on a horizontal plane from an unobstructed hemisphere of overcast sky.

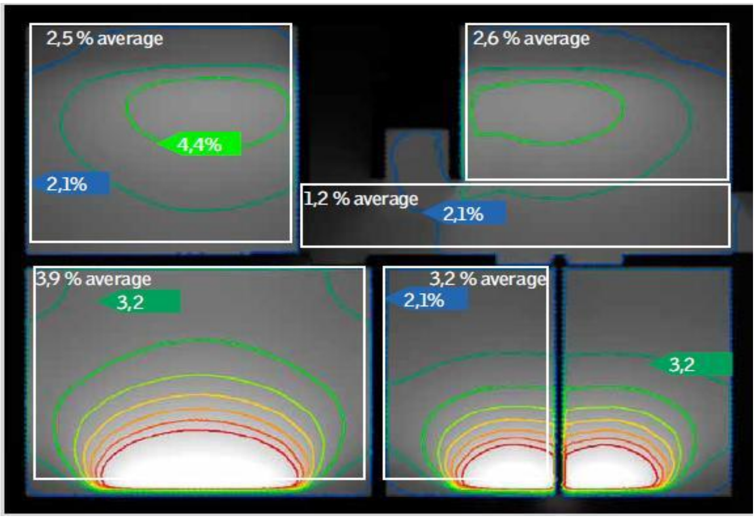
The Norwegian Planning and Building Act [Planning and Building Act 1986] with the associated Technical Regulations [Technical regulations 1997] states that:

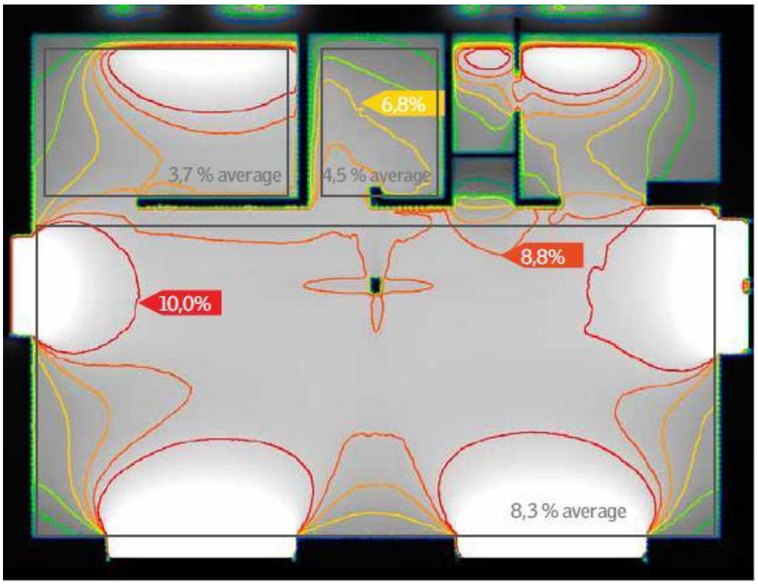
‘Every room should have adequate lighting in relation to the room’s function and user needs. Rooms for permanent residence shall have windows and views. For some rooms, this can be facilitated by adequate openings to other rooms or skylights.’

‘All rooms shall have satisfactory lighting without unpleasant heat load. Rooms for permanent occupation shall be provided with daylight, unless the dwelling or working situation should indicate otherwise’

Norway has a large seasonal variation with daylight intensity due to low solar altitudes, large seasonal variation in day-length and frequent cloudy skies. Low solar altitudes make it difficult to control direct sun radiation and simultaneously allow daylight inside. During winter, south orientation of the facade is not preferable. Similarly during spring, summer and autumn, facades facing west and east will give the same problems (38). The general understanding of the Norwegian Sky conditions mainly considered is overcast.

The extensive use of facade windows and roof windows, the Active house ensures maximal use of Daylighting. The daylight factor has been simulated using Velux Daylight Visualizer 2. The simulation results were provided by the Velux A/S. The results for the active house are shown in the figure ().





The rooms with an average DF of 2% are considered day-lit. A room will appear strongly day-lit when the average is above 5%. As the result clearly shows, every room in the ground floor meets the average DF factor. The effect of the roof windows further adds luminance in the common first floor area.

The design of the house also focuses on the effect of outdoor view. Apart from the concern with light being admitted, the windows ensure outdoor view to the natural landscape. An outdoor view of nature ensures restorative benefits, both physiological and behavioural (40). Larger windows also give a larger spatial appearance.

3 Life Cycle assessment:

3.1 Methodology:

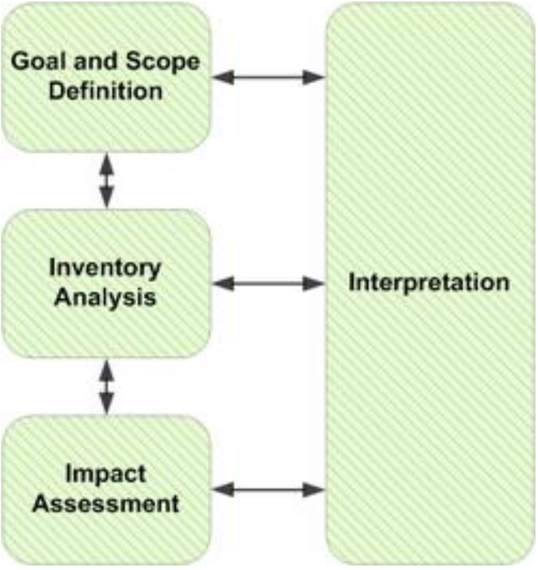


Figure 10: Stages of Life Cycle Analysis (Source: Wikipedia)

Life Cycle Assessment is a holistic approach to conduct consistent environmental assessment to compare technological systems. Life Cycle Assessment has obtained significant commercial attention as its framework has been elaborately defined in the International Organization for Standardization (ISO), particularly in 14040. The ISO 14044 gives a requirements and guidelines on how to conduct a Life Cycle Assessment.LCA assesses the environmental impacts of a product throughout the product's life cycle. It is a process based bottom up perspective. By including all the life stages of a product in the analysis, there is a smaller chance to make environmental decisions based on wrong foundation. It also makes it easier to understand which of the primary area of emission and how it needs to be tackled. This includes the initial processes of extraction of raw materials, manufacturing, use and end of life waste management. The processes are inclusive of material and energy use.

An LCA has four major steps as shown in the figure 2: Goal and scope determination, Inventory analysis, Impact Assessment and interpretation.
(The description provided below are from the lecture notes of Anders Strømman for the course*TEP4223: LIVSSKLUSANALYSE*)

3.1.1 Goal and scope definition

This is the defining phase of the study. The foremost step in the study requires the determination of a functional unit. The functional unit is a quantitative measure of the process in demand. All the material and energy transactions in the system are connected to this via several networks.
The emissions that are emitted due to the process or activity from which the functional unit is derived are the direct emissions while the emissions generated from the processes as a result of the requirement of the functional unit are the indirect emissions.
A system boundary is also defined in this stage- with a simplified flowchart which includes the unit processes that are included. This chiefly includes inputs and outputs of the main manufacturing process, transport and energy use, maintenance of products disposal of waste and products and other additional operations.

3.1.2 Inventory Analysis (LCI)

It is understandable that LCA is an extremely data-intensive process. Based on the foundation of Leontief's Input Output model which analyzes inter-industry flows, LCA requires the data for inter-industry material or energy flow for the production of a unit process. This is primarily the construction of the A matrix, where the a_{ij} is the requirement coefficient which suggests the input requirement of process i for a unit process j. The A matrix is divided in different sections. Equation 1 shows an illustration. The foreground system, Aff, is where the main system components of the study are gathered and where all other inputs from the background are connected. Abb is the background system and contains data from the generic database. The generic database used in this study is the Ecoinvent 2.0 (2007) which is one of the most comprehensive databases with over 4000 datasets. Abf is the amounts going from the background to the foreground. Afb is the amount from the foreground going to the background and being reused for the process development. This is often used to model recycling.

$$A=\begin{bmatrix} \boldsymbol{Aff} & \boldsymbol{Afb} \\ \boldsymbol{Abf} & \boldsymbol{Abb} \end{bmatrix} \qquad \textbf{(1)}$$

For a functional unit y, or the final demand, the total outputs from the different processes in the system can be calculated. This matrix is called the x-matrix and the equation is expressed in Equation 2 and 3. The total production equals the internal production plus the final demand.

$$\boldsymbol{x = Ax + y} \qquad \textbf{(2)}$$

$$\boldsymbol{x = (I - A)^{-1}y = Ly} \qquad \textbf{(3)}$$

The term $(I-A)^{-1}$ is called the Leontief Inverse matrix, or the L-matrix, and gathers the output from process i per unit external demand of product j.

In order to get a fair amount of impact share there needs to be certain modelling done for Allocation in multi-product generating industries (by partitioning or substitution) as well as modelling transport just that the requirements and the leading impacts are correctly distributed in the system. This is also carried out at this stage.

3.1.3 Impact Assessment

To calculate the total emissions for a given external demand we need a stressor matrix. The stressors can be of several types environmental loads not just traditional emissions such as CO_2 or 1,4 dibenzaldehyde . Stressors can be from a handful up to thousands. The S matrix should be constructed analogously to the A matrix**.** To find the total emissions from the processes in the system, the total output must be multiplied with a stressor matrix called S. $S_{str,pro}$ is the emissions of stressor str per unit output of process pro. Equation 4 shows the resulting emission matrix e.

$$\boldsymbol{e = Sx} \qquad \textbf{(4)}$$

e_{str} gives the total emissions of stressor for the given external demand y. To find the stressor amount of each process, the x matrix must be diagonalized, giving the resulting E-matrix as shown by Equation 5.

$$\mathbf{E = S\hat{x}} \qquad \textbf{(5)}$$

The characterization matrix, C, distributes the stressors to the different impact categories. Examples of impact categories are Climate Change or Acidification potential. To find the total impact potential, the C-matrix must be multiplied with the emission matrix, e. The result is Equation 6 which shows the total impact potential of the system as a whole.

$$\boldsymbol{d = Ce} \qquad \textbf{(6)}$$

To see what impacts can be attributed to the different processes in the system, must the C-matrix be multiplied with the E-matrix (formula 2.5) to make Equation 7.

$$D = CE \tag{7}$$

The characterization matrix distributes the stressors to the impact categories. The primary objective of the ReCiPe method used in this study is to transform the long list of inventory results into limited number of indicator scores (ReCiPe, 2009). The indicator scores express the relative severity on an environmental impact category. The ReCipe method has 3 perspectives: individualistic, heirarchist and egalitarian.

1) Individualistic: This perspective is based on technological optimism and has a short time frame (20 years for climate change) substances that have complete proof of their effect are included.

2) Hierarchist: A pragmatic perspective based on common policy frames regarding time frames (100 years). Substances are included if there is consensus regarding their effect.

3) Egalitarian: Is a risk-aversive, precautionary perspective with an extremely long time frame (500 years for climate change). It includes every substance included.

The ReCiPe midpoint method includes 18 midpoint impact categories with each of these perspectives. For this study the Hierarchist perspective is chosen as it provide fairly rational results. The impact categories chosen in this study are chosen based on the weighted environmental problems of the studied scenario reflecting the goal and scope of the study.

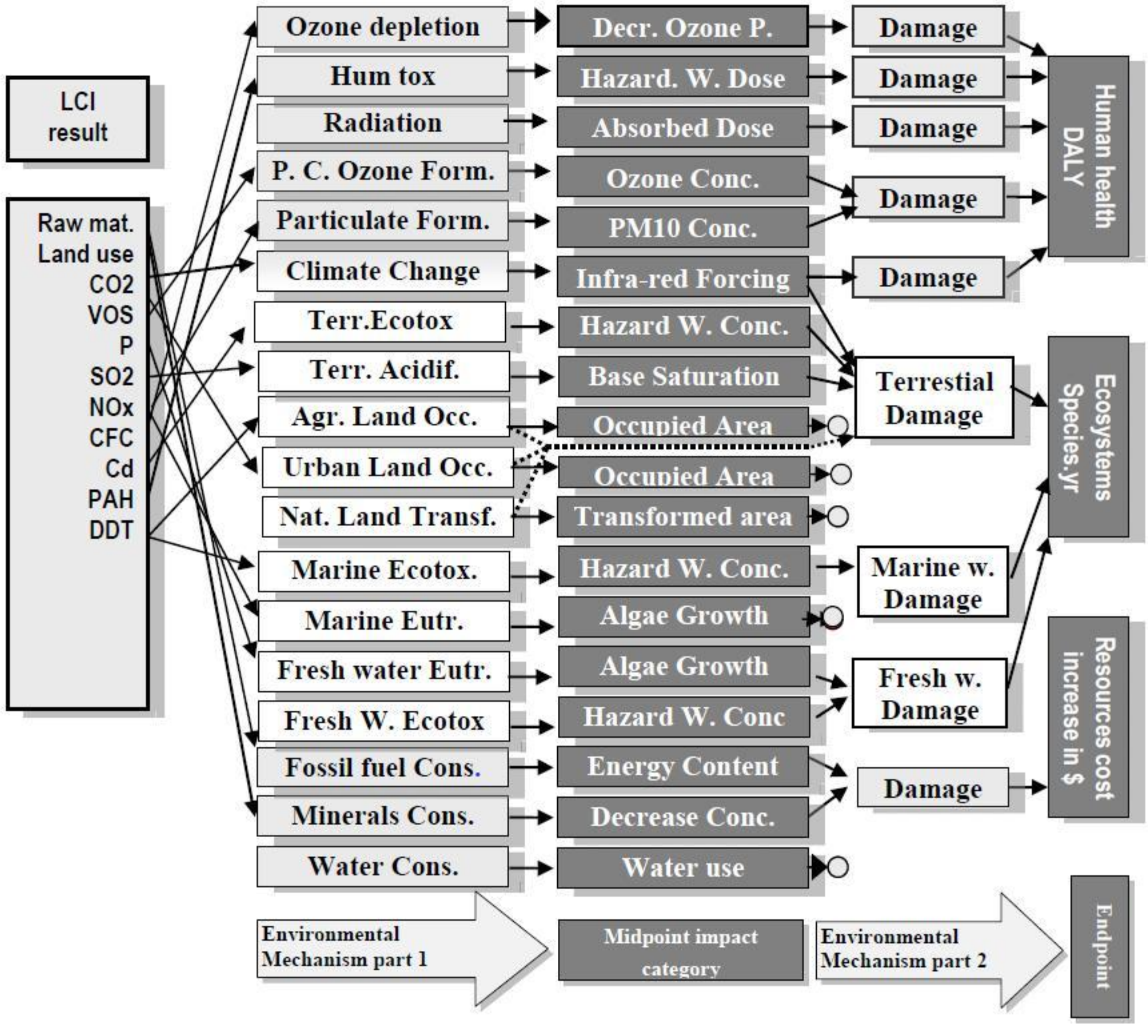


Figure 8: Impact Analysis based on the effects of different stressors. (ReCiPe, 2009)

3.1.4 Interpretation

This is the final stage for the analysis of the results of the LCA. Results should be consistent with the defined goal and scope. Limitations and uncertainties in the study should be discussed with the conclusion.

3.3.5 Simulation software:

The LCA software interface used for the calculations in this project is Simapro 7.3.3. This tool is integrated with the Ecoinvent database, which has been used as the generic database for this project. The other simulation tools used to generate data for this project are SIMIEN2.0 for energy and indoor air modelling and Velux Daylight Visualizer to determine daylight factor. AutoCAD 3D was used to make necessary measurements of the site details.

3.2 Functional Unit

The functional unit for this study is:

"1 m^2 of useful floor area (BRA) of the model Active house and the assumed control Passive house, including the whole building lifecycle assuming the lifetime of the building as 60 years."

The whole building lifecycle includes all the building phases: construction, maintenance and surface finish, operational energy and water use and end of life treatment within the stipulated 60 years of the building's lifetime. This is further defined in the system boundaries of this study.

3.3 System Boundary

The system boundary for this study is similar to previous LCA studies carried out on passive houses in Norway (4). The main life cycle stages are construction, house in operation and end of life management. The construction phase includes all the materials used, energy for building machines used and waste during construction. Transportation of the materials from the production site has also been included. However, transport of workers and equipment to the site has not been included. Most of the construction materials were pre-fabricated from local producers. The use-phase of the building consists of the operational energy use, renovation and surface finish (inclusive of painting, renovation of floors, bathroom, doors and windows); In case of the Active house, additional maintenance for the solar collectors is also included. Household waste generated during the use phase of the house has not been included. The end of life treatment of the building includes demolition energy, transportation of the materials to treatment site and treatment. Further detail of waste treatment has been addressed in another chapter. Materials produced from recycling or recovered incinerated energy from the waste treatment of the materials has not been included in the system, although use of secondary (recycled) material is used in certain processes, where specifically mentioned.

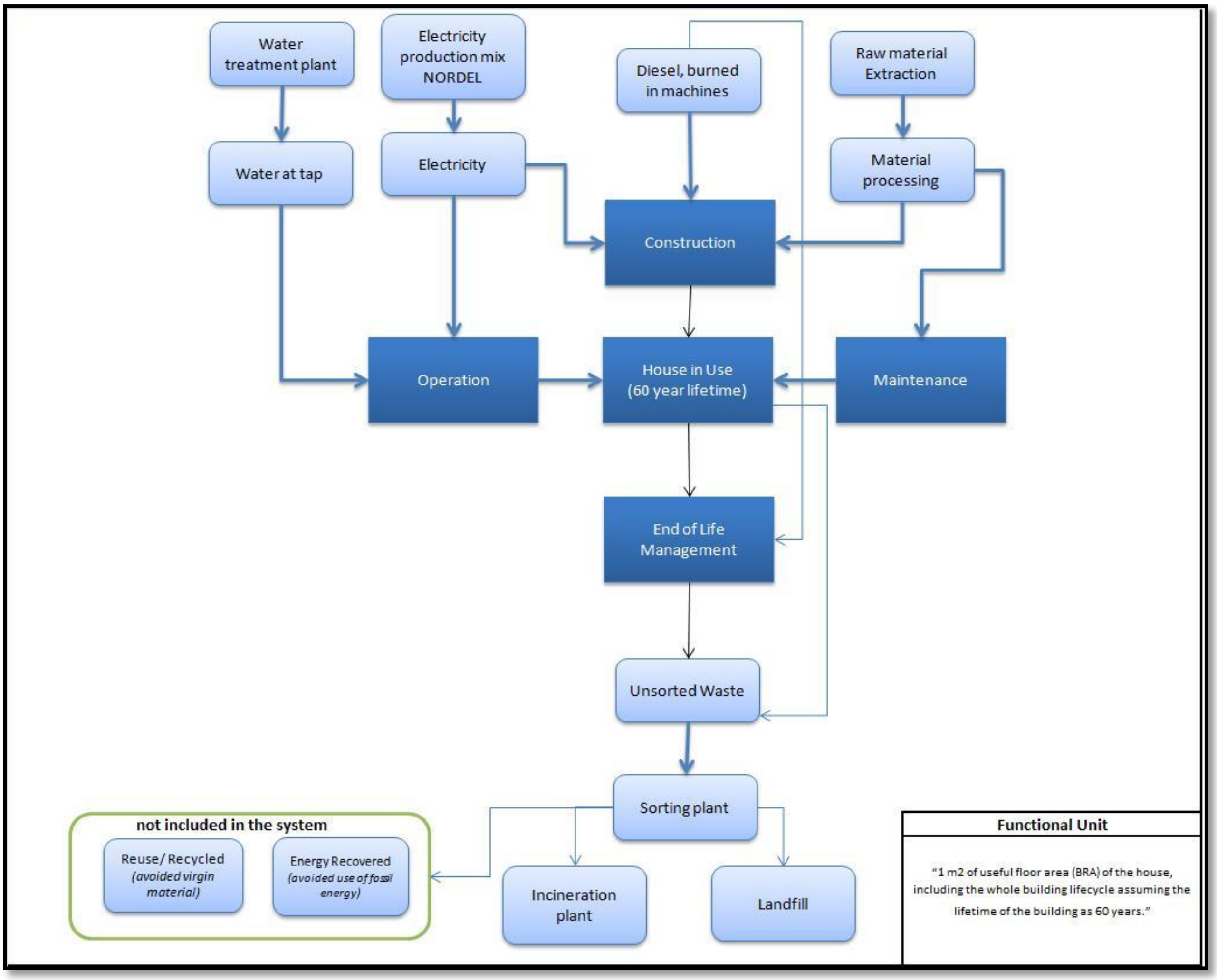


Figure 11 System Boundary

3.4 Life Cycle Inventory:

The life cycle inventory has been divided into 4 phases namely – construction, operation, maintenance and surface finish and end of life treatment.

3.4.1 Construction

This section provides a description of the construction phase; comprising of all the building materials used as well as materials in excess, which were transported from the site as waste; apart from this energy for the operation of building machines and electricity during construction has also been included.

Since the project was carried out in a rather short time, technical drawings and material lists were unavailable from the architects. However, most of the data on construction technicality was provided on the basis of personal communication with the head carpenter- Roger Lille. Basic drawings of the floor plan were available. Calculated values from the plans using AutoCad 3D was useful to estimate the required amounts of material for the construction. Invoices of the materials were available from the contractor- Richard Ligård and partner Velux A/S. Some of the materials were not covered in the invoices, such as the materials for mechanical ventilation system, electrical installations and plumbing. Assumptions have been made from previous qualified studies to provide a complete inventory. The building materials used for the Active house has been mostly from local producers and some products have established Environmental Product Declarations (EPDs) which has helped in using gathering data for raw material extraction. For other materials, the generic data from Ecoinvent was used, which was modified.

Building elements have been further divided into several subcategories.

3.4.1.1 Construction Material and Energy:

Construction of modern buildings are equally material and energy intensive. Modern passive houses need. The embodied energy of modern low energy houses account for 45% of the entire lifecycle (42). The embodied energy could be lowered with the material type, material obtained from local producers, etc. It has been proved that houses with timber framework have lesser embodied energy and carbon than concrete based buildings (43). The assessed house in this project is a timber based house using a variety of materials from several suppliers. Most of the data for wood based products have been adopted from the lifecycle inventories published by the MIKADO project, which has collected data and energy use for timber products such as wallboard, structural timber studs, I-beams, water resistant particle board and laminated wood (44). Data on other construction materials has been obtained from EPDs published by suppliers or relevant EPD similar to the products used has been used. To complete the inventory generic data has been used from Ecoinvent database and previous LCA study on Passive houses.

The energy choice for production of materials has been adjusted based on where the material is produced. Building materials produced in Norway or the Scandisk region has been adjusted to the Nordic medium voltage electricity mix. Other imported material has been considered under the UCTE electricity mix (electricity mix considered for Europe).

Transportation from the suppliers to the construction site as well as construction waste to the treatment plant has been approximated from different suppliers within the country and abroad. Almost all the cargo transportation is via road in 16-32t lorry. Materials supplied from abroad also include an added fleet transportation. The table 8 summarizes the assumptions:

Table 8 Estimated transport distances

Transport	
From supplier	**(km)**
Short distance	**100**
Moderate distance	**500**
Long distance	**1350+ 135**
Treatment plant	**85**

3.4.1.2 Construction Energy:

Development of the site, requires substantial use of building machinery and equipment , such as construction dryer, tent, electricity for lighting. The energy requirement was obtained from the invoices provided by the contractor. The house required 7095 kWh energy during the construction phase. The diesel required for building machinery was approximately 566 litres.

Estimation for material such as screws, particleboard etc has been assumed from previous study on passive house (4).

3.4.1.3 Foundation and Basement:

The building foundation is made of concrete, insulated with 200mm of expanded polystyrene (isopor).

The walls of the basement are constructed of Leca Isoblocks, which are light-weight concrete blocks, with 100mm extra insulating material in the centre of the blocks. In addition, 50 mm of expanded polystyrene on the outside of the wall was attached. The construction of the basement walls ensures a U-value of 0,14. The data for Leca Block walls was available from the EPD published by Leca and Weber Norge (Saint Gobain) (45). The data for concrete and expanded polystyrene was based on the Ecoinvent database.

3.4.1.4 Exterior walls:

The exterior walls are built based on the usual timber framework and have the following construction from the interior to outward cladding: 16mm chipboard plate, 50 mm Glava insulation (glasswool) , Vapour barrier, 200 mm of Glava insulation, the structural framework is based on a 300 mm I-beam, a layer of cross beams of 36*48mm are laid horizontally with another 50 mm Glava insulation, a layer of vertically laid beams of 36*48 mm and another layer of 50mm insulation is added on top , this is followed by the wind protection system (which consists of windbreak foil and windbreak sheets- 30mm of bitumen plates); the windbreak system provides structural support to the framework as well as air-tightness. Finally the outer layer is covered by paint-treated Timber cladding. The data for insulation is available from the EPD published by Glava (46) and data for bitumen plates was available from Hunton asphalt vindtett. The total thickness of insulation of the exterior wall is 350mm and the entire wall is 440mm thick.

The external wall construction on the bathroom region is slightly different. Instead of a gypsum board and a chipboard plate, it is covered by a wet board plate provided by Litex and grease based membrane to provide water-proofing and prevent moulding.

3.4.1.5 Interior walls:

The interior walls have a much simpler framework than the external walls. It consists of a wall board or chipboard plate of 16mm, with 50mm glasswool for acoustic insulation and spruce panels of 14*70 mm with white paint.

3.4.1.6 Floors

3.4.1.6.1 Ground Floor (ceiling to the basement):

The ground level floor is partially a ceiling to the basement, which covers the tiled common area and the bathroom floor, while the floor of the bedrooms on the ground floor is directly above the planed gravel. The non-tiled bedroom floors cover 35 m^2 of the entire ground floor. This floor consists of 300 mm thick expanded polystyrene (EPS) on planed gravel, this is layered by 100mm concrete. A vapour barrier is sandwiched between the concrete and EPS. The construction consists of 100 mm of ground insulation (Glava glasswool), 22 mm of particleboard and 15mm thick parquet. Sealants and tape used has also been accounted.

The tiled floor of the common area and the bathroom which is also the ceiling over the basement is constructed on 150mm concrete, 50mm EPS sandwiched with another 60mm concrete. The topmost layer is lined with ceramic tiles. The reinforced steel used on the concrete type is assumed to be of type K189, Ø6 steel net (4).

3.4.1.6.2 First Floor

The first floor is suspended between the ground floor and first level entirely. The floor construction consists of 300mm thick I-beams placed 60 cm apart. The gaps are filled with 200mm glasswool insulation. The outer edge has a 22mm water resistant particle board plate on the upper side as well as 15 mm thick parquet. The underside of the floor has a particle board of 22mm and a 13 mm gypsum board.

3.4.1.6.3 Stairway

The house has two sets of stairs with 28 steps in total. The stairway is supplied by the local producer Trapperingen. The staircase is made of laminated wood, with supportive pillars and railings of structural wood. Assumptions for the metallic parts and surface finish were taken from previous study (4).

3.4.1.7 Roof

The roof construction has a tetrahedral pyramid structure. The architects have combined the traditional roof design with this experimental form. Approximations of the material input and framework for the roof were made on the basis of personal communication with the carpenter and previous studies on roof construction (47; 4). The roof ceiling has 500mm insulation glasswool insulation, laid in 4 different layers. The load bearing stud is 300mm thick. The non-load bearing studs are of 48 and 72 mm thick. These provide the structural support for layering the insulation. A wind barrier is placed on the outer side and a vapour barrier covers the inner layer. The roof ceiling is a 13mm gypsum board. The ceiling is supported by a wooden pillar, in the centre of the building. The pillar ‘s dimensions are 180*180mm and it is 4,8 m long, covered by a 13mm gypsum board on either side.

The roof cladding is supplied from Rheinzink, Germany. The cladding is made of titanium-zinc alloy. This is based on fine zinc with additives of copper, titanium and aluminium. This element is relatively more expensive and energy intensive than most other roof tiles; however it is highly resistant and does not require maintenance for 60-70 years. The inventory for this alloy sheet was available from the EPD published by Rheinzink (48).

The roof accessories- rain gutters and roof snow protectors were also included. They were produced from zinc and galvanized steel.

3.4.1.8 Auxiliary Area

The auxiliary area of the house includes the garage and the entrance hallway, garden and terrace. The house has an unheated double garage covering 38m^2 of the area. The technical detail for the garage walls and ceiling were unavailable from the site. The structure was assumed from Sintef Byggforskserien (49). The garage floor was assumed to have a ring wall foundation. The garage ceiling construction was similar to the 1st floor ceiling as defined earlier. Thought the garage is attached to the main house, its construction is subordinate to the main construction. Hence the amount of material and insulation used is lesser than the 1st floor within the house. The garage walls have boards with diagonal braces for structural support. The walls have a wind barrier inside the cladding to prevent sand and snow flies into the garage. The garage and the entrance way have doors at both ends which were prefabricated in the factory and brought to site. They were delivered by Hormann. The entrance doors are made of single glass panes with metallic frame. The garage doors are made of structural wood.

The boundary wall of the garden is supported by Leca block partially and the structural timber. The wall is painted on either side. The boundary wall also includes two glass panes. The timber wall for the garden and the terrace have similar framework. They are hollow and serve only aesthetic and design purposes.

3.4.1.9 Doors and Windows

The external glass doors to the terrace and the facade windows have been supplied by Nordan. The U-value of the door is 0,8 and the vertical facade windows is 0,7. The entire glazed area on the building facade covers 38,2 m^2 and 27,2 m^2 for the Active and the Passive (control case) respectively. The data for the Nordan windows has been obtained from a previous LCA study on modern triple glazed windows (30). The doors and windows provided by Nordan have a lifetime of 30 years.

In addition to the facade windows the Active house also has roof windows. The U-value of the roof windows is 1,0. These windows have been provided by Velux and the data was available from an EPD published by Velux (50).

The window frames are timber-based. The inner doors consist of a door leaf, door frame, lining, paint and hardware. All the roof windows and vertical windows on the south facade have automated solar screening attached to the frame. These are usually made of glass fibre and polymerized resins. The roof windows have a lifetime of 20 years.

3.4.1.10 Electrical equipment and Plumbing:

The data for electrical equipment and plumbing were adopted entirely from previous studies (1; 4), this was further based on generic data from the Ecoinvent database (2007).

3.4.1.10.1 Electrical Equipment

Electrical system in the house includes power outlets and a HDPE wall box, lamp switches, cables for floor heating and powder coated fuse-box. The quantities of electrical circuit around the house were adjusted with the gross floor area.

3.4.1.10 .2 Plumbing

The plumbing system includes tap water and sewage system installation. Polyethylene pipes are installed to tap points in the bathrooms and the kitchen with 40mm sewage pipe. The toilets are mounted with 110mm sewage pipes. The bathroom includes ceramic fittings for bathtub and toilet.

3.4.1.11 Heating Systems

Both the Active house and the case control Passive house have the primary installation assumed for heating. Each house consists of two 600W electric panel heaters, two modern wood stoves and a hot water tank. The lifetime for the panel heaters and the hot water storage is assumed to be 25 years .The data for the panel heaters was adopted from (1), based on manufacturer Adax. The heater inputs are 90 percent steel and mixture of plastics. The wood stoves and chimney are manufactured by Jøtul. They are made of 100 percent cast iron.

In addition the Active house has flat-plate solar collectors for combined system for hot water and heating. The solar collectors were provided by Velux but the production details of the panels were not available. However, production of a complete solar system was available from an Ecoinvent report by Niels Jungbluth (51). This consists of all components such as the flat plate collector, pipes, 40W pump. The hot water storage tank has been removed from this inventory and adjusted to the Norwegian producer of hot water tanks, OSO hot water.

The main materials of the solar collector are copper, chromium steel, propylene glycol, silicone product and rockwool. The life expectancy of the solar collector and the hot water is assumed to be 30 years and the pumps are renewed every 20 years.

3.4.1.12 Ventilation Unit

The data for the ventilation system combined with a heat recovery unit was difficult to obtain and generic data was adopted from the Ecoinvent with adjustments based on the product declaration provided by Systemair VR 400 DCV/B (52).

3.4.2 House in Use

This operational phase of the house is divided into two parts Maintenance and electricity and tap-water use.

3.4.2.1 Maintenance

The maintenance of the house includes indoor and outdoor painting, renovating the entire bathroom, changing the parquet, glazed door s and windows periodically within the building's lifetime, to maintain the appropriate functional and aesthetic value. Maintenance and replacement of heating systems is also included. Though solar collectors need low maintenance, it is assumed that the pump and the heat transfer fluid are replaced once every 15 years. The maintenance and replacement are assumed to be the same for the active house and the control case. A summary of the maintenance frequencies of the different components is given below. This is inclusive of the installation and surface finish in the year of construction.

Table 9 Surface finish and Maintenance in 60 years

	Frequency (year 0-60)		Lifetime (years)
	Active	Passive	
Bathroom	2	2	30
Parquet	3	3	20
Paint indoor	6	6	10
Paint outdoor	7	7	8
Windows and Outer doors	2	2	30
Roof Windows	3	3	20
Hot Water Tank	2	2	25
Electric Panels	2	2	25
Solar Collectors	2	0	30
Maintenance of Solar Collectors	4	0	15

3.4.2.2 Operational Energy

The operational energy use has been simulated using an energy simulation model SIMIEN 2.0, provided by Programbyggerne AS. This tool allows simulating energy and indoor air quality models of buildings within particular specifications of building's technicalities (wall/ foundation types, facade designs, and ventilation), assumed user behaviour and climatic conditions essentially for Norway. The model also assesses the building based on the Passive house standard and produces an energy marking certificate. The annual energy simulation is given in Appendix C.

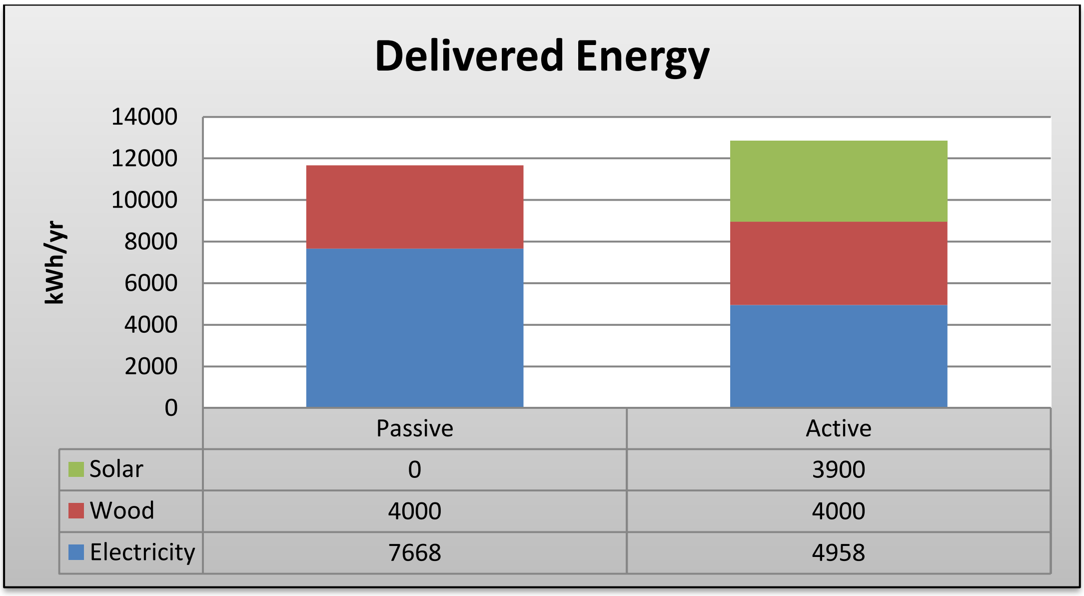
The software has the climate data based on Værnes, which is in Stjørdal. The average outdoor temperature is 5,3° C. The indoor temperature to be maintained is 20°C. The building specifications have been entered as defined in the above chapter. The Active house includes additional use of solar energy. The user behaviour for the lighting and mechanical ventilation has been adjusted for each house. Since the Active house has more and larger windows , the use of lighting hours are lesser than the Passive house. The mechanical ventilation for the Active house is inactive in the summer months. Based on these specifications the energy need in both cases is given below:

Table 10 Simulated Annual energy requirement

Annual Energy Required (kWh/m^2)		
	Active House	**Passive House (Control Case)**
Space Heating (incl ventilation)	38,5	23,1
Hot water	26,3	26,3
Other Electronic Equipment (incl lighting)	29,7	36,4
Total	**94,5**	**85,8**

The total annual energy required by each house is each year is 12858 kWh for the Active house and 11668 kWh for the Passive house. The energy required is different than the delivered energy. The calculated delivered energy is less than the required energy, as there is substantial energy produced on site. However, for the primary calculations for the lifecycle; it is considered that the that both the houses use direct supply electricity from Nordel low voltage electricity mix.

On the otherhand, the delivered energy for each building varies largely depending on sources available and the options chosen bythe residents. According to the NS 3700 standard, 40 percent of the energy consumption is covered by the renewables. In case of Passive, only wood and in the Active house solar and wood. It is assumed that each house uses an input of 960 kg of wood. Energy of logs of softwood is 15 MJ/ kg. The graph below 2 gives the assumptions used for delivered energy in this study.



Graph 2 Delivered energy sources

This condition is based on approximated values for the availability of solar energy for the entire year. The results are solely based on this approximation.

3.4.2.3 Tap water

The average use of water per person each day is 212 litres (53). Assumed that the house will accomodate 4 residents, the annual use of water is 309520 litres.

3.4.3 End of Life Treatment

According to the waste accounts for Norway, there has been 10 percent decrease of construction waste in landfills (54). Though the treatment of all the building material used is assumed according to the generic methods of incineration, recycling or landfill; the waste scenario is assumed based on the current Norwegian statistics.

Table 11 construction waste treatment based on statistics norway

Waste type	**Treatment (%)**		
	Recycled	**Incineration/ energy recovery**	**Deposit**
Paper	57	17	20
Metal	85	10	5
Plastic	14	36	30
Concrete	18	NA	38
Other Materials	15	70	15

The inventory also includes **waste during construction**. During construction, several building materials are purchased in bulk and fitted to size. Most of the materials purchased in bulk are timber, cement, insulation, sealing tape etc. The waste during construction is assumed to be 10 percent of the construction material. The waste generated during maintenance and surface finish is also considered .All the waste treated is based on the above table.

The complete inventory for the raw materials used in the Active house is given in Appendix B.

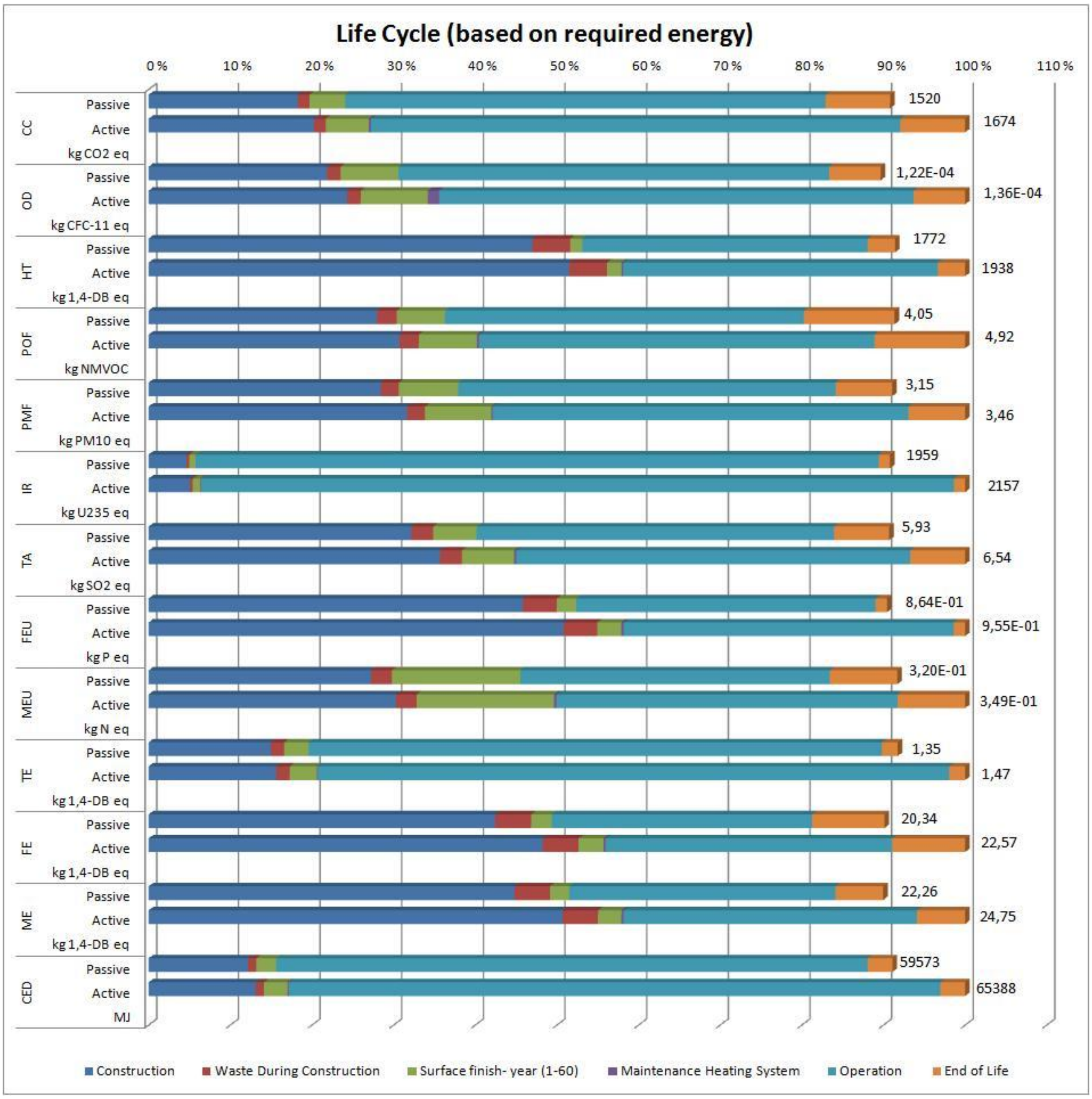
4 Life Cycle Impact Assessment:

The following chapter presents the life cycle environmental impact of the Active house in comparison with the control Passive house. The results are presented for the entire lifecycle of 60 years from cradle to grave, followed by disaggregated sections: Construction, surface finish (year 0-60), house in operation and End of Life.

The results are characterized based on the European hierarchist ReCiPe method. This is the most scientifically consensus methodology used in most European LCA study results. Each of the graphs is normalized to the results of the Active house to understand the relative difference. The impact per functional unit **Heated Floor Area m^2** is represented on the tip of each bar in each of the figures.

4.1 Life Cycle results

The results are based on the total impacts due to construction and construction waste, surface finish and maintenance, house in use- with operational energy based on energy requirement (supplied 100 percent from Nordel low voltage energy mix) and end of life.

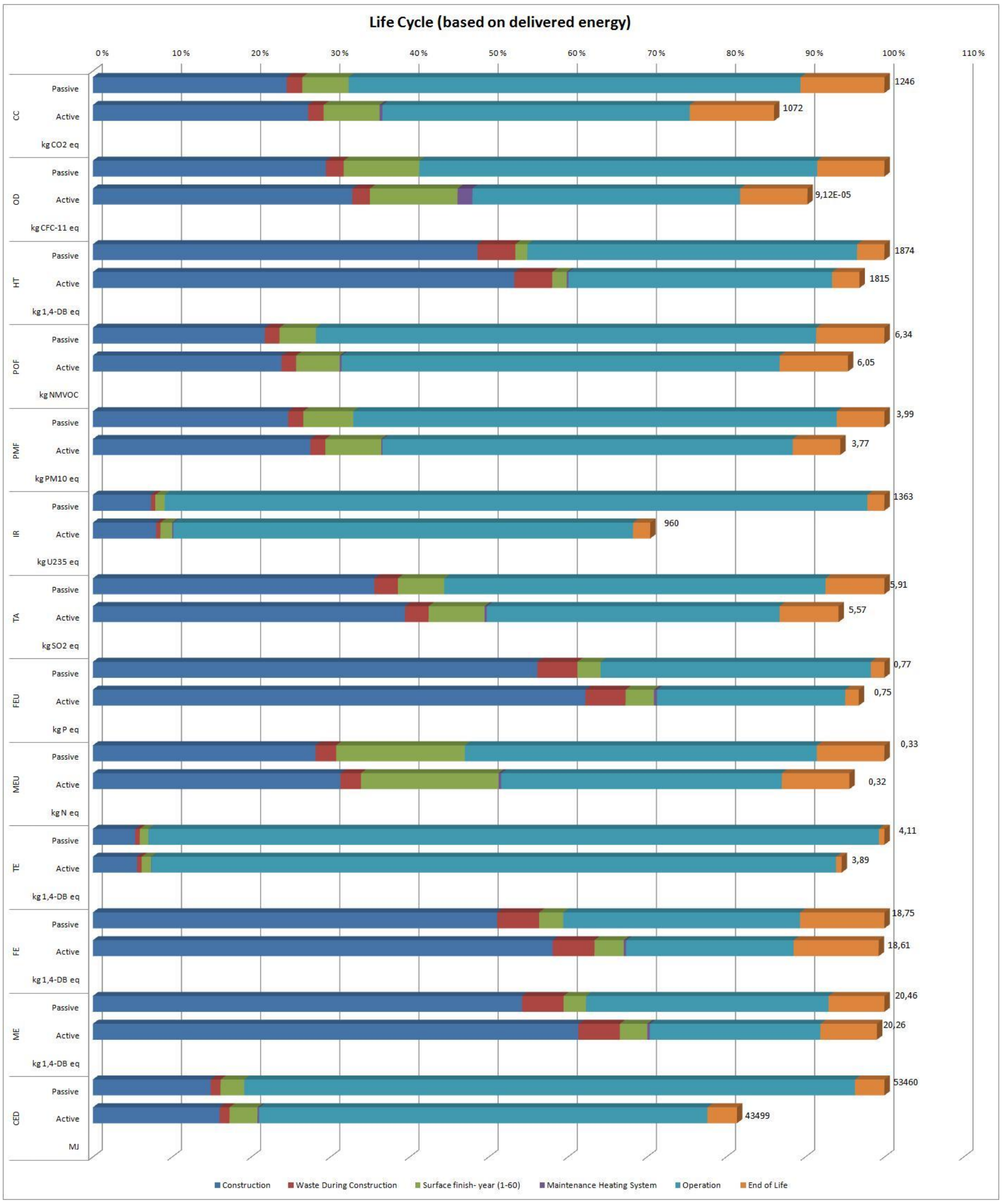


Graph 3 Lifecycle impacts based on required energy

The primary analysis from the lifecycle impact results suggests that the Active house has around 10 percent higher impacts in every impact category than the control passive house. Construction contributes to 18 % of the impact in the Climate Change Category and 11 percent in the Cumulative energy demand. But its contribution is higher, around 50 % in categories such as Human toxicity, Freshwater eutrophication, as well as marine and freshwater ecotoxicity. Impact contribution to particulate matter formation and photochemical oxidation is around 30%. Impacts from surface finish and maintenance is about 4-6% in most impact categories and about 12% in marine eutrophication. The operational energy is the most contributing factor in every impact category and since the Active house has higher requirement the impacts are also higher, particularly in Climate Change (64%), Ionising radiation (92%), Terrestrial Ecotoxicity (78%) and Cumulative energy demand (84%). Impacts from waste during construction are about 2% in all impact categories. The impact from end of life treatment and demolition of the house is 10-12% in most impact categories and less in human toxicity (4%), Ionizing radiation (2%), Terrestrial Ecotoxicity (2%) and Cumulative Energy demand (2%).The above analysis was made based on the energy required by the house based on the house specifications.

4.1.1 Life cycle results (based on delivered energy)

However, the delivered energy to the house differs on several sources as shown on graph (), the impact results are given below. It is interesting to note that since operational energy is the primary contributor of all impact categories, source of delivered energy has a significant effect in the total impact. The results on the graph show that, Active house which substitutes some of its operation with solar energy has a better performance than an equivalent Passive house with only wood and electricity as the primary source of electricity.



Graph 4 Lifecycle impacts based on delivered energy

Though the construction and maintenance impacts of the Active house are higher than an equivalent Passive house, the reduction in the source of operational energy reduces the impact of an active house in almost all categories. An active house lifecycle has 15 % lesser impact to Climate change than a Passive house. Similarly, impact on Ozone depletion is 10% lower, Ionizing radiation and cumulative energy demand by 30% lower. The impact intensity is only slightly lower than in categories such as human toxicity (5%), photochemical oxidation (7%), particulate matter formation (7%), terrestrial acidification (8%) and, fresh and marine water ecotoxicity (2%).

The impact to climate change is 1072 kg CO$_2$ eq/ m^2 HFA for the active house in an entire life cycle compared to 1246 kg CO$_2$ eq/ m^2 HFA of an equivalent Passive house.

The life cycle results of both the chosen cases have been summarized in the table 12 below.

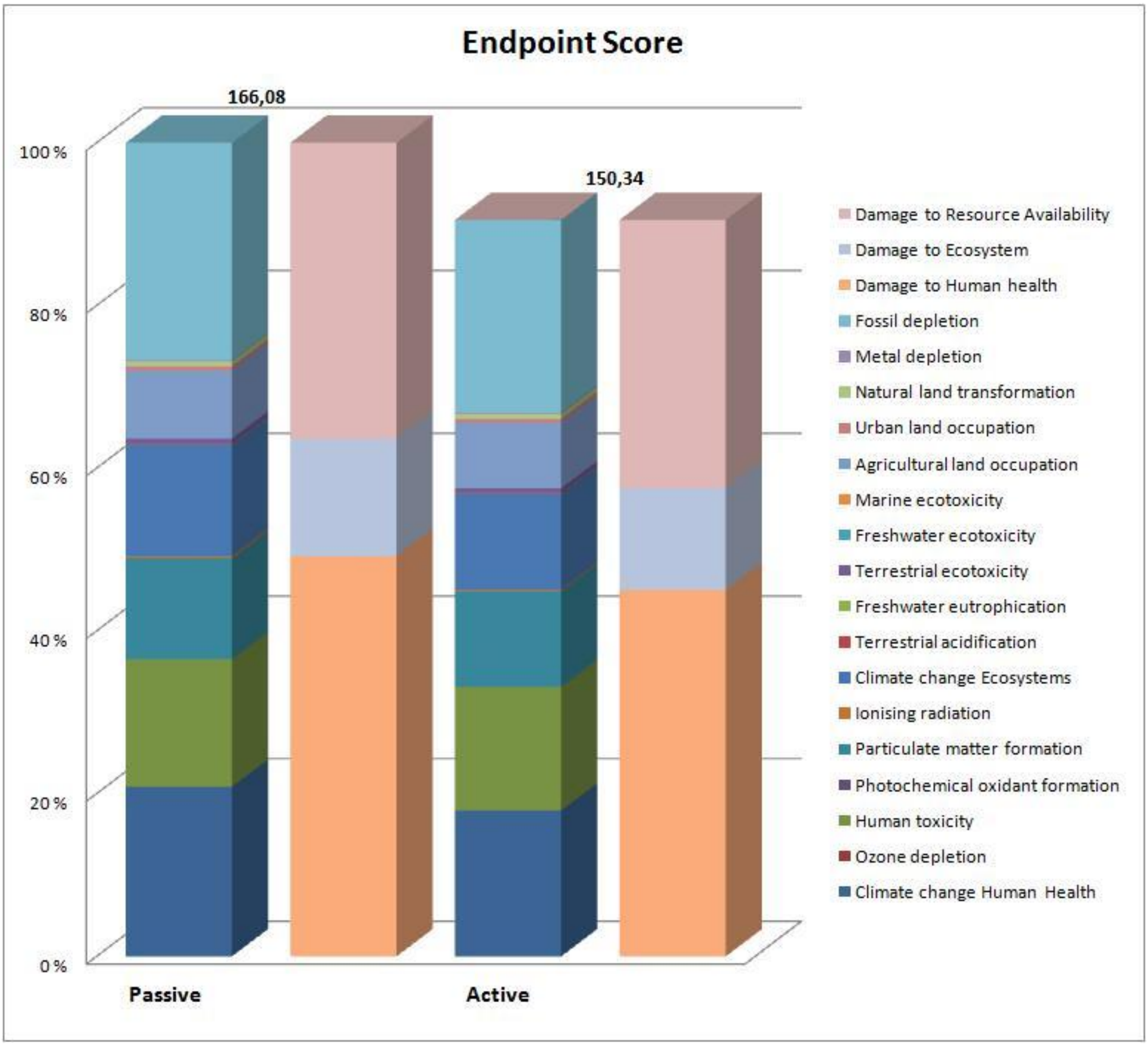
Table 12 Lifecycle results

	Required Energy		Delivered Energy		
Impact category	**Passive**	**Active**	**Passive**	**Active**	**Unit**
Climate change	206746,4	227668,2	169482,5	145865,2	kg CO$_2$ eq
Ozone depletion	1,66E-02	1,85E-02	1,37E-02	1,24E-02	kg CFC-11 eq
Human toxicity	240966	263585	254977,4	246944,6	kg 1,4-DB eq
Photochemical oxidant formation	612,1553	670,0722	863,2129	823,4676	kg NMVOC
Particulate matter formation	429,593	471,7322	543,4134	513,1045	kg PM10 eq
Ionising radiation	266453,8	293436,3	185454,5	130583,2	kg U235 eq
Terrestrial acidification	806,9514	889,773	804,9142	758,2959	kg SO2 eq
Freshwater eutrophication	117,5	129,9071	106,0685	102,6373	kg P eq
Marine eutrophication	43,54683	47,48849	46,00132	43,96694	kg N eq
Terrestrial ecotoxicity	183,6974	200,2263	560,196	529,8971	kg 1,4-DB eq
Freshwater ecotoxicity	2766,317	3069,757	2550,215	2531,62	kg 1,4-DB eq
Marine ecotoxicity	3028,306	3366,228	2782,559	2756,37	kg 1,4-DB eq
CED	8101900	8892878	7270548	5915924	MJ

4.1.2 Endpoint indicator

The lifecycle results are also presented in the form of a single score Endpoint indicator. Endpoint scores provide an estimation of the final effect to the midpoint causes. It is an easier understood method to interpret results for decision making. The indicator used is based on ReCiPe, heirarchist average which weighs the values based on the European set.

The results are normalized to the values of the Active house. The endpoint score points per m^2 of heated floor area are presented on the tip of the column bars for each house. The column on the left indicates the impact categories to climate change effect on human health, human toxicity, particulate matter, photochemical oxidation and Ionizing radiation which cumulatively lead to Damage to Human health on the right column. Similarly, effects of climate change to ecosystem, marine and freshwater eutrophication, terrestrial acidification, fresh and marine water ecotoxicity effects cause the final damage to ecosystems and finally, land and fossil use lead to damage to resource availability.



Graph 5 Endpoint impact results

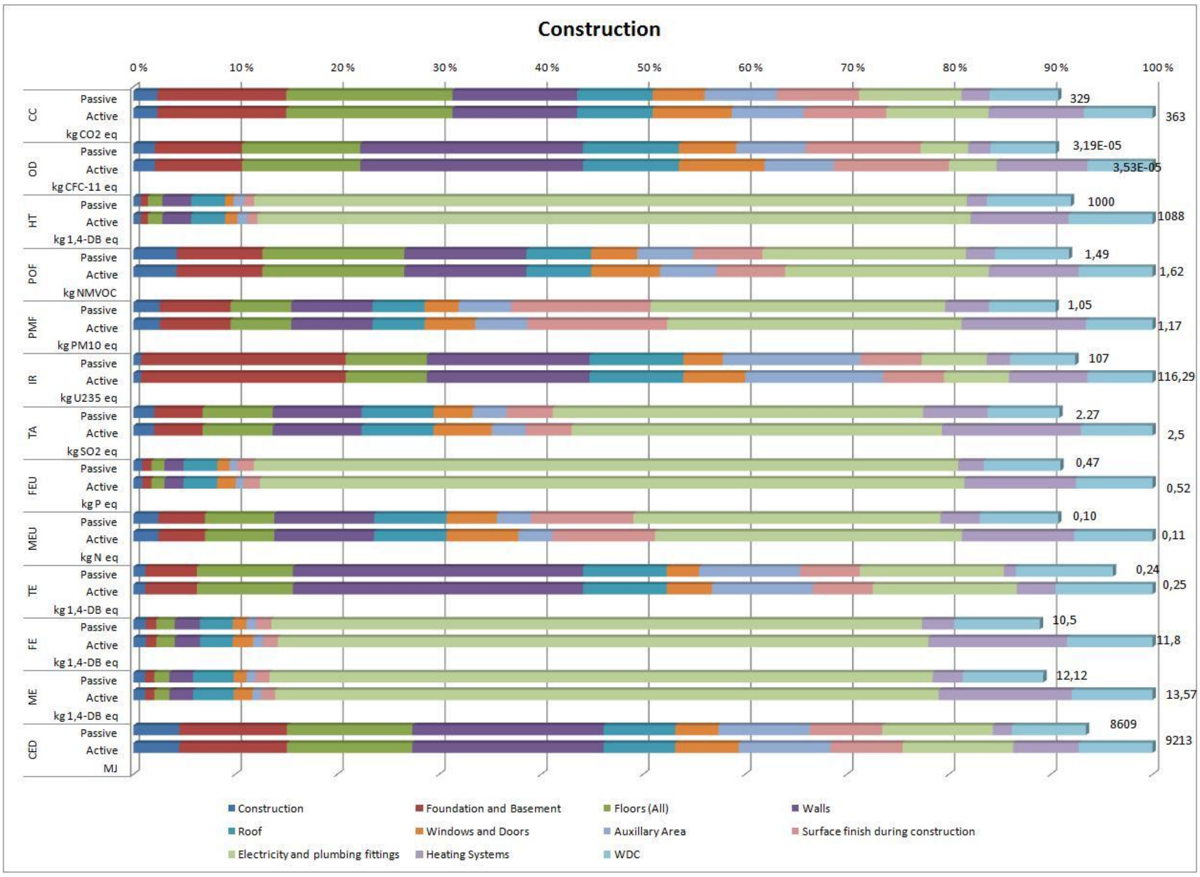
The Active house has and endpoint score of 15,34 points per m^2 HFA, while an equivalent passive house would have 166,08 points per m^2 HFA. The relative contribution of Active house to Climate change human health is 17%, human toxicity is 15%, particulate matter formation is 11% and fossil depletion is 23%. The contribution to damage to resource human health is 45%, followed by damage to human health 32% and the damage to ecosystem 12% is the least in comparison to the former causes.

4.2 Life Cycle Disaggregated

This section further analyzes the impact during each life cycle phase and their contribution. The phases are 1) Construction (inclusive of waste during construction), 2) Surface finish and maintenance (year 1-60), 3) House in Use (Operation) and 4) End of Life.

4.2.1 Construction

The graph presents the impacts from the construction phase, inclusive of waste produced during construction. This graph further defines the impacts from various contributing elements of the house.



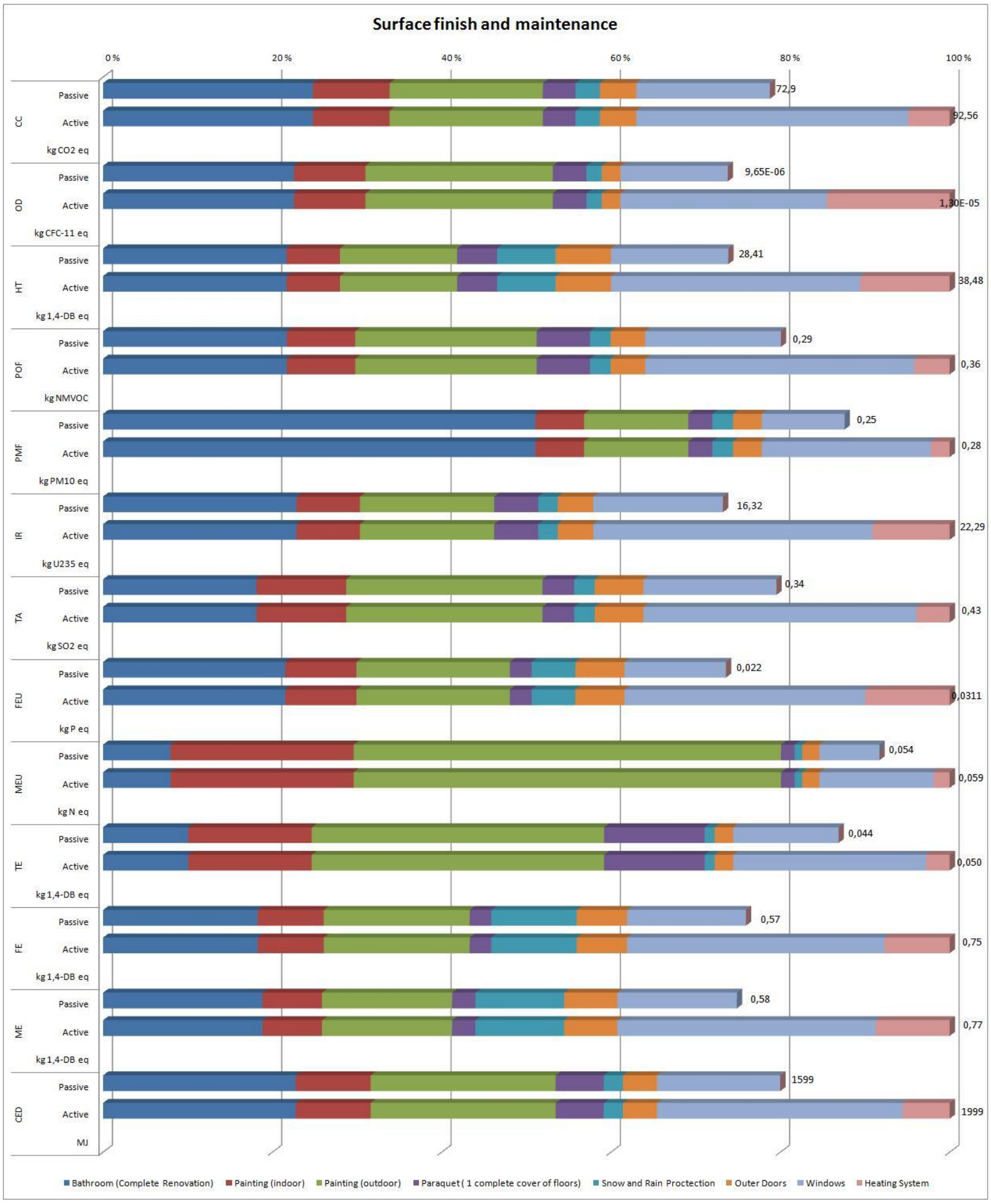
Graph 6 Impacts from construction

Since the fundamental construction of both the houses is the same, there is no difference between most of the contributing elements. However, the impact differences of construction between the Active and the passive house are about 9- 10%. The additional impact contribution is due to more material use in the Active house with respect to heating systems and windows. The additional heating system (solar collectors) adds about 8% to the impacts and glazed surface around 2%.

Floors are the most contributing element to Climate change, followed by basement and walls. Electricity and plumbing fittings contribute the highest to human toxicity, fresh and marine water ecotoxicity as well as fresh and marine water eutrophication. The impact on climate change per m^2 of heated floor area during construction stage is 363 kg CO_2/m^2. It is interesting to note that though construction might not play strongest contributor to the entire lifecycle impact, the design and construction accuracy determines the energy modelling of the house. For example: additional insulation might result in added impacts during the construction phase but reducing additional energy need during operation reduces the overall impact. Similarly, though additional glazed surface might add only 2 % of the impacts during construction, it contributes to more heat loss during operation.

4.2.2 Surface Finish and Maintenance (1-60 years)

The following graph represents the impacts from surface finish of the building and maintenance of heating system and glazed surface refurbishment. As mentioned in the inventory, the surface finish for both the buildings are exactly similar, however there is additional maintenance of the Active house, with refurbishment of roof windows as well as maintenance of the solar collectors.



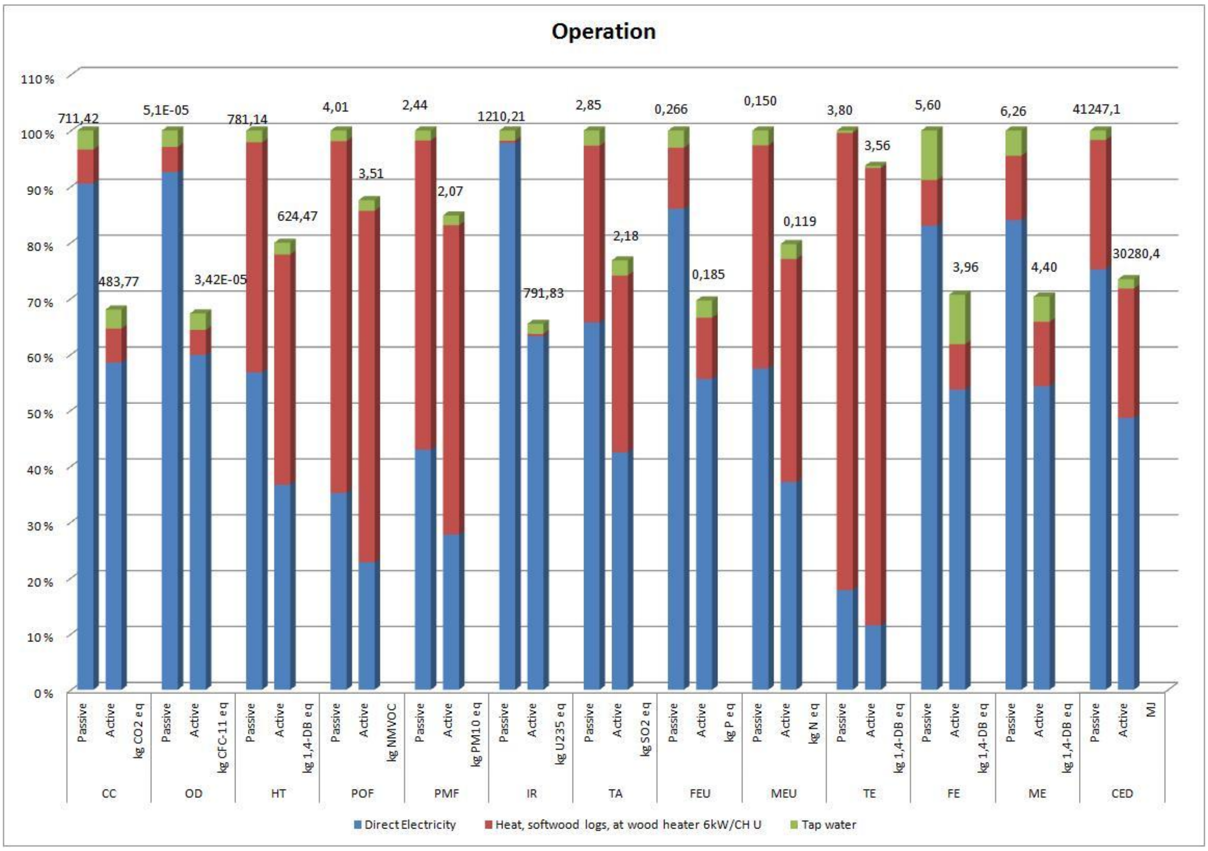
Graph 7 Impacts from surface finish and maintenance

The impact to Climate change is highest from the maintenance of windows in the active house, around 36%; on the other hand the Passive house window refurbishment contributes to about 16% of the total impact. This is because the roof windows need to be replaced every 20 years and the vertical windows, once in 30 years. Maintenance of solar collectors adds 4-6% additional impact in most categories. However, the impact is higher towards ozone depletion (14%), Human toxicity

(12%) and Ionizing radiation (8%). The entire bathroom renovation, once in the lifetime contributes to about 20% in most impact categories. Outdoor painting is the next largest impact contributor, especially to marine water eutrophication (46%).

4.2.3 Operation

The operational phase of the house is the largest contributor to each of the impact categories in the entire lifecycle. The graph represents the impacts from the source of delivered energy and tap water. Since solar energy substitutes about 30 percent of the annual energy requirement, over a lifecycle of 60 years the total impacts from operation for an Active house is around 34 percent lesser for Climate change.



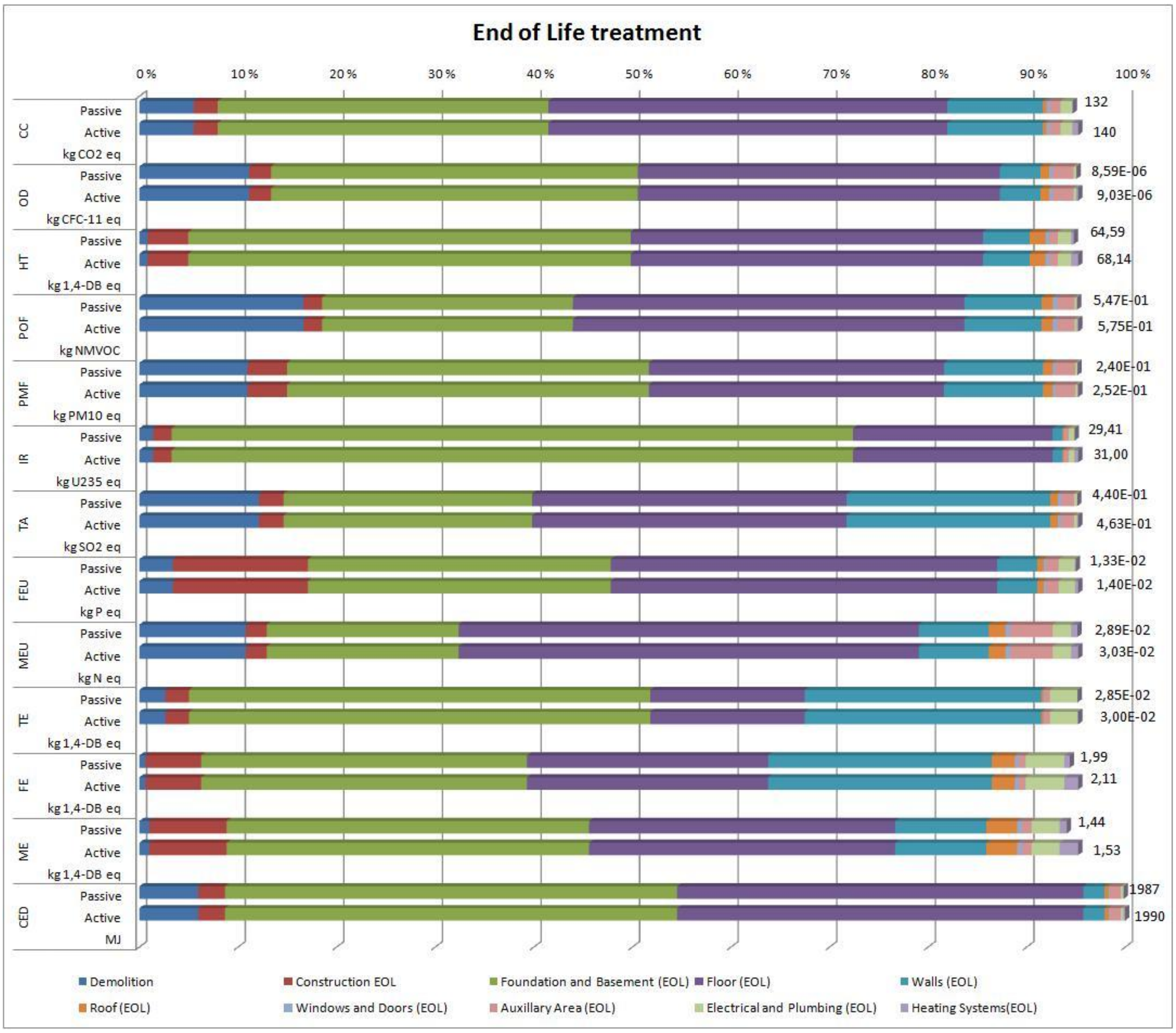
Graph 8 Impacts from Operation

The results above suggest that direct electricity from the grid has the maximum contribution to Climate change (90%), Ozone depletion (92%), Ionizing radiation (98%), Freshwater Eutrophication (86%), Fresh and marine water ecotoxicity (82%) and Cumulative energy demand (74%). However, impact from heat energy from wood has high impact on human toxicity (40%), particulate matter formation (56%) , photochemical oxidation (60%), terrestrial acidification (30%) and marine water eutrophication (40%). The highest impact of biofuel energy is towards terrestrial ecotoxicity (81%).Tap water use has around 2% impact in all categories, except freshwater ecotoxicity (10%).

The impact of Active house is 33% less in Climate change as well as in other impacts Ozone depletion (32%), Human toxicity (21%), particulate matter formation (27%), ionizing radiation (36%) terrestrial acidification (75%), fresh (32%) and marine water eutrophication (23%), fresh and marine water ecotoxicity (31%) and cumulative energy demand (28%). The impacts are heavily dependent on the source of energy, since most of the impact to terrestrial ecotoxicity is due to wood fuel which is the same quantity used in each house and hence the impact difference is less than 10%.

4.3.4 End of Life Treatment

The end of life phase includes the demolition of the building. The waste treatment of the Active house and the equivalent Passive house is the same; hence the impacts do not show much difference.



Graph 9 Impacts from End of life

The maximum contribution to impact categories during end of life treatment is from the foundation and the floors, which contribute 70-80% of each impact category. Energy used for demolition contributes to al impacts ranging from 2-15%. The impacts from construction end of life are the materials which had been used to start off construction such as nails and screws and chemical anchors which contribute to about 2-5% of the impacts. The total impact to climate change is 140 kg CO_2/ m^2 of the functional unit.

The following chapter reflects on the impacts of the building or building element under several scenarios. An advanced contribution analysis has not been carried out for this house, since it uses the same structural pattern of a Passive timber frame house, and has been dealt with much detail in a previous study by Oddbjørn Dahlstrøm (2011) (4).

5 Sensitivity Analysis

5.1 Impact based on Electricity mix

It is often debated that since most of the energy in Norway is from hydropower which has much lower impact than other conventional sources of energy, whether it is really necessary to locally invest on other renewable sources. There is credible complexity and challenges of determining emissions from grid electricity consumption. Norway is a part of the Scandinavian and the European electricity mix via international electricity grid (55), and hence uses electrcity imports which are not necessarily from renewable sources. The carbon emissions of the nordic mix is 0,21kg CO_2/kWh, while the norwegian mix has 0,017kg CO_2/kWh. The figure below shows the assumed residual electricity mix for Norway and the calculated one based on present diclosures from the study.

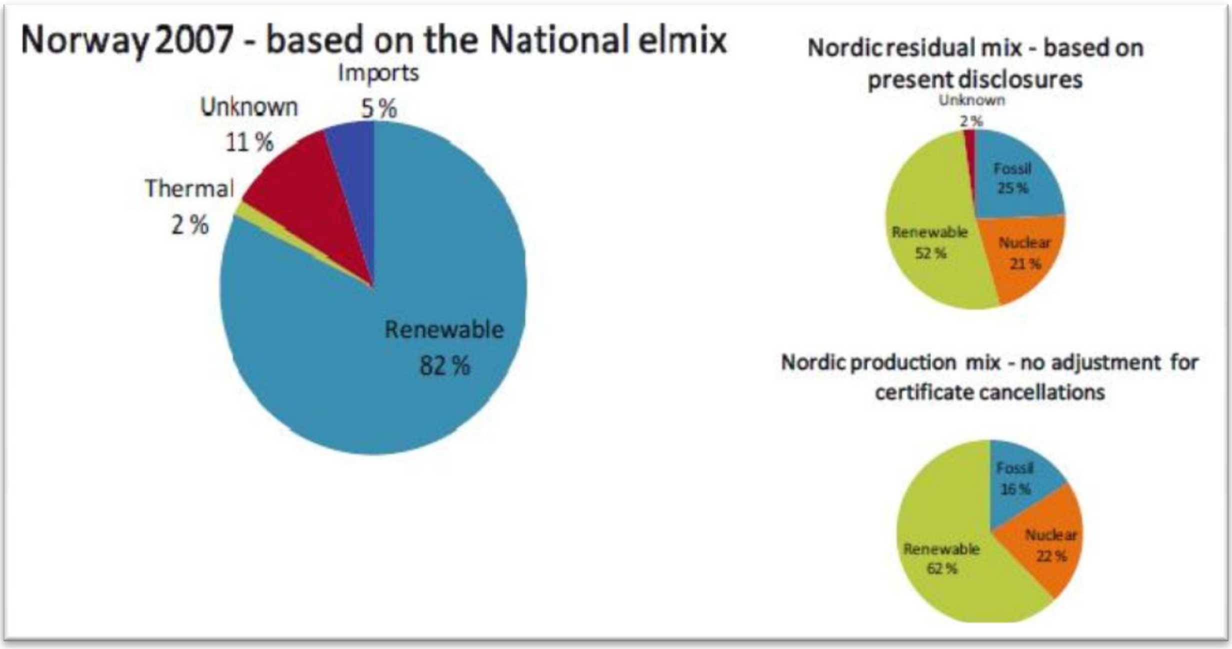
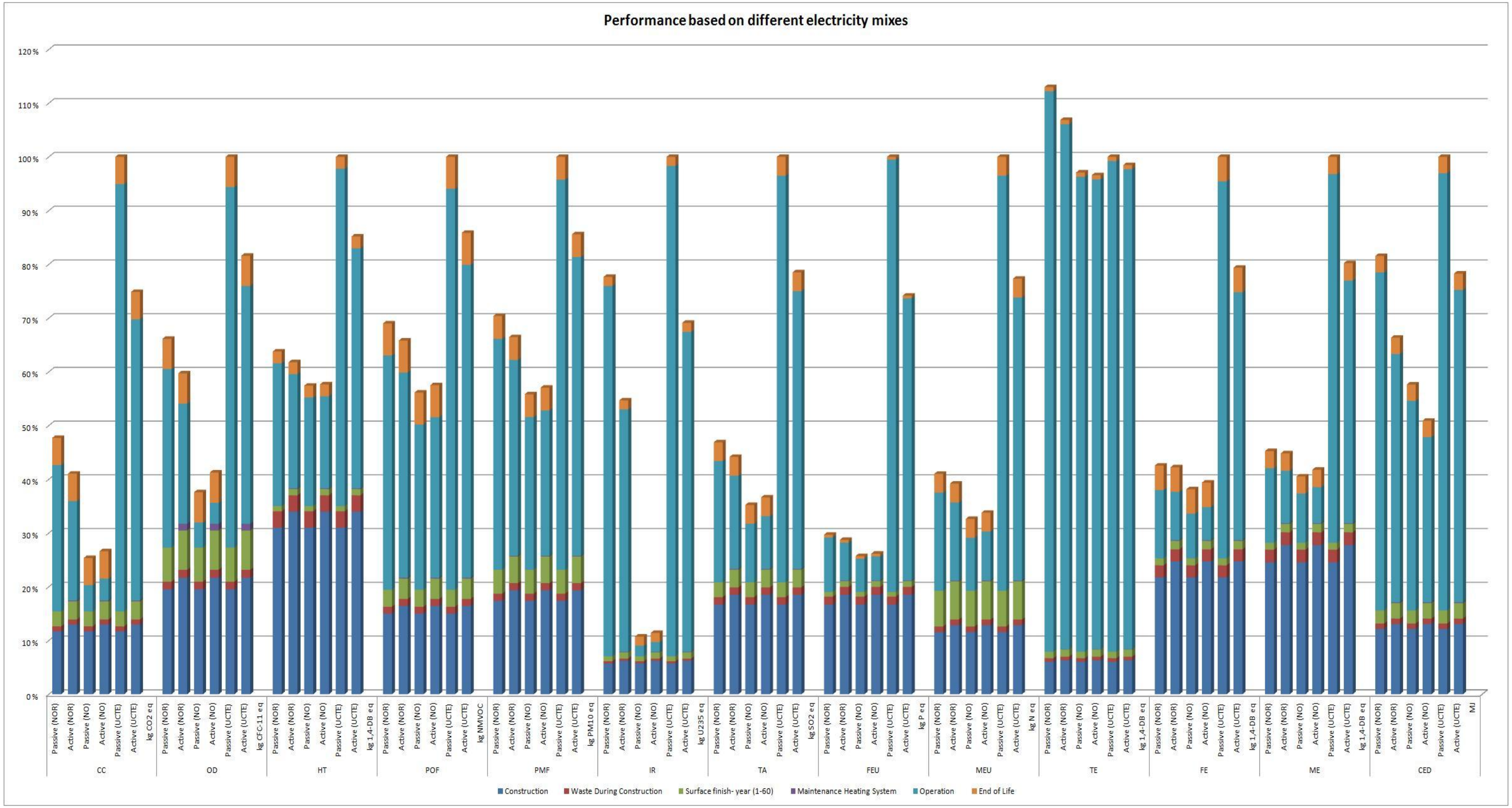


Figure 12 Electricity mix for Norway based on exports

Due to the existing discrepancies, the energy supply for our case is based on the Nordic production mix, which is the chosen on common scientific consensus. However, a sensitivity analysis on the graph 10 with different energy supplies has been carried out to compare the results.

It is interesting to note that if we had considered, only the Norwegian electricity mix as the primary grid electricity source, the impact of operational energy would be much lesser than construction and maintenance challenges. The impacts have also been compared to the conventional European electricity mix (UCTE), which has the highest impact since most of the operational energy is supplied from non-renewable, fossil based energy. It could be further deciphered that, it is very important to focus on better construction to reduce use of grid electricity than focus on source of grid electricity, to reduce the overall impact.



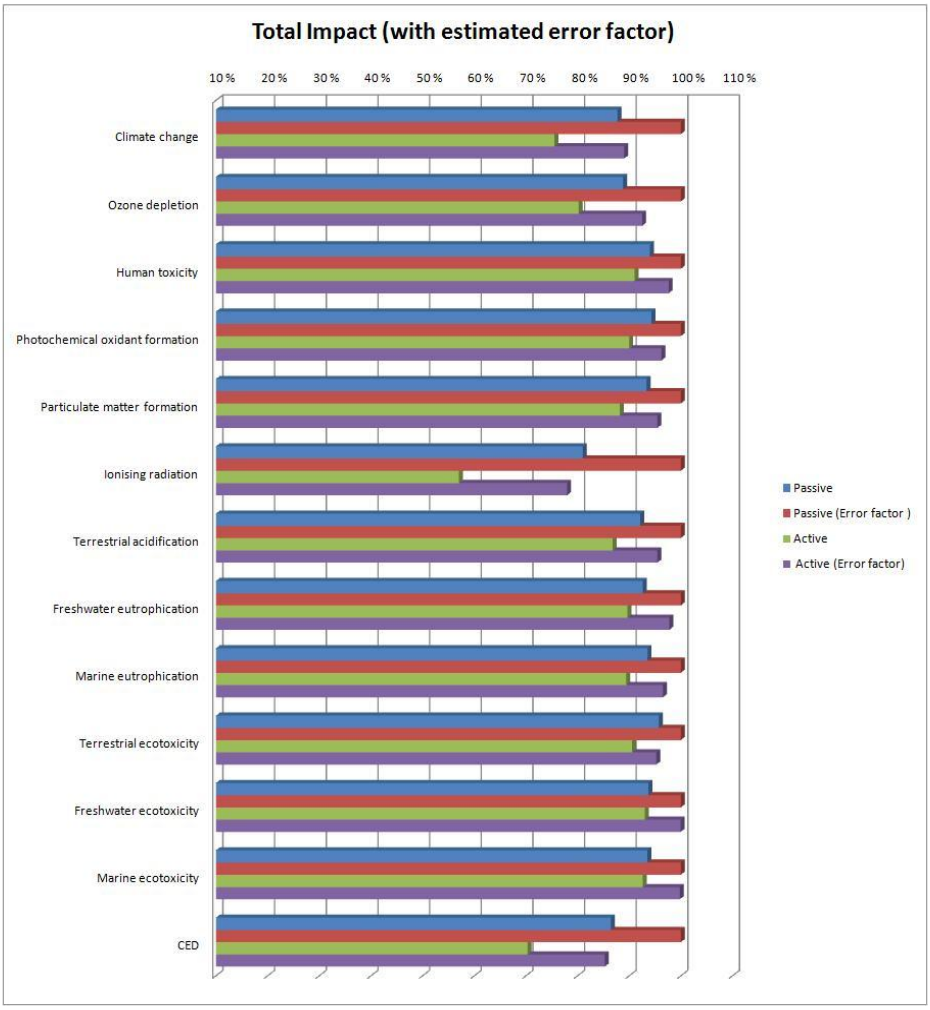
Graph 10 Impacts from different electricity mixes

5.2 Impacts inclusive of Error factor

Most of the lifecycle results of the various buildings that have been carried out previously in Norway have used results based on energy simulations, which often under-estimate the operational energy use of buildings. This is more often due to several reasons:

- Operational use is resident/user dependent.
- Technical errors- small construction errors can lead to high air leakage
- Exceptionally low temperatures – (Weather in the northern latitude is highly variable and can often have spells of severe winters (eg.2010)
- Inefficiency of installed renewable sources of energy (solar collectors could be ineffective due to bad weather or choosing space heating with electricity, over wood even in extremely cold temperatures).
- Rebound effect- assuming the energy required for heating is lowered; residents often increase energy consumption for domestic hot water and appliances.

Recent studies on the LCA of multifamily buildings at Løvåshagen, Karlstad and Lindås, built on passive house standards installed with solar collectors prove that actual energy consumption is significantly higher than simulated (2; 56; 57). The estimated error of each of the studies is of the same range for low energy houses to about 26-28%. Hence in this particular case the estimated error percentage in operational energy was added to the case and the case control study, to estimate the effect on total impact.



Graph 11 Impacts with estimated error factor

The impact with the estimated error in operational energy as expected is much higher especially in the categories where the electricity from grid largely contributes to the impact; such as Climate change, Ionizing radiation and Cumulative energy demand. The impact differences are about 15%-20%. A summary of the total impacts per m^2 of HFA has given in the table below.

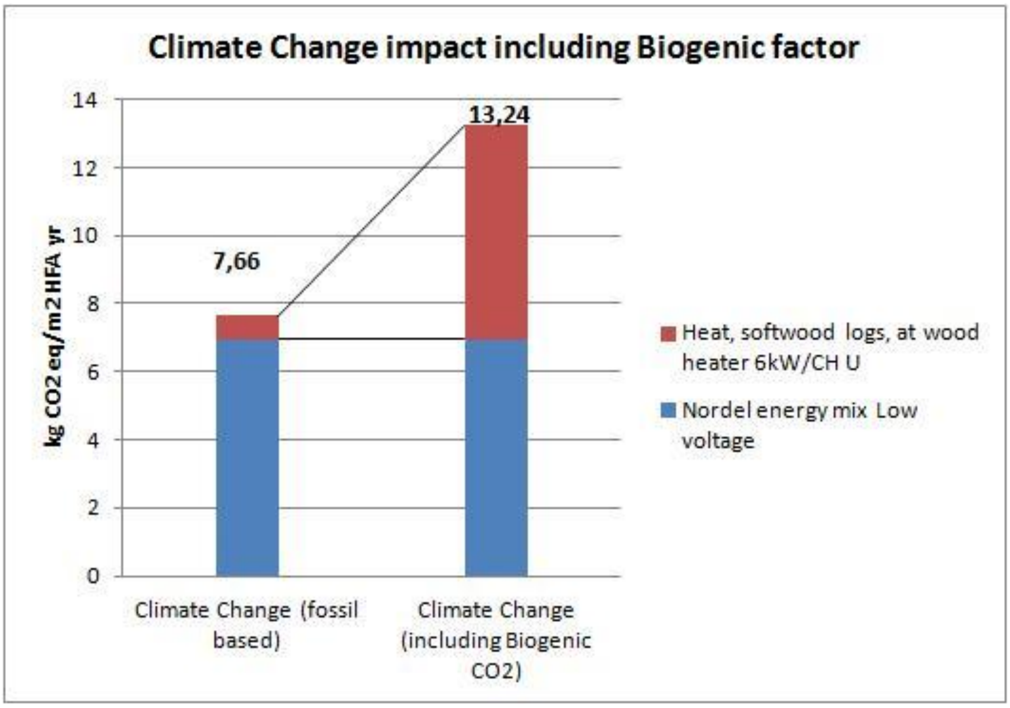
Table 13 Impacts based on simulated energy and estimated error (per m2 HFA/60 years)

	Passive		Active		
	Simulated	(with Error factor)	Simulated	(with Error factor)	Unit
Climate change	1246,19	1420,10	1072,54	1264,25	kg CO2 eq
Ozone depletion	1,01E-04	1,14E-04	9,12E-05	1,05E-04	kg CFC-11 eq
Human toxicity	1874,83	1994,52	1815,77	1947,70	kg 1,4-DB eq
Photochemical oxidant formation	6,35	6,73	6,05	6,48	kg NMVOC
Particulate matter formation	4,00	4,28	3,77	4,08	kg PM10 eq
Ionising radiation	1363,64	1683,24	960,17	1312,49	kg U235 eq
Terrestrial acidification	5,92	6,42	5,58	6,13	kg SO2 eq
Freshwater eutrophication	7,80E-01	8,42E-01	7,55E-01	8,23E-01	kg P eq
Marine eutrophication	3,38E-01	3,62E-01	3,23E-01	3,49E-01	kg N eq
Terrestrial ecotoxicity	4,12	4,30	3,90	4,10	kg 1,4-DB eq
Freshwater ecotoxicity	18,75	20,01	18,61	20,00	kg 1,4-DB eq
Marine ecotoxicity	20,46	21,88	20,27	21,83	kg 1,4-DB eq
CED	53459,91	61837,64	43499,44	52734,76	MJ

5.3 Effect on Climate change (including biogenic factor)

The above results, for Climate change include only the carbon emissions from fossil fuel sources. Traditionally, carbon emissions from wood combustion have been assumed climate neutral, i.e. the CO_2 released from biofuel combustion approximately equals the CO_2 sequestered in biomass (58). This is a widely accepted principle in lifecycle assessments of bioenergy systems hence neglecting its contribution to Climate change before being recaptured by biomass regrowth. Methodology to quatify CO_2 emissions from biomass combustion is being researched upon by LCA practitioners (58). Combined accounting of biogenic CO_2 with existing CO_2 stock is important as it can have significant impact on the total GHG emission.

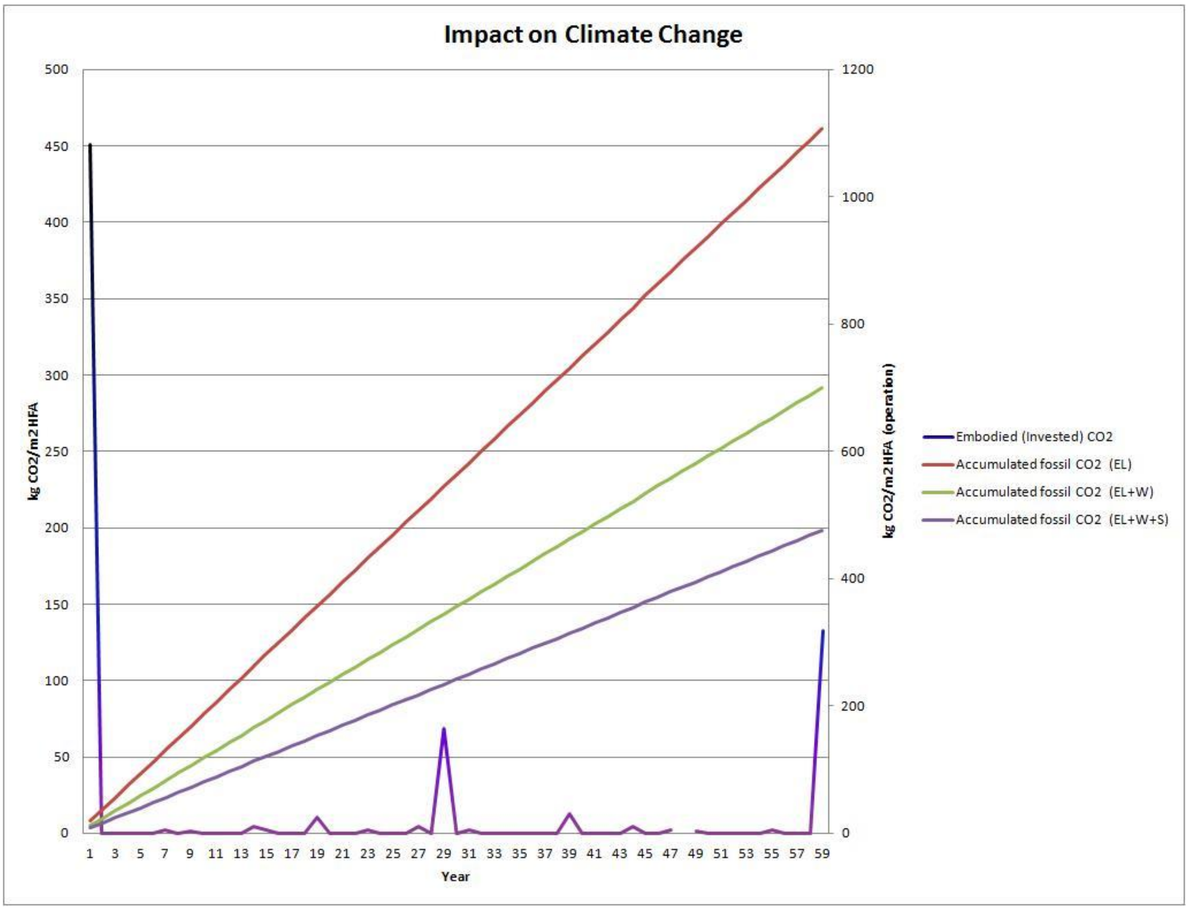
This factor is of relative importance in our case study, as 31 percent of the energy used in our case is assumed to be from wood used for space heating. It is approximated that the building requires 960 kg / year of wood to provide around 4000 kWh of energy. The wood process chosen is the generic Simapro process 'Heat, softwood logs, at wood heater 6kW/CH U' which includes 12,7g CO_2/ kWh of heat produced. This is a fairly low score and includes only the fossil based CO_2 from lumbering and transport. To calculate the biogenic global warming potential, the fossil based CO_2 is multiplied by factor based on the rotation period of the wood source. Since the wood available in this case is from Norwegian forests which have a rotation cycle of 100 years, the factor it needs to be multiplied by is 0,43 based on the calculation model provided in a study by Cherubini., et.al (2011). The graph below shows the difference in the CO_2 released per m^2 HFA of the Active house operation in a given year.



Graph 12 Increase in Climate change impact with biogenic factor

The impact to climate change during the operation of the building is 13,24 kg CO_2 eq/m^2 of HFA which is approximately 42 percent more than impact only from fossil based CO_2. Even though these carbon emissions are assumed to be sequestered from the existing growth of certified forest cover, the impact of biogenic CO_2 is often neglected.

An overview of the total carbon emissions of the building has been given in the graph below. The graph gives an estimation of the amount of CO_2 emitted during the different phases of construction, maintenance and end of life treatment. This is considered as the invested CO_2 emissions. The figure also includes the accumulated carbon emissions released over the operational phase with time. The focus of investment on low-energy house is the reduce energy demand which in consequence would lead to lower emissions. The graph reflects the carbon impact only of the Active house (case control Passive not included).



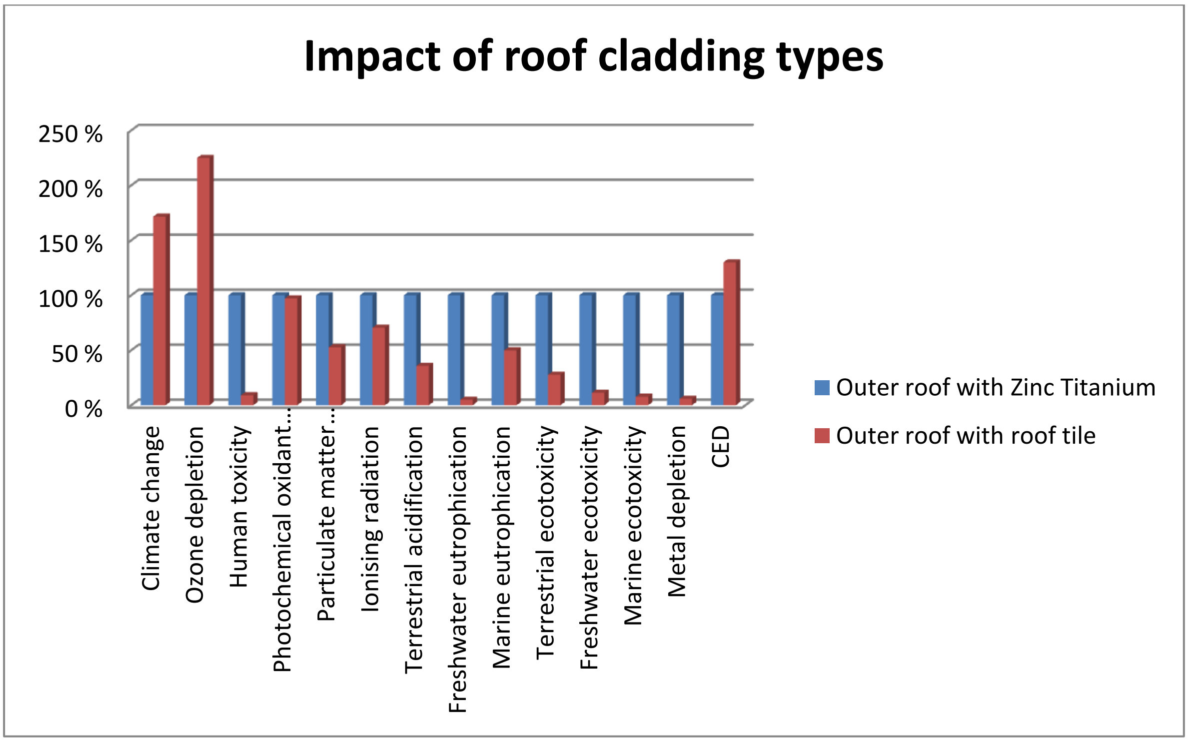
Graph 13 Embodied and Accumulated carbon emissions

The invested carbon impact is highest during construction about 450kg CO_2/ m^2 HFA. The carbon emission also peaks around the 30th year to about 70kg CO_2/m^2. This is due to the replacement of the solar heating system as it expires its lifetime. Replacement of roof windows every 20 years contributes 730 kg CO_2 each time. The demolition and end of life treatment contribute to 140 kg CO_2 eq/m^2 HFA.

The accumulated CO_2 trends are given for the three sources of delivered energy. Undoubtedly the maximum emissions are from energy coming straight directly from the grid. The accumulated CO_2 with only electricity consumption is 1106 kg CO_2/m^2 HFA. When some energy for space heating is substituted with use of wood for heating the accumulated fossil based CO2 is 699 kg CO_2/m^2 HFA. With on-site production of energy with the help of solar collectors, the emission is further reduced to 475 kg CO_2/m^2 HFA.

5.4 Impact of specialized roof cladding

An interesting constructional feature of the house is the roof cladding. Instead of the conventional use of roof tiles, this house uses an alloy of zinc titanium. Zinc titanium cladding is beneficial particularly because it requires no maintenance and has a lifetime of 60-70 years (48). The cladding sheets are light, durable, corrosion resistant and completely recyclable. The alloy is particularly made of fine zinc, with additives of titanium, aluminium. Though the production requires reasonable energy input, the data for this material was obtained from the EPD produced by the manufacturer whose claim is that energy consumption is kept low during extraction and smelting (59). This was compared with the generic data on roof tiles which are conventionally used and require refurbishment after 30 years. Conventionally roof tiles are primarily made of clay, limestone and some reinforcing metal (steel) and plastic. Another impact contributing factor to both kind of roof types are is transport. Zinc titanium is produced in Germany and hence needs to be imported while roof tiles are locally manufactured. In the calculation, the roof cladding with zinc titanium has been installed once, and the outer roof with tiles is installed twice in the entire lifetime. The impact results of the roof have been normalized to 1 m^2 surface area of the roof of the Active house with zinc titanium cladding for easier comparison.



Graph 14 Impacts of different roof cladding material

It is observed that in comparison to the impacts given more weighting – the contribution of roof tiles is higher, such as Climate change by 70%, Ozone depletion by 124% and cumulative energy demand by 30%. However, in the case of almost all other impacts the contribution of zinc titanium cladding is higher especially in human toxicity as well as fresh and marine water ecotoxicity where the impact of zinc cladding is higher by 89-92%. Contribution to particulate matter formation and marine eutrophication is 50 % more in case of zinc titanium cladding. Another relevant impact category in this case is metal depletion. The roof with zinc cladding uses 746 kg Fe eq of metal, while the roof with tiles uses only 43 kg. Metal procurement can be large contributor to other impacts.

6 Sustainibility scoring

Building sector is projected to have has the largest potential for reducing climate change impacts. Sustainibility moderators of modern buildings such as BREEAM(UK), DNGB (DE) and LEED(USA) are the forerunners of driving life cycle assessments in the building industry. These standardization measures are widely recognized as they provide a holistic approach to the building's environmental performance and score them on a broad range of categories. They include a broad energy use, health and well-being, material use, waste, transport and management processes.

BREEAM is a UK based international standardization system for sustainable buildings and rapidly being adopted in Europe.BREEAM NOR is Norway's first engineering, auditing and grading method at the building level (60). It follows the same standard methods of BREEAM UK, but developed and tailored to the Norwegian market. It has been launched since 20 October 2011 by the Norwegian Green Building Council. BREEAM uses a straightforward scoring system that is transparent, flexible and easy to understand , supported by evidence-based science and research. BREEAM rewards credits to various aspects of building performance. Currently BREEAM NOR is focussed only on commercial buildings. Hence the information presented here is based on BREEAM UK- Code for sustainable homes (61). The assesses criteria are given below:

- Energy: operational energy and carbon dioxide (36,4%)
- Health and Wellbeing: indoor and external issues (noise, light, air quality, etc) (14%)
- Materials: embodied impacts of building materials, inluding lifecycle impacts like embodied carbon dioxide (7,2%)
- Management: site management and procurement (10%)
- Water consumption and efficiency (9%)
- Surface water run-off (2,2%)
- Waste: construction resource efficiency and operational waste management and minimisation (6,4%)
- Pollution: external air and water pollution (2,8%)
- Ecology: ecological value, conservation and enhancement of the site (12%)

The total number of credits gained in each section is multiplied by an enviromental weighing factor (given in parenthesis) . The section scores are added together to produce an overall single score. The overall score for a building is tranlated into a scale of:

Table 14 BREEAM ranks and required percentage points

Scale	Total Percentage Points Score (equal to or greater than)
Unclassified	36
Pass	48
Good	57
Very Good	68
Excellent	84
Outstanding	90

A BREEAM scorecard as shown in Appendix E, ensures the building performance during the design as well a post construction phase. This necessciates the required functioning of the building during the building lifetime.

BREEAM certifications can be given only by authorized BREEAM auditors. However, with the basis of the available information on the current case study, an attempt has been made to evaluate the house on the three high weighed categories to provide a sustainibility score. **This is only a trial score based on BREEAM based Technical guide and should not be used for commercial purposes.** Each category has several sub-sections which provide a credit point.

The three main chosen categories are:

Table 15 Scoring categories

Scoring Categories	Total Credits	Weighting Factor (%)	Approximate Weighted Value of each credit
Energy and CO_2 emissions • Dwelling emission rate • Fabric Energy efficiency • Energy display devices • Drying space • Energy labelled white goods • External lighting • Low and zero carbon technologies • Cycle storage • Home office	**31** 10 9 2 1 2 2 2 2 1	**36,40**	**1,17**
Materials • Environmental Impacts of materials • Responsible sourcing of materials- basic building materials • Responsible sourcing of materials- finishing elements	**24** 15 6 3	**7,20**	**0,30**
Health and Well being • Daylighting • Sound Insulation • Private Space • Lifetime homes	**12** 3 4 1 4	**14,00**	**1,17**

6.1 Energy scoring:

Energy scoring is particularly based to recognise and encourage building designed to minimise operational energy demand consumption and CO_2 emissions. The definitions of each of the contributing issues have been taken from the UK based –Code for Sustainable homes and the calculations for the credits have been fit in the Norwegian context.

6.1.1 Dwelling Emission Rate

Emission arising from the operation of a dwelling in a year. Credit value is based on % improvement from the current building standard (in this case TEK2010). The CO_2 emission calculation also accounts for CO_2 emission offset from additional sources of delivered energy and residual CO_2 from biofuel. The calculation model is given in the Appendix F-1. The Active house releases 7,66 kg CO_2/m^2 /year, while the TEK 10 house releases 24,16 kg CO_2/m^2/year. Hence, the improvement of the Active house is 69% above the current building standard. Hence it earns 7/10 credit points.

6.1.2 Fabric Energy Efficiency

Energy demand for space heating and cooling expressed in kWh/m^2/year. Credits are awarded when all the mandatory requirements are met. The Active house follows all the mandatory requirements for a low energy house based on NS 3700:2010 using 38,5 kWh/m^2/year (Appendix F-2). Hence it gets the complete score.

6.1.3 Energy display device

Credits are based on empowering dwelling occupants to reduce energy use. This is done by electricity and/or primary heating fuel consumption data are displayed to occupants. The Active house has an installed KNX control system connected to switch boards which make the occupants conscious of the temperature and power use as well as current emissions. Hence, the building gets 2 whole credits.

6.1.4 Drying space

Credit based on provision of internal or secure external area drying clothes- capable of holding 6 m of drying line.Fittings/ fixing should be a permanent feature of this space. An internal unheated area is also acceptable where it confirms that the ventilation is adequate to allow normal climatic conditions and prevents condensation or mould growth. Such an area is unspecified in this building. Hence it does not earn a credit.

6.1.5 Energy labelled White goods

All technical equipment should be certified with A+ rating for fridges and freezers, while A rating for Washing machines and diswashers based on the *EU Energy labelling scheme.* In case white goods are not provided but EU energy efficiency labelling information is provided to each dwelling a credit point is awarded. The Active house recommends use of only energy efficicient goods, though it is not provided with the building. Hence it get 1 credit point.

6.1.6 External Lighting

Provision of energy efficient external lighting with appropriate control system including both space and security lighting. All lighting equipment used for the Active house is using LED bulbs. Hence gaining 2 credits.

6.1.7 Low and Zero Carbon technologies

Encouraging the use of energy sources with low or zero carbon emissions and running costs. Depending on 10-15% reduction of CO_2 emissions with this investment provides 1-2 credits respectively. The Active house uses solar collectors to substitute an essential amount of energy requirement. Proper functioning of solar collectors under full efficiency can providea CO_2 reduction of upto 20%. Hence , the Active house gains 2 credits.

6.1.8 Cycle storage

Provision of wider use of bicycles as transport by providing adequate secure cycle storage facilities, hence reducing need for short car journeys. This should include The Active house has a double garage space- with adequate space for a car and 3-4 cycles. Hence, gaining 2 credits.

6.1.9 Home Office

To promote the occupants with necessary space and service to work, thus reducing the need to commute. The space for home office must have adequate ventilation and achieve an average daylight factor of 1,5%. The Active house has a space reserved for workplace on the first floor with the necessary requirements. Hence gaining another credit point.

Table 16 Scores obtained from Energy category

Scoring Categories	Total Credits	Awarded Credit
Energy and CO_2 emissions	**31**	**27**
• Dwelling emission rate	10	**7**
• Fabric Energy efficiency	9	**9**
• Energy display devices	2	**2**
• Drying space	1	**0**
• Energy labelled white goods	2	**1**
• External lighting	2	**2**
• Low and zero carbon technologies	2	**2**
• Cycle storage	2	**2**
• Home office	1	**1**

6.2 Material Scoring:

Material scoring necessciates the use of building materials with lower environmental impacts over their lifecycle. Material specifies the requirement for an Life cycle assessment (though it is currently carried out in BREEAM approved template tools- Envest2® from BRE, ATHENA® EcoCalculator, ATHENA® Impact estimator, Eco-Quantum from IVAM and Equer from Ecole des Mines) . It also enforces the use of a minimum number of building products with Environmental Product Declaration and Eco- labelling.

6.2.1 Environmental Impacts of Materials

There are 15 credits that can be awarded in the key elements of the building. In the UK-based code credits are awarded if atleast mandatory building elements have achieved a GreenGuide rating of A+ to D (62). This rating is based on certified environmental profiles which are further based on product LCAs. Each rating awards certain number of credits as shown in Appendix F-3. It is mandatory that three of the elements of the building envelop achieve the requirements of the guide. The mandatory requirement applies to 100% of the area.

With the LCA already carried out of the Active house, it is possible to the results of the various framework of the elements to the framework requirements of the Green Guide (63). However, this is a bit difficult because the framework of the UK guideline are from 2008, where some elements come with lower embodied emissions, while higher user phase emissions. Norwegian standard for U-values is relatively much lower than UK standards. Hence, the credits are only comparative.

Table 17 Total score on material impact based on LCA results

Category	Rating	Credit
Foundation	D	0,25
Seperating Floor	A	2
Floor Finishes	A	2
External Wall Construction	A+	3
Roof Construction	A+	3
Windows	A	2

6.2.2 Responsible sourcing of Materials- Basic Building Elements

To promote the responsible sourcing for the materials for basic building elements such as the frame, floors, roof, walls, etc, where 80% of the assessed materials in building elements are responsibly sourced. This necessciates, the availability of evident documentation for recycled and reused productsfor every material. This stresses on product declarations. This category has a maximum of 6 credits which are given based on the points earned from the source of the material for each element. The credit structure is given in the Appendix F-4 .This requires detailing of the supply chain for each element however based on the available EPDs for the materials used for the Active house, the scores are given:

Table 18 Total score on basic material scoring

Category	Points
Foundation	2,5
Floors	5
Walls	4
Roof	3
Windows	4

In the assessed five elements, the total points scored based on the source of materials is 18,5 which gives it a complete credit of 6. This is particularly because the house is made of timber and all of it is sourced from local FSC certified forests.

6.2.3 Responsible sourcing of Materials- Finishing elements

To promote the responsible sourcing for the materials for finishing building elements such doors, staircase, skirting, panelling. This category can provide a maximum of 3 credits.The Active house is completely based on timber (Chipboard, MDF, treated particle board are assessed as timber).

Materials accounting for less than 10% by volume (such as screws, addhesives, additives) are excluded. Scoring this section has been difficult and broader than the others. It is known that the finishing material is all timber, and many of the products such as door and staircase are factory manufactured to limit waste. However, there is no knowledge of use of recycled material or the availability of certification.

Considering all the material for the finishing elements is virgin timber from certified forests as well as other products such as glass and metal for doors are from primary source, the building gets a credit point of 2/3.

Table 19 Total score obtained in Material category

Scoring Categories	**Total Credits**	**Awarded Credits**
Materials	**24**	**20,25**
• Environmental Impacts of materials	15	**12,25**
• Responsible sourcing of materials- basic building materials	6	**6**
• Responsible sourcing of materials- finishing elements	3	**2**

6. 3Health and Well-Being Scoring:

Health and wellbeing is a highly weighed criterion as it enforces to promote the quality of life, even with the reduction of energy consumption. This category focuses on daylighting, acoustic insulation, availability of private space in the building design. Overall credits earned from this criterion are 12.

6.3.1 Daylighting

This issue promotes good daylighting and reduces the energy for lighting the home. The assessment suggests the minimum average daylight factor for the kitchen is of at least 2 %. All living rooms and dining rooms must achieve an average daylight factor of 1,5%. 80% of the working plane (including kitchen, living room, dining room and study/home office) must receive direct light from the sky. Based on figure () the average daylight factor of the living space (including kitchen and study) is 3,7%-8,3% average. Hence it gets all the 3 credits.

6.3.2 Sound Insulation

To promote the provision of improved sound insulation to reduce the likelihood of noise complaints from neighbours. This issue can provide a maximum of 4 credits if the airborne sound insulation values are at least 8dB higher and the impact of sound insulation values are at least 8dB lower. By default detached dwellings gain 4 credits.

6.3.3 Private Space

This issue aims to improve the quality of life by promoting the provision of an inclusive outdoor space which is at least partially private. It should be of a minimum size that allows all the occupants to use this space. The auxiliary area of the Active house has been particularly designed keeping this in priority. Hence, the building earns another credit.

6.3.4 Lifetime Homes

This issue promotes the construction of homes that are accessible and easily adaptable to meet the changing the needs of current and future occupants. Lifetime homes were developed by the Habinteg Housing Association by Joseph Rowntree Foundation and the Helen Hamlyn Foundation in the early 1990’s. The code incorporates 16 design features that create a flexible blueprint for accessible and adaptable housing for the occupants. The purpose of this Code is not to deliver housing for designed for wheelchairs but a wide population (inclusive of aged people) to enable everyone to participate equally and independently in everyday activities. The specifications of Lifetime homes are available at- lifetimehomes.org.uk (64). Each of the criteria is mentioned briefly in the Appendix F-5.There are 16 criteria to be fulfilled, which earns the building a total of 4 credits. An exemption from the criteria 2 and/or 3 can give the home 3 credits but all other criteria must be compiled with.

The Active house is designed with enough space making it flexible to be used by all age group. Hence, it gains the 4 credits.

Table 20 Score obtained in Health and Well-being category

Scoring Categories	Total Credits	Awarded Credits
Health and Well being	**12**	**12**
• Daylighting	3	**3**
• Sound Insulation	4	**4**
• Private Space	1	**1**
• Lifetime homes	4	**4**

6.4 Total Score (3 chosen categories)

Based on the total credits awarded in the 3 categories, the scores are as follows:

Table 21 Total BREEAM score on basic categories

Categories	Obtained Score	Maximum obtainable score
Energy and CO_2 emissions	31,5	36,27
Material	6,015	7,2
Health and Well-being	14,04	14,04

Covering categories which contribute 57% of the weighting in BREEAM certification, the Active house has a total score of 51,5. This is a very good score, and establishes that the Active house has the minimum requirements for a BREEAM certified building. But the BREEAM performance of the house cannot be judged on this score alone as the house has not been assessed in the 6 other categories due to lack of information and accessibility. Certain categories such as waste generation and water use have not been assessed- these require some post- construction data. High performance in some categories can also have trade-offs in other categories. For example- the use of wood for space heating can help in gaining credit in the energy category; however reduce credit scores for NO_x emissions. Hence it is impossible to gain a 100 percent score.

7 Discussions:

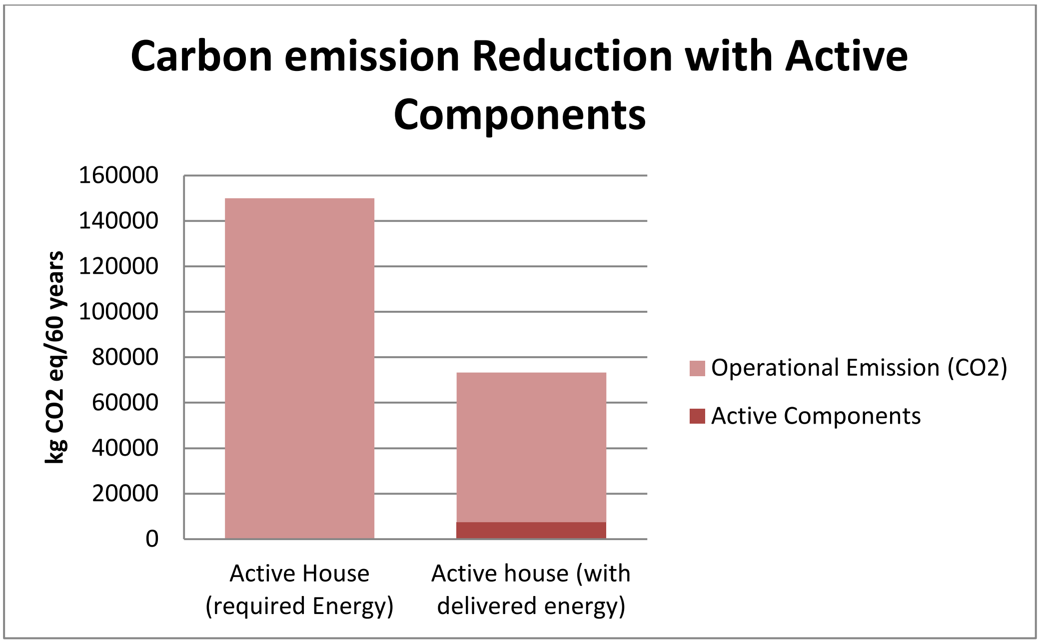
The primary aim of this study was to determine the environmental performance of the Active house based on Lifecycle analysis; this was followed up by scoring the same house on Green sustainability measure. The impact from construction design of an Active house is relatively higher than an equivalent Passive house which is already material intensive and yet requires more energy for space heating due to heat loss by extensive glazed surface. On the other hand, it provides the benefit of supplementary energy for domestic water heating and reducing the level of impact. If the equivalent Passive house is installed with solar collectors, it would also have a good environmental performance as it reduces the impact from the most contributing factor. Based on the obtained results from the LCA and the sustainability score, a discussion has been presented in the following chapter.

7.1 Environmental Performance

The Lifecycle Assessment of the Active house, shows that it has about 10% and >20% higher impact than an equivalent Passive house in the construction stage and maintenance stage respectively. The impact during the end of life is about 2-5% higher. However, the most important contributing in every impact is the operational phase. Higher requirement of energy during the operational phase, contributes to 60%-90% in all categories. Based on the construction structure of the Active house, the operational requirement is higher than an equivalent Passive house and hence contributing to higher impact than the Passive house by 10% in totality.

7.1.1 Impact from energy

The increased impact of the Active house during the construction and maintenance phase is due to the additional material input. The additional inputs of windows increase the requirement of energy especially for space heating; on the other hand installation of solar collectors helps in reducing the energy requirement, particularly for domestic water. The analysis based on the delivered energy in the operational phase suggests that impacts in the operational phase of the Active house are reduced by 10-15% in several categories. As mentioned, the source of energy plays an important role in the total environmental impact. It is observed that though there is significant lower contribution of the Active house towards Climate change, Cumulative energy demand and Ionizing radiation. The impact difference is minimal towards terrestrial acidification, fresh and marine water ecotoxicity. This is because major contributions to these impacts are from stressors of burning wood for energy which is used in as a common heat source in both cases. It is interesting to note that the total embodied carbon emissions of the Active components are only 5% of the total carbon emissions in a lifetime. On the other hand, they contribute to reduce the lifetime emissions by >50 percent. The graph () demonstrates this comparison.



Graph 15 Amount of carbon emission reduced over lifetime

7.1.2 Impact from Building elements

The contribution of construction to most impact categories can range from as low as 5% in terrestrial ecotoxicity to 70% in fresh water eutrophication. An active house has 9-10% higher impact than an equivalent Passive house in the construction phase.

The highest impact contributing factor building elements towards ozone depletion, particulate matter formation, photochemical oxidation and terrestrial ecotoxicity are the basic elements for the foundation, floors and walls. The foundation and the floor are based on the use of concrete and expanded polystyrene which contribute 20-40% respectively towards ozone depletion, particulate matter formation and photochemical oxidation. The basement walls are made of Leca blocks which are energy intensive and hence have a high contribution towards ionizing radiation. Use of glasswool in the walls contributes around 40% of the impact towards ozone depletion, 30% towards particulate matter formation and 26% towards photochemical oxidation. The walls also have a high contribution towards terrestrial ecotoxicity- this is due to the use of treated wooden elements such as I-studs, cladding timber and particle board. Use of gypsum board also has a high contribution towards terrestrial acidification. Gypsum boards have been used for walls, floors and the ceiling. The impact from gypsum board can be lowered if it is disposed in an inert landfill rather than sending it to a sorting plant as assumed here (4).

Another essential impact contributing building element analyzed in this study is the roof cladding made of zinc titanium. This roof definitely has longer longevity compared to other types of roof cladding and also lesser impact to Climate change and other energy intensive impact categories. However, the impacts on ecotoxicity and eutrophication of fresh and marine water as well as terrestrial acidification are considerably high. Processes contributing to more than 5% of the impacts to fresh and marine water eutrophication are given in the Appendix A1 and A2. 60-80% contribution to these impacts is during the metal beneficiation, when the extracted ore is separated into mineral and gangue.

Impacts of electrical and plumbing fittings have very high impact towards fresh and marine water eutrophication as well as fresh and marine water ecotoxicity. The single most contributing stressor to this is the abundant use of copper wires. The Active house has additional electrical fittings as it has a control mechanism installed which senses the indoor temperature and air quality as well as controls the windows. Copper use is solar collectors is also extensive, which contributes to higher impacts in all categories.

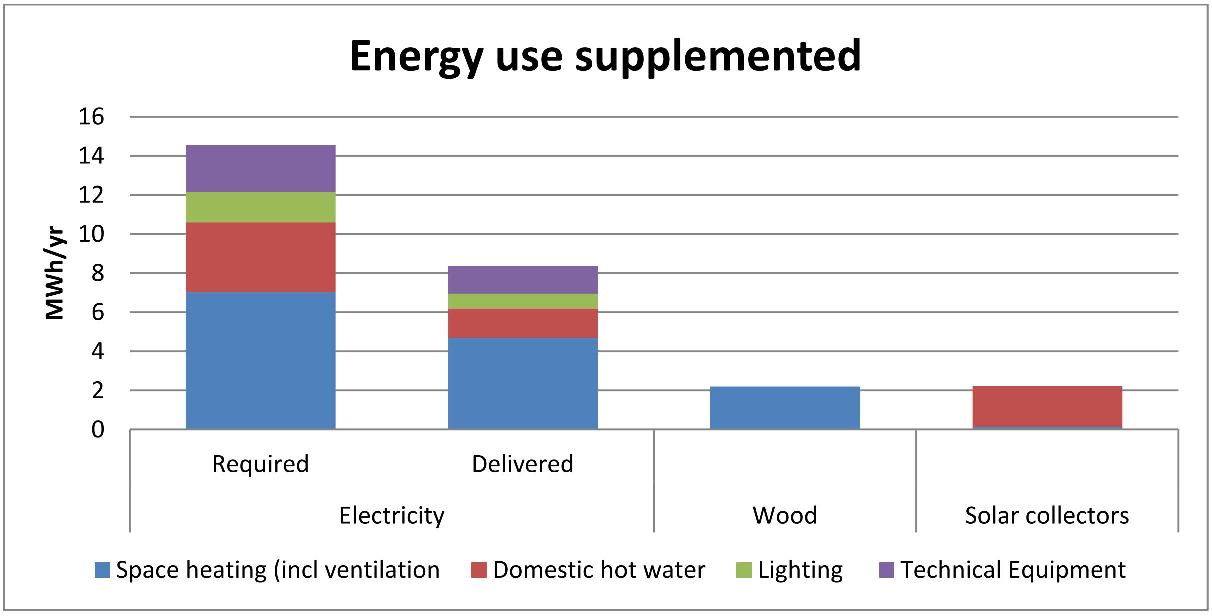
Surface finish contributes 5-10% of most impacts, but nearly 20%-30% towards marine eutrophication. This is due to relatively high maintenance rate required for painting. Outdoor painting can be done for two purposes a) maintenance of cladding and b) aesthetic purpose. Research towards producing paint which lasts long enough, providing the required aesthetic value even under harsh climatic conditions is currently being carried out at Sintef Byggforsk. Proper maintenance of wet areas such as the bathroom with good ventilation preventing excessive moist can promote the longevity of the bathroom surface preventing mould formation.

The increase in glazed surface increases the impact up to 2% in all categories, but the glazed surface of the roof windows have a lower lifetime and need a replacement every 20 years. This adds 15% impact during to the maintenance phase and hence contributing to the increase of environmental impact by the Active house.

Impacts in the construction phase can be reduced by choosing localized materials and emphasizing on building materials with product declarations, which focus on reduced energy use as well as considerable recycled or reused material.

7.2 Energy Performance

Energy performance of the various sources is extremely important in determining the total lifecycle impact. The Active house uses an interesting combination of several heating sources as well as harnesses the use of solar based design. Certain assumptions have been made to determine the energy performance of the Active house. It is considered that the house uses 960 kgs of wood to substitute space heating in the winter months which contributes to 31% of the total annual energy demand; meanwhile 30% of the annual energy demand is substituted by solar collectors. The Passive house uses the same amount of wood which contributes to 34% of the annual energy requirement. The rest of the energy is obtained from electricity from the grid. The Active house also has additional benefits of increased daylighting, which reduces the annual demand for lighting the house to 5,6 kWh/m^2, which is a reduction by 51% than the standard. The graph () shows that based on the construction design and standard, the Active house requires nearly 14MWh of operational electricity, however the compensation by supplementary sources reduces the direct need of electricity to about 8MWh.



Graph 16 Amount of energy supplemented with Active elements

The energy performance of every building is also extremely resident/user dependent. The construction detailing of low energy houses does help in reducing the energy requirement for space heating but often residents tend to use more energy for other facilities such as lighting or technical equipment. Hence the impacts have been calculated for the Active house using an error factor based on operative performances of similar passive or low energy houses. The impact difference based on simulated energy in addition to approximated error factor suggests that the impact of both the Active house or the equivalent Passive house increases by 15%.

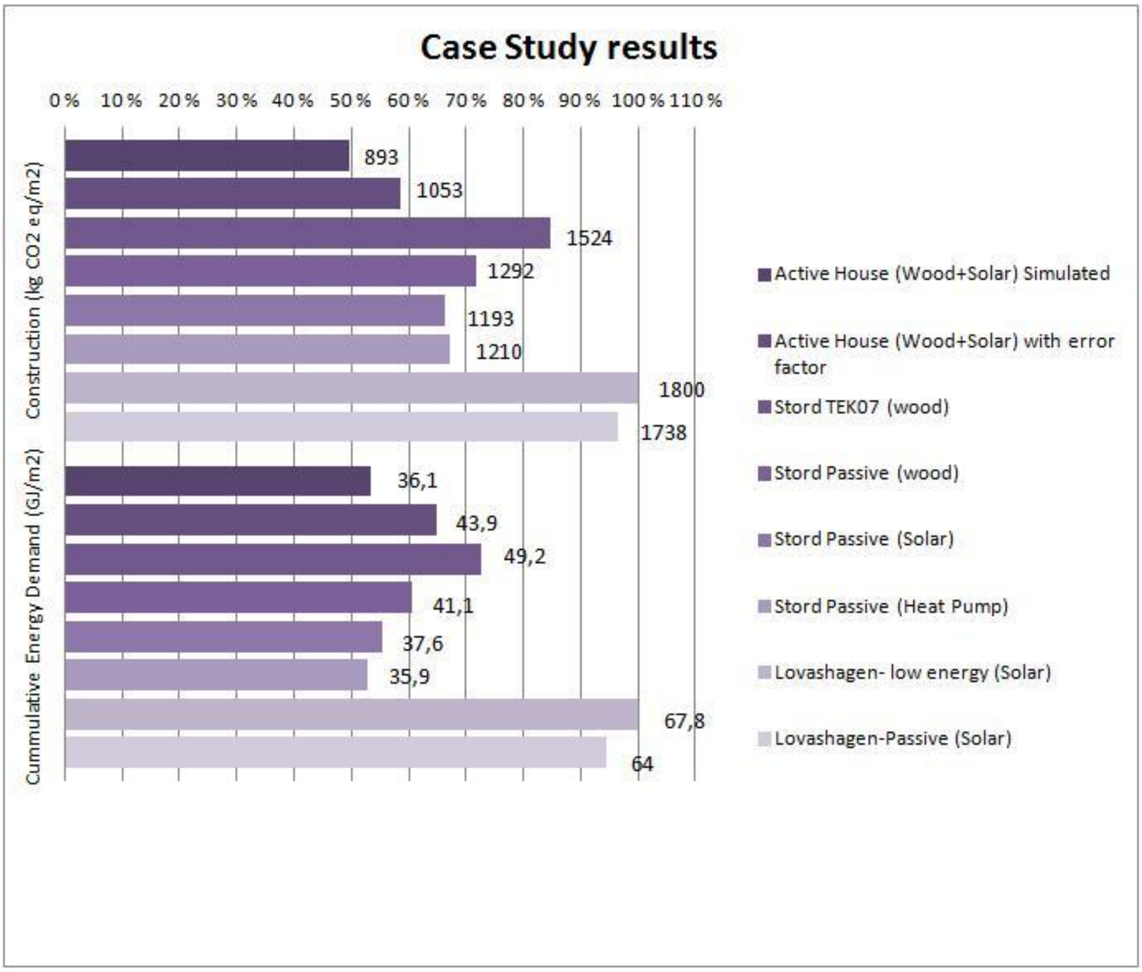
7.3 Total sustainability performance

A better environmental performance of a house is dependent on several factors, though material use and sourcing as well as operational energy source are the primary factors influencing it. Studies based on dynamic data of energy use of buildings suggest that residents often use more energy than simulated for passive or low energy houses probably due to lack of awareness or construction errors (2). There are often other sources of environmental impact, such as waste generation, excessive water usage, poor indoor air quality- etc. Resident comfort is also an inherent part of building design. A building needs to be designed to cater to the well-being of the resident. It is necessary to make the resident aware of the best way to use the building. Hence, there are green certification modules such as BREEAM being introduced which monitor a building during the design phase as well as post-construction to ensure that buildings function as they have been assessed for.

The scoring for the Active house has been done for 3 out of 9 categories based on the code of sustainable homes for BREEAM. Based on the credits scored by the Active house it definitely passes as a BREEAM house, in the most weighed categories of operational energy and associated emissions, material and design on well being. The Active house scores complete credits based on the requirements for health and well-being. This category focuses on necessary daylighting, provision of personal space as well as design to house which suits to the adaptability of a wide spectra of age-groups. Providing credits for energy and associated emissions was easier with the help of energy simulation data as well as the LCA results. Further energy credits were also based on the design of the household for the provision of spaces for drying, cycle storage, and encouraging purchase of energy efficient technical equipment. Type of equipment/material chosen can influence the indoor air quality in several ways, for instance use of panel heaters can usually lead to burning of accumulated dust or carpeted floors harness dust, which are sources of discomfort. Credits for material was more challenging as the LCA of the various components of the Active house had to be compared to UK based LCA record of building elements, which might have different values as they have different system boundaries. Since, the Active house has a timber based framework; it has a better performance than several other building material choices. Also wood is a locally available product in Norway and assuming that most of it is sourced from local sustainably managed forests; so the active house earns more credits. This score is relatively broad. However it needs to be assessed in the categories such as management, operational waste management, water use and pollution.

7.4 Comparisons with other Case studies:

Comparisons of impacts from previous LCA studies (4; 1; 2)of Passive houses in Norway, installed with different sources of renewable energy have been presented here. The first two studies are for single family houses in the same geographic location (Stord) , constructed on the TEK 07 standard using electricity and wood as the source of energy; the other house is a Passive house, constructed in the equivalent design as the TEK07 which has been analyzed under three heating systems- 1) electricity and wood, 2) electricity and solar collector and 3) electricity and heat pump. The size of both the houses is 187 m^2. The operational phase for the Stord house has been estimated using SIMIEN 2.0. The third study is based on LCA of multi-family residence apartments at Løvåshagen. The apartments are divided in low-energy and passive houses. Both the apartment types use electricity and solar energy. The aggregated HFA for these apartments is 6475 m^2. The operational energy for the Løvåshagen apartments has been measured on site. The system boundaries for each of these cases are similar as they have been taken from previous theses. However, all the three cases have been analyzed for 50 years. Hence, the Active house impact has been reduced to 50 years. The Active house is compared with both the simulated value as well as with an error factor. The comparison is based on total climate change impact and total cumulative energy demand. A normalized graph based on impact per m^2/ HFA is presented below:



Graph 17 Comparative impacts of previous case studies

It is interesting to note that, the impact performance of the Active house is lower than the Passive house at Stord. It is also interesting to note that, the difference in the impact is relatively very small with the use of solar collector or heat pumps. Moreover, heat pumps have a higher invested cost involved (1)which makes it a slightly lesser choice. Heat pumps also have certain limitations especially if the user is unaware. Heat pumps are not very effective in very low temperatures; moving heat from a very cold climate to a mild indoor temperature requires more energy than a milder temperate climate. If residents continue using the heat pump during the harsh winters they will be consuming more energy. The small difference in the low-energy and passive apartments at Løvåshagen suggests that the small constructional difference does not make a large difference in the total impact. It is interesting to note that the impacts in each case are dependent on the size as well. Even if the impacts have been given based per m^2 HFA, the impacts are highest for the cases with larger area in the actual case. This can possibly be due larger space requires higher energy for heating.

7.5 Discussion Closure:

Based on the above discussion results, the Active house can be classified as a low-energy house can have lower environmental impact than a passive house based on certain prioritized assumptions with energy use. Additional material input definitely increases the environmental impact of a building. Potential reduction is possible by responsible sourcing and use of localized material. It is equally important for the choice of material/ equipment used in the building. Certain materials might have lower energy or carbon-based impact but have higher contribution towards ecotoxicity. Certain building materials/equipment also releases stressors such as dust arising from insulation, carpeted floor as well as dust burning in panel heaters or NO_x gases while burning wood in a lower efficient stove which diminish the indoor comfort for residents.

Effect of the constructional design and the construction phase can be largely compensated by efficient energy use. Source of renewable energy is an added advantage to low-energy houses. A building should also be designed to increase user awareness. The Active house has might have increased electrical fittings to arrange a control system for the house, to make the user aware of the indoor air and temperature as well as control the operation of windows. The Active house also benefits the with some design change, providing relative importance to health and well-being, focussing on daylighting and natural ventilation- which are also potentially reduce energy requirement. Care has been taken to prevent over-heating by providing necessary screening and reducing the requirement for cooling. If such installations effectively help the resident to reduce overall consumption, then it is beneficial.

7.6 Uncertainty

There is significant uncertainty within an LCA study due to the several assumptions. The assumptions and related uncertainty are presented in this section. One of the biggest difficulties in estimating data was the absence of detailed drawings or total material requirement. Only basic design drawings were available on AutoCAD 2. The detailed drawings on the framework of the building were obtained on a personal interview with the carpenter of the site. The Active house was compared to an equivalent Passive house with the exact heated floor area, with a few minor changes in the construction- reduction of glazed surface area to 27,2 m^2 from 38,2 of the Active house, also certain approximations in the energy simulation were made which have been elaborated here.

7.6.1 Material Input:

The estimation of material input and inventory was the most laborious task of this project. Unavailability of a detailed material list could be one of the main reasons for the uncertainty in the inventory. However, previous work on the *'Lifecycle Assessment of single-family residence'* by Oddbjørn Dahlstrøm (2011) has provided a detailed inventory for norwegian single family residences built on the TEK07 and passivhus NS3700 standard. This was reasonably helpful to estimate the requirements for a number of processes, once the framework details were obtained from the carpenter. The drawing of the building designs availble on AutoCAD was beneficial to calculate the exact dimesions of the house, though the approximations with the material input is high. Invoices were also available for the material quantities, especially the windoors, doors, ventilation system and solar collectors.

The Ecoinvent database was used as the generic data for this study. Material data for products produced in Norway were adjusted using the Nordel medium voltage energy mix. Materials such as concrete, gravel, reinforced steel and aluminium were assumed to be from local producers. Several products also had available EPD's from their manufacturer such as insulation material from Glava, Leca blocks from Weber(Saint Gobain), and roof cladding with zinc titanium from Rheinzink. Hence, new processes were made from the data available in from these product declarations. The Active house is a timber based house and EPDs based on wood-based building material (except particle board) in Norway have been assessed and generated by the MIKADO project (65). Particle board data has been obtained from the environmental report (2009) of Byggma Forestias factory, which is one of the largest producer of particle boards. This has been further dealt in Oddbjørn's study (4). The material input for for solar collectors was assumed to be as provided by a study by Jungbluth for a regular single family house (51). Though the size of the flat-plate has been altered, the amount of steel and copper used in the pipes have been assumed to be the same.

Data for construction energy as well as fuel use was estimated from provided invoices. The approximations from the invoices also include certain amount of uncertainty as the aggregated monetary amounts were available which were converted to kWh based on the current electricity prices.

It has been estimated that ten percent of the construction material is usually waste based on a study by Monahan and Powell (2010) (43). Waste during construction has also been considered during surface finish and maintenance based on the estimated intervals. The treatment of materials is based on the current statistics of construction waste treatment. The waste treatment is subjected to change, especially with increasing emphasis on recycling and reused construction material, which has not been considered in this study.

7.6.2 Transport:

Impacts from transportation are due to approximate transportation distances were used from the sources of production. Heavy materials such as concrete and gravel were assumed from local manufacturers within 100km. Other products manufactured in Norway were considered at a moderate distance from close to Oslo. Imported materials were all assumed to be from Germany, this might be a liberal estimation for long-distance imported material. Distance to the site of disposal was based on previous report by Avfall Norge (4). Mode of transport was unknown as was estimated to be mainly via 16-32 ton containers based on EURO V (least euro emission category among large good vehicles) and imported material was brought by transoceanic freight. Transportation of workers to the site was not included.

7.6.3 Operational Energy:

Estimating the operational energy has been a challenge and might contain reasonable uncertainty as it has been estimated over a lifetime. The operational energy has been simulated based on the average climatic conditions around Stjørdal. The annual simulation is not reliable for a lifetime of 60 years as the climatic conditions might fluctuate. During the simulation, estimation was also made on the number of hours the house would require heating in different months as well as energy for ventilation (considering use of natural ventilation during summer- about 3 months), lighting and technical equipment. Another approximation is based on the amount of delivered energy from the solar collectors per year. The average value considered here is based on the mean solar insolation/ radiation per m^2 each month which is variable on the number of overcast days. The amount of wood used each year is also an approximate value and is dependent on the resident, cost and availability.

The tight structure of a low-energy or passive house can lead to overheating; this effect can be intensified in an active house due to large glazed surface. Protection from overheating has been considered only by solar screening and natural ventilation.

Also the source of electricity can considerably change the impact, as shown in figure (). The source of Norwegian electricity is further dependent on climate, supply and imports. This is difficult to be predicted over a time of 60 years. Keeping in mind possible errors during the operational phase due to various reasons, the impacts have been assessed with an error factor from previous studies (2; 57).

7.6.4 Sustainable scoring:

The sustainability scoring in this case has been reasonably broad, with the basic understanding from the available data on the UK based BREEAM code for sustainable houses. The difficulty lay as most of the key points provided were UK based and translating it in the Norwegian context. The scoring was relatively simple with energy and well-being as they were primarily based on the building design and the LCA results. However, awarding credits based on material type was difficult as the certification methodology used previously carried out LCA results for various frameworks of different building elements. The uncertainty increases in comparing the data from this project to the UK based LCA as it is a different geographical location and the results were from 2008 or before. Sourcing of material was also difficult to estimate as UK probably uses timber from various sources- possibly non-certified forests and also has added impacts transportation impacts, on the other hand Norway uses its timber from regional certified forests with maintained lumbering. Material sourcing for Norway is more relevant for other building materials such as imported steel from China or available reinforced steel from Mo I Rana.

8 Conclusion

Active house qualifies as low-energy house which requires 10 percent more material input than an equivalent Passive house. However, the delivered energy from renewable sources helps in reducing environmental impact by 15% than a basic Passive house. Using renewable sources of energy does not completely diminish the dependence of direct energy supply from the grid but creates the benefit of partial sufficiency for additional energy demand for necessities other than space heating.

Apart from the use of renewable, this project also focuses on the need of standardized certification of buildings which monitor the pre-design as well as post-construction. The certification method is an approach for all the stakeholders of the building to be participative in the best function of the building. An effective design, resident well-being as well as user awareness can positively influence the building.

8.1 Further work

Much work has proceeded towards whole building LCA especially of residential complexes in the past few years. Whole building LCA is a top-down approach. It is very helpful in to understand an estimated environmental performance especially with new design, technical differences and typical material use. However, several estimations made lead to high uncertainty in values. It would be interesting and benefiting for the building industry, to bring a bottom-up approach to the LCA of buildings.

Focus on LCA of various building framework for different elements of the building such as wall, floor, foundation and roof. For instance: LCA can be carried out for different types of walls- with different insulation material or cladding. These studies might have been carried out on a generic level by various databases, but more resolution to the data within specific boundaries gives a clear idea on material sourcing and also makes whole building LCA easier especially in the construction phase. This is a possible method of combining the results of EPDs from local or foreign manufacturers with whole building impact analysis. With available impact values of these elements, allows stakeholders of the building- designers, residents and sustainability assessors to choose or recommend materials.

A bottom-up approach can also focus on the percentage of reuse and recycled material possible in the frameworks of different building element. Narrowing the focus on the frameworks also promotes ongoing research on different building materials such as low-carbon concrete, nano-insulation material, types of finishing used on cladding to increase service life.

A qualitative analysis could be useful to estimate the resident behaviour with considerable awareness of their energy use compared to unawareness in the same kind of passive or low-energy building.

Works Cited

1. **Sørnes, Kari.** *Heating and Ventialtion of Highly energy Efficient Residential Buildings: Environmental Assessment of Technology Alternatives.* Trondheim : Norwegian University of Science and Technology, 2011.

2. **Melvær, Martin.** *LCA of Multi-family residence apartments.* Trondheim : NTNU, 2012.

3. *Energy demand in the Norwegian Building StockØ Scenarios on potential reduction.* **Sartori, I., B.J. Wachenfeldt, and A.G. Hestnes,.** 5, s.l. : Energy Policy, 2009, Vol. 39. p.1614 -1627.

4. **Dahlstrøm, Oddbjørn.** Life Cycle Assessment of a Single Family House Residence- built to Passive house standard. Trondheim : NTNU, 2011.

5. **Nilsen, Jannicke.** *Automatisk strømmåling i 2013.* [Newspaper] s.l. : Tekniskukeblad, 2012.

6. **Feist, Dr Wolfgang.** Step by Step towards Passive Houses. [Online] 23 09 2006. [Cited: 27 04 2012.] http://www.passivhaustagung.de/Passive_House_E/step_by_step_towards_passive_houses.html.

7. BSI-025: The Passive House Standard- A comparision to other cold climate low enery houses. *Building Science Insights.* [Online] [Cited: 30 April 2012.] http://www.buildingscience.com/documents/insights/bsi-025-the-passivhaus-passive-house-standard.

8. *Kriterier for passivhus og lavenergihus Bolibygninger.* s.l. : Norsk Standard , 2010. NS 3700:2010.

9. *Endringsblad A1 - Beregning av bygningers energiytelse - Metode og data.* s.l. : Norsk Standard, 2010. NS 3031: 2010.

10. **Isachsen, W. Rode and.** Implementation of EPBD in Norway. [Online] June 2008. http://www.buildingplatform.org/.

11. **NS EN, 15316-3-1.** Varmesystemer i bygninger Metode for bregning av systemets, energikrav og systemvirknings grader, Varmvannssystemer og varmtvannbehov. s.l. : Standard Norge, 2008.

12. Karakterskalaen. *Energimerking.no.* [Online] 2011. http://www.energimerking.no/no/Energimerking-Bygg/Om-energimerkesystemet-og-regelverket/Energimerkeskalaen/.

13. **Janson, Ulla.** *Passive Houses in Sweden: Experiences from design and construction phase.* Lund : Division of Energy and Building Design, Faculty of Engineering, Lund University, 2008.

14. *Sustainibility in construction industry: A review of recent developments based on LCA.* **Oscar Ortiz, Francesc Castells, Guido Sonnemann.** s.l. : Construction and Building Materials, 2009, Vols. 23-1. 28-39.

15. **Stjøstrand, Karin.** *Transforming the Dwelling Stock to reach the 2°C Climate Target – Combining MFA and LCA Approaches for a Case Study on Norway .* Trondheim : NTNU, 2010.

16. *Passive House projects in Norway- an Overview.* **Dokka, Inger Andresen and Tor Helge.** Bregenz, Austria : International Passive House Conference, 2007.

17. *Illustrating limitations of energy studies of buildings with LCA and actor analysis.* **Birgit Brunklaus, Catarina Thormark and Henrikke Baumann.** Gothenburg : Building Research and Information, 2010, Vol. 38:3. 265-279.

18. *Energy Use in the life cycle of conventional and low-energy buildings: a review article.* **I Sartori, and A.G. Hestnes.** Trondheim : Energy and Buildings, 2007, Vol. 39. 249-257.

19. *Life Cycle Assessment of four multi-family buildings.* **Adalberth, K., Almgren,A. and Petersen,E.H.** s.l. : International Journal of Low Energy and Sustainable Buildings, Vol. 2. 1-21.

20. *Life Cycle energy and environmental performance of a new university building: modelling challenges and design implication.* **Scheuer, C., Keoleian, G.A. and Reppe, P.** s.l. : Energy and Buildings , 2003, Vol. 35. 1049-1064.

21. *District heating and energy efficiency in detached houses of differing size and construction.* **Joelsson, A. and Gustavsson,L.** 2, s.l. : Applied Energy, 2008, Vol. 86. 126-134.

22. *Life-Impact Analysis of Energy Systems for Buildings.* **Ries, Ayat Osman and Robert.** s.l. : Journal of Infrasturcture Systems, 2004. 87-97.

23. **Kohler, N., Quante, K., Wagner,A. and Moosmann,C.** *Low emission Buildings: Final Report.* Karslruhe : Institut fu¨r Industrielle Bauproduktion and Facbereich technischer Ausbau, University of Karslruhe, 2004.

24. *Solar heating systems for passive houses in the Nordic countries- An Overview.* **Inger Andresen, Klaus Ellehauge, Björn Karlsson and Jyri Nieminen.** s.l. : Passivhus Norden, 2008.

25. *Life cycle assessment of wood-based heating in Norway.* **Christian Solli, Marte Reenaas, Anders Hammer Strømman, Edgar G.Hertwich.** Trondheim : International Journal of Life Cycle Assessment, 2009, Vol. 14. 517-528.

26. **Judith Thomsen, Magnar Berge.** *Inneklima i energieffektive boliger: - en litteraturstudie.* Trondheim : Energi og arkitektur, Sintef Byggforsk , 2012.

27. *Life cycle assessment of residential ventilation units in a cold climate.* **Nyman, M and C.J.Simonson.** 1, s.l. : Building and Environment, 2005, Vol. 40. 15-27.

28. **Heidi Arnesen, Tore Kolås and Barbara Matusiak.** *A guide to daylighting and solar shading systems at high latitude.* s.l. : ZEB, The Research Centre on Zero Emission Buildings, Sintef, 2011.

29. **Athienitis.A.K., and Tzempelikos, A.** *A methodology for simulation of daylight room illuminance and light dimming for a room with a controlled shading device.* s.l. : Solar Energy , 2002.

30. **Dahlstrøm, Oddbjørn.** *Life Cycle Assessment of Modern Highly effective Windows.* Trondheim : NTNU, 2010.

31. *SOLTAG, a development project focussing on: Energy, Architechture, Daylight and Indoor Climate.* **thomsen, Torben Thyregod Jensen and Pia.** s.l. : 1st Nordic passive house conference, Passivhus Norden 2008, 2008.

32. **Group, Velux.** *Model Home 2020; Buildings of the Future.* s.l. : Velux A/S, 2011.

33. *Simulation analysis for the active solar heating system of a passivehouse.* **Badescu, Viorel.** 17-18, Romania : Applied Thermal Engineering, 2005, Vol. 14. Pages 2754–2763.

34. NORSK SOLENERGIFORENING. *Teknologi.* [Online] 2010. http://www.solenergi.no/om-solenergi/.

35. GAISMA. *Trondheim, Norway - Sunrise, sunset, dawn and dusk times, table/graph.* [Online] May 2005. http://www.gaisma.com/en/location/trondheim.html.

36. **Ligaard-gruppen.** *Future Active House Norway.* Stjordal : Velux A/S, 2012.

37. **Solheim, Siri Birkeland.** *Effect of Solar screening on Passive houses.* s.l. : NTNU, 2012.

38. **Heidi Arnesen, Tore Kolås and Barbara Matusiak.** *A guide to daylighting and solar shading systems at high latitude.* Oslo : Sintef-ZEB/ Byggforsk, 2011.

39. *Daylight metrics and energy savings.* **J Mardaljevic, L Heschong and E Lee.** Leicester, UK : Lighting Res. Technology, 2009, Vol. 41. 261-283.

40. **Galaslu, Jennifer A. Veltch and Ance D.** *The Physiological and Psychological Effects of Windows, Daylight and View at home: Review and research Agenda.* Ottawa : National Research Council of Canada, , 2012.

41. **Decaestecker, Deepa Ananthakrishnan and Jason.** *Calculating the Daylight Factor (Lecture notes).* Las Vegas : University of Nevada, 2006.

42. *A low energy building in a life cycle—its embodied energy, energy need for operation and recycling potential.* **Thormark, C.** 4, Lund, Sweden : Building and environment, 2001, Vol. 37.

43. *An embodied carbon and energy analysis of modern methods of construction in housing: A case study using a lifecycle assessment framework.* **Powell, J. Monahan and J.C.** 1, Norwich, U.K : Energy and Buildings, 2010, Vol. 43. 179-188.

44. **MIKADO.** Kartlegging og documentasjon av miljøegenskaper for tre og trebaserte produkter. [Online] Sintef, Norwegian Institute of wood technology, May 2009. http://www.sintef.no/Projectweb/MIKADO/Mer-om-prosjektet/.

45. **Rønning, Anne.** *EPD Vegg av 15cm Lecablokk.* s.l. : EPD-norge, 2009 (valid till 2014).

46. **GLAVA.** *Glasswool Insulation, Class 37.* s.l. : EPD norge, 2007 (Valid till 2012).

47. **Edvardsen, Knut Ivar.** *Trehus.* s.l. : Sintef Byggforsk, 2006.

48. **KG, Rheinzink GmbH& Co.** *EPD RHEINZINK Titanium Zinc.* Datteln, Germany : s.n., 2005. AUB-RHE- 11105-E.

49. **Kirkhus, Anders.** Carporter og små garasjer. *Byggforskserien.* [Online] November 2007. [Cited:] http://bks.byggforsk.no/DocumentView.aspx?sectionId=2&documentId=279.

50. **A/S, Velux.** *MRPI, Roof window.* Ostbirk : s.n., 2003. GGL S06 3059.

51. **Jungbluth, Neil.** *Flachkollektoranlage, Einfamilienhaus, Wärmespeicher.* s.l. : Ecoinvent , 2007.

52. **SystemAir.** Vertical Units (Residential AHU), VR 400 DCV/B L Heat Recovery unit. [Online] 2011. http://catalogue.systemair.com/index.aspx?doc=http%3A//catalogue.systemair.com/item/ite.

53. **SSB.no.** Statistics Norway. *KOSTRA: Municipal water supply 2010.* [Online] June 2011. http://www.ssb.no/english/subjects/01/04/20/vann_kostra_en/.

54. —. Waste accounts for Norway. Final figures 1995 to 2010. *Statistics Norway.* [Online] 14 December 2011. http://www.ssb.no/avfregno_en/.

55. *Calculation of residual electricity mixes when accounting for the EECS- need for a harmonized system.* **Raadal, e.a.** 477-489, s.l. : Energies, 2009.

56. **Persson, G.** *SEGLET- att bygga ett energisnålt hoghus.* 2008.

57. *Energy efficient terrace houses in Sweden Simulations and measurements .* **Wall, M.** 2005 : Energy and Buildings, Vol. 38. 627-634.

58. *CO2 emmissions from biomass combustion for bioenergyØ atmospheric decay and contribution to global warming.* **Francesco Cherubini, Glen Peters, terje Berntsen, Anders H. Strømman and Edgar Hertwich.** 413-426, s.l. : GCB Bioenergy, 2011, Vol. 3.

59. Rheinzink. *Ecology and Durability.* [Online] PE Europe GmbH. http://www.rheinzink.us/77.aspx.

60. About BREEAM NOR. [Online] Norwegian Green Building Council, 2011. http://www.ngbc.no/index.php?q=content/om-breeam-nor.

61. **UK, BREEAM.** *Code for sustainable homes- Technical Guide.* s.l. : bre, 2010. www.communities.gov.uk.

62. Green Guide 2008 Ratings. *breglobal.* [Online] bre, 2012. http://www.bre.co.uk/greenguide/ggelement.jsp?buildingType=Housing&category=1009&parent=6&elementType=10121.

63. bre. *Green guide ratings 2008.* [Online] breglobal, 2012. http://www.bre.co.uk/greenguide/ggelement2.jsp?buildingType=Housing&category=1009&parent=6&elementType=10121&eid=17278.

64. Lifetime Homes. *16 LTH criteria.* [Online] Habinteg Housing association. http://codeassessors.lifetimehomes.org.uk/pages/lth_criteria.html.

65. **Wærp, S.,Grini,C.,Folvik, K.,Svanæs,J.** *MIKADO-Miljøgenskaper for tre-og trebaserte produkter over livsløpet- Prosjektrapport.* s.l. : Sintef, 2008.

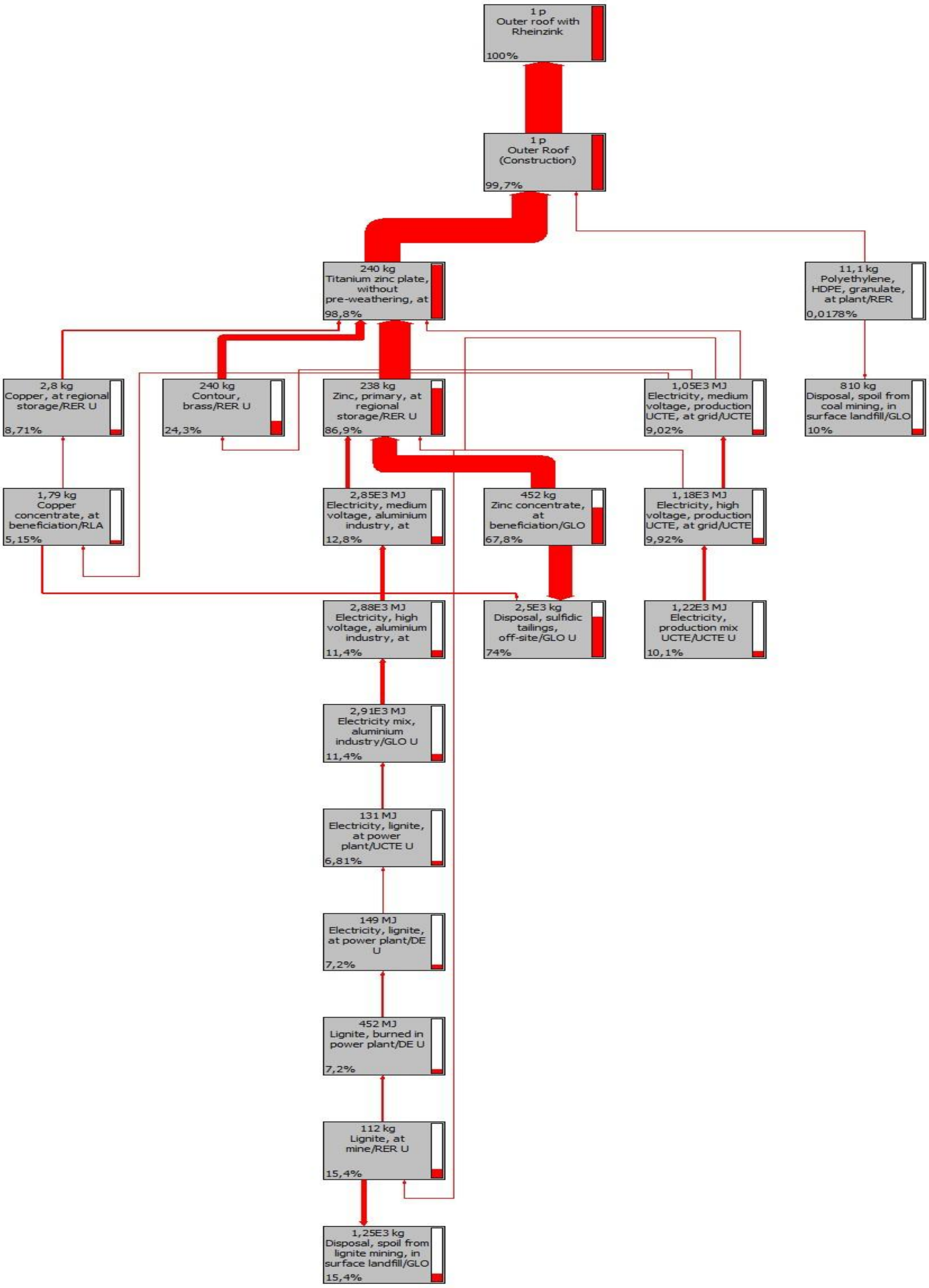
66. *Calculation of residual electricity mixes when accounting for the EECS- the need for a harmonized system.* **Raadal, et al.** 2009, Energies, pp. 477-489.

67. **(UK), Building Research Establishment.** *BREEAM- The world's foremost environmental assessment method and rating system for buildings.* s.l. : www.breeam.org, 2011.

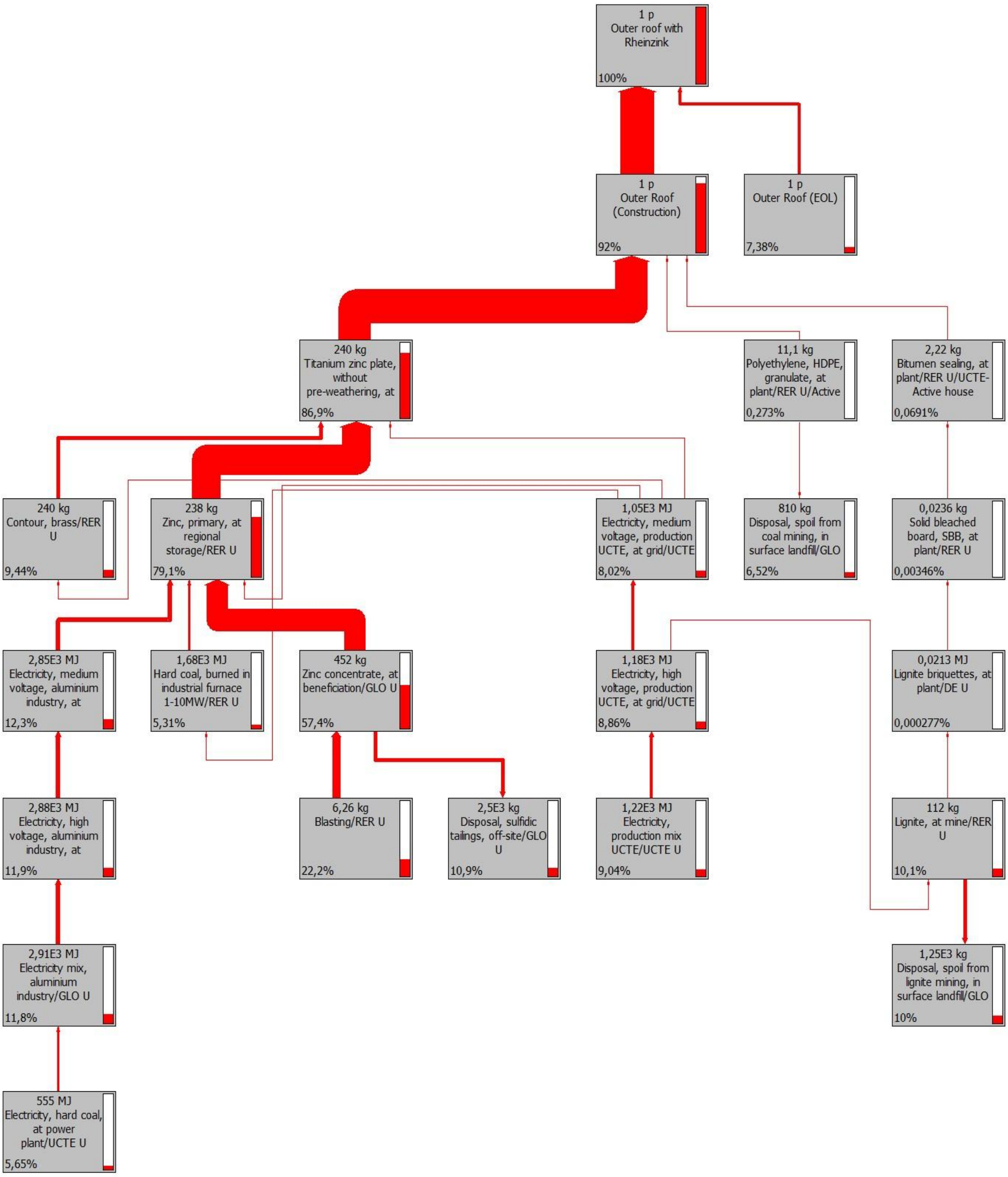
Appendices

Appendix A

Appendix A 1- Process tree for Freshwater Eutrophication (Outer Roof)



Appendix A-2 Process tree for Marine Eutrophication (Outer Roof)



Appendix B Inventory for Active house

Construction Materials and Energy

Construction Materials	Input	Unit
Particleboard glue	11,54	kg
Steel, for screws and nails	204,31	kg
Chemical anchor (83 % steel bolt, 17% chemicals)	19,20	kg
Total electricity	7095,05	kWh
Diesel, excavator and crane	480,94	kg
Transport lorry	117,52	tkm

Demolition	Input	Unit
Diesel for excavator	705,6	kg
Transport excavator	640	tkm

Basement

Foundation Block	Input	Unit
Polystyrene foam slab	46,80	kg
Sill membrane (80% bitumen, 20% polypropylene)	69,60	kg
Concrete	2218,32	kg
Reinforcing steel	39,60	kg
Transport lorry	365,95	tkm
Transport ferry	9,40	tkm

Foundation Wall	Input	Unit
ISOBlock- LECA	8877	kg
Concrete	19125,9	kg
Polystyrene extruded plastic (XPS)	88,77	kg
Transport lorry	2844,68	tkm

Gravel and Drainage	Input	Unit
Gravel, crushed at mine	112,41	ton
Polyethylene, HDPE	62,40	kg
Extrusion Plastic pipes	62,40	kg

Floor

Ground Floor (incl basement ceiling/ bathroom floor)	Input	Unit
Polystyrene floor slab	634,10	kg
Vapour Barrier	28,56	kg
Concrete	13,13	m3
Reinforcement Steel	205,36	kg
Polybutadiene	2,30	kg
Sealing Tape (aluminium/PE, 50mm wide)	3,20	kg
Interior wood (planed timber)	84,15	kg
Transport lorry	3725,54	tkm
Transport ferry	4,60	tkm

1st Floor	Input	Unit
Particle wood floor board	1047,20	kg
Planed Timber	160,36	kg
Insulation	508,07	kg
I - beam - 300mm	142,17	m
Spruce furring strip	92,24	kg
Gypsum plaster board	551,20	kg
particle board, floor use (end wall I-beam edging)	93,89	kg
Laminated wood	166,46	kg
Transport lorry	1303,02	tkm

Stairs (Both)	Input	Unit
Laminated Wood	267,62	kg
Timber planed at plant	292,71	kg
varnishes	9,67	kg
Transport lorry	60,87	tkm

Walls

External Wall	Input	Unit
Wood Cladding	5807,85	kg
Planed Timber	2150,60	kg
Windbreak foil PP	16,43	kg
Windbreak sheet (hundtolitt asphalt)	686,07	kg
Pillars I- studs	419	m
Insulation	1750	kg
Vapour barrier	180,19	m
Wall board (Forestia Particle Board)	1916,90	kg
Mouse barrier, 55%Al, 45% Zn	28,8	kg
Sealing tape	12,11	kg
Sealant Bitumen	8,50	kg
Transport lorry	6208,22	tkm
Transport ferry	2,78	tkm

Inner Wall	Input	Unit
Particle wood- wall use	529,52	kg
Insulation	41,17	kg
Planed Timber	350,66	kg
Transport lorry	424,23	tkm

Roof

Outer Roof	Input	Unit
Zinc sheets	265,35	kg
Planed Timber	353,40	kg
Wind and water barrier, under roof	22,77	kg
Sealing: Polyethylene	11,12	stk
Sealing: Bitumen based	2,22	kg
Transport lorry	592,66	tkm
Transport ferry	37,62	tkm

trusses	Input	Unit
Planed Timber	489,11	kg
Steel, low-alloyed	30,39	kg
Transport lorry	288,62	tkm
Transport ferry	4,10	tkm

Ceilings and insulation	Input	Unit
Insulation	679,36	kg
Planed Timber	177,79	kg
Vapour barrier	10,20	kg
Gypsum board	475,80	kg
Transport lorry	334,30	tkm

Rainwater and snow protection and sealing	Input	Unit
Steel, low-alloyed,	35,20	kg
Sheet rolling, steel	7,67	kg
Zinc coating, steel	9,53	kg
Powder coating, steel	30,15	kg
Pillar (wood stud 180x13mm)- Planed Timber	77,76	kg
Gypsum board	28,75	kg
Transport lorry	94,53	tkm

Auxiliary Area

Garage Foundation	Input	Unit
Polystyrene foam slab	59,76	kg
Sill membrane	88,87	kg
Concrete	2832,62	kg
Reinforcing steel	50,57	kg
Transport lorry	467,29	tkm
Transport ferry	12,00	tkm

Ceiling/terrace floor	Input	Unit
Particle board	785,40	kg
Planed Timber	604,09	kg
Insulation	381,05	kg
I - beam - 300mm	106,62	m
Spruce furring strip	69,18	kg
Gypsum board	390,93	kg
Roof skirting	22,47	kg
I beam edging	70,42	kg
Laminated wood	124,84	kg
Transport lorry	1172,73	tkm

Walls	Input	Unit
Gypsum board	667,24605	kg
Wind barrier	6,7233176	kg
Planed Timber	441,87412	kg
Sealants	2,7632653	kg
glass pane	2	p
Leca Block	40	m2
Transport lorry	559,3034	tkm
Transport ferry	1,3816327	tkm

Windows and Doors

Windows	Input	Unit
Façade Windows- Complete window with wooden cladding, U-0,8	15,00	p
Roof Window-Complete window with aluminium cladding, U1,2	4,00	p
Encasement profiles, wood, MDF -chipboard	332,14	kg
Paint lining	22,11	kg
Transport lorry	1352,88	tkm
Transport ferry	40,50	tkm

Outer Door	Input	Unit
Complete outer door, with frame and lining, U0,8	2,00	p
Wood, MDF, door, frame and lining	82,11	kg
Wood, timber planed	57,31	kg
Aluminium	22,01	kg
XPS	11,23	kg
Paint	6,27	kg
Door locks	2,00	p
Transport lorry	78,46	tkm

Inner Door	Input	Unit
Wood, MDF, door, frame and lining -Planed timber	60,00	kg
Wood, timber -doorframe (Laminated wood)	111,07	kg
cardboard	10,93	kg
coating	19,01	kg
Hardware	7,00	p
Transport lorry	100,50	tkm

Surface Finish

Bathroom	Input	Unit
Wet room plate (Litex)	51,94	kg
Extension Element (Polypropylene)	10,51	kg
Smør membrane Bitumen	14,82	kg
Ceramic Tiles	1782,19	kg
Glue	365,56	kg
Sealant	156,60	kg
Planed timber	747,73	kg
Transport lorry	3785,66	tkm
Transport ferry	314,51	tkm

Parquet (all floors)	Input	Unit
Parquet- Laminated wood	717,99	kg
Parquet varnish, 6 coats	64,62	kg
Transport lorry	1134,78	tkm
Transport ferry	105,65	tkm

Painting	Input	Unit
Painting indoor, H2O based, 2 coats	516,40	kg
Painting roof ceiling, 2 coats	31,71	kg
Painting outdoor, primer	20,15	kg
Painting outdoor,2 coats	516,00	kg
Transport lorry	704,77	tkm

Electricity and Plumbing

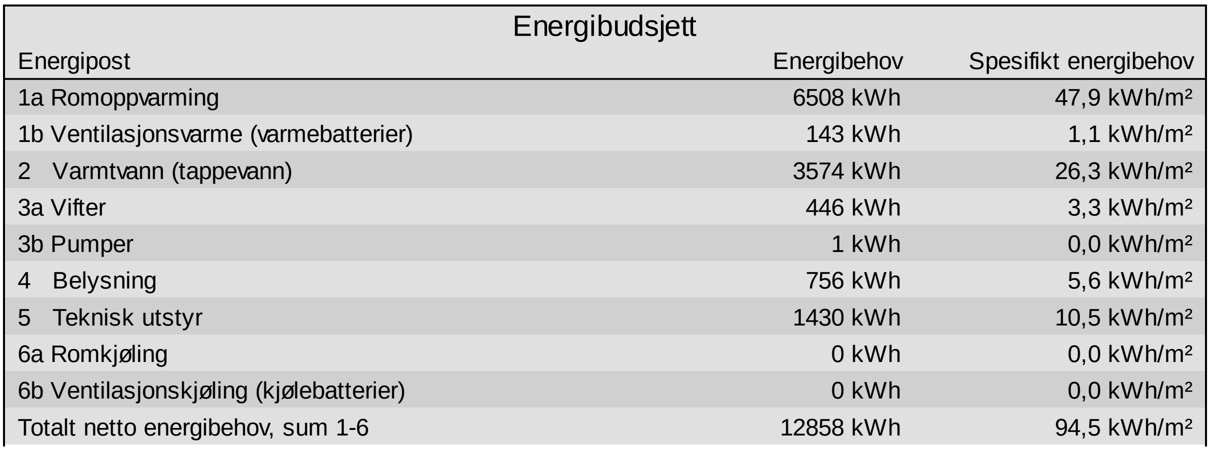
Electrical Fittings	Input	Unit
Fusebox- Steel low alloyed+ powder coated steel	15,00	kg
Plugs, inlet and outlet, for computer cable	11,31	kg
Sheet rolling steel	9,57	kg
Polyvinylchloride cable	20,91	kg
Cable, without plugs	349,64	m
Cable, three-conductor cable, at plant	5,00	m

Heading System	Input	Unit
Wood stove	2	p
Chimney, Active House	1	p
OSO Hot water tank 200l	1	p
Hydronic heat distribution system, radiator and floor heating	1	p
Solar system, flat plate collector, Active House, combined system	1	p
Panel heater (1000 W)	2	p
Ventilation Unit- Active House (Swegon)	1	p
Balanced Ventilation system, 60yr, Active House	1	p
Transport lorry	91,54	tkm
Tranport ferry	14,04	tkm

Plumbing	Input	Unit
Tap fittings-Polyethylene, HDPE	8,06	kg
Tap fittings- polyvinylchloride	6,90	kg
Sewer- Polypropylene	27,62	kg
Transport lorry	61,74	tkm
Tranport ferry	5,75	tkm

Appendix C Energy Simulation Results- Simien 2.0

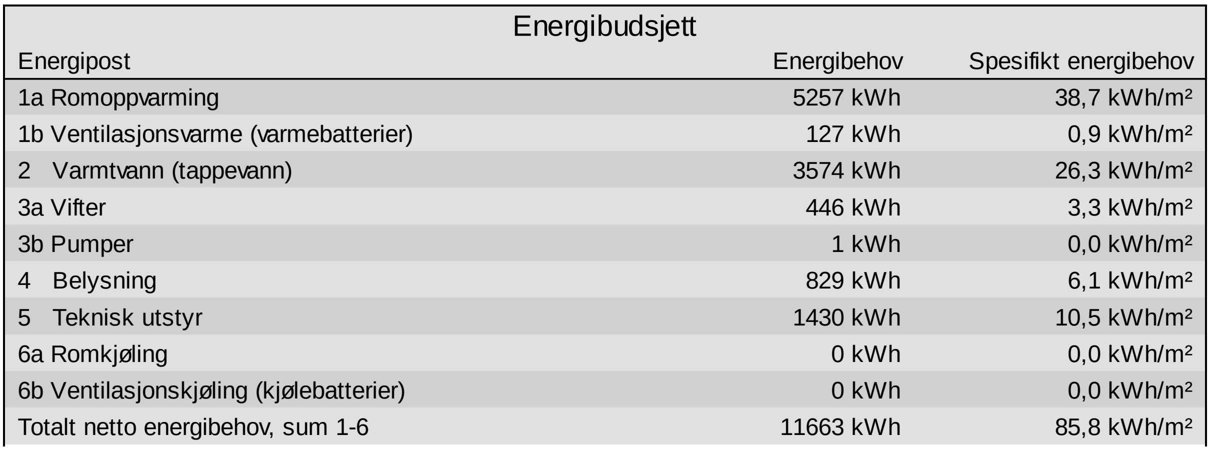
Active House



Energibudsjett

Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	6508 kWh	47,9 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	143 kWh	1,1 kWh/m²
2 Varmtvann (tappevann)	3574 kWh	26,3 kWh/m²
3a Vifter	446 kWh	3,3 kWh/m²
3b Pumper	1 kWh	0,0 kWh/m²
4 Belysning	756 kWh	5,6 kWh/m²
5 Teknisk utstyr	1430 kWh	10,5 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	0 kWh	0,0 kWh/m²
Totalt netto energibehov, sum 1-6	12858 kWh	94,5 kWh/m²

Passive House

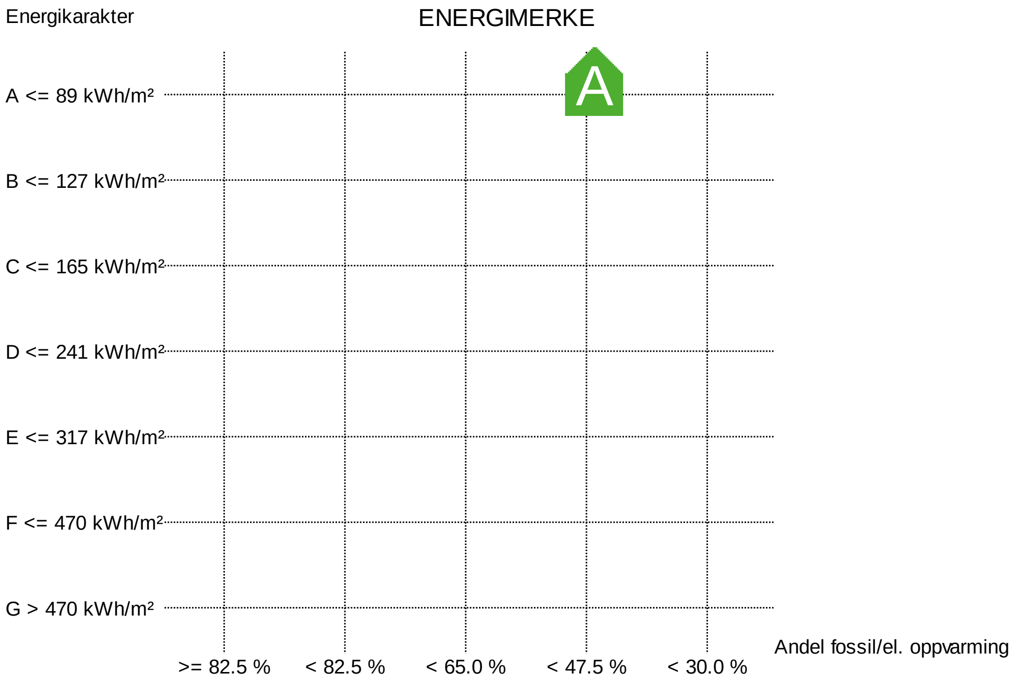


Energibudsjett

Energipost	Energibehov	Spesifikt energibehov
1a Romoppvarming	5257 kWh	38,7 kWh/m²
1b Ventilasjonsvarme (varmebatterier)	127 kWh	0,9 kWh/m²
2 Varmtvann (tappevann)	3574 kWh	26,3 kWh/m²
3a Vifter	446 kWh	3,3 kWh/m²
3b Pumper	1 kWh	0,0 kWh/m²
4 Belysning	829 kWh	6,1 kWh/m²
5 Teknisk utstyr	1430 kWh	10,5 kWh/m²
6a Romkjøling	0 kWh	0,0 kWh/m²
6b Ventilasjonskjøling (kjølebatterier)	0 kWh	0,0 kWh/m²
Totalt netto energibehov, sum 1-6	11663 kWh	85,8 kWh/m²

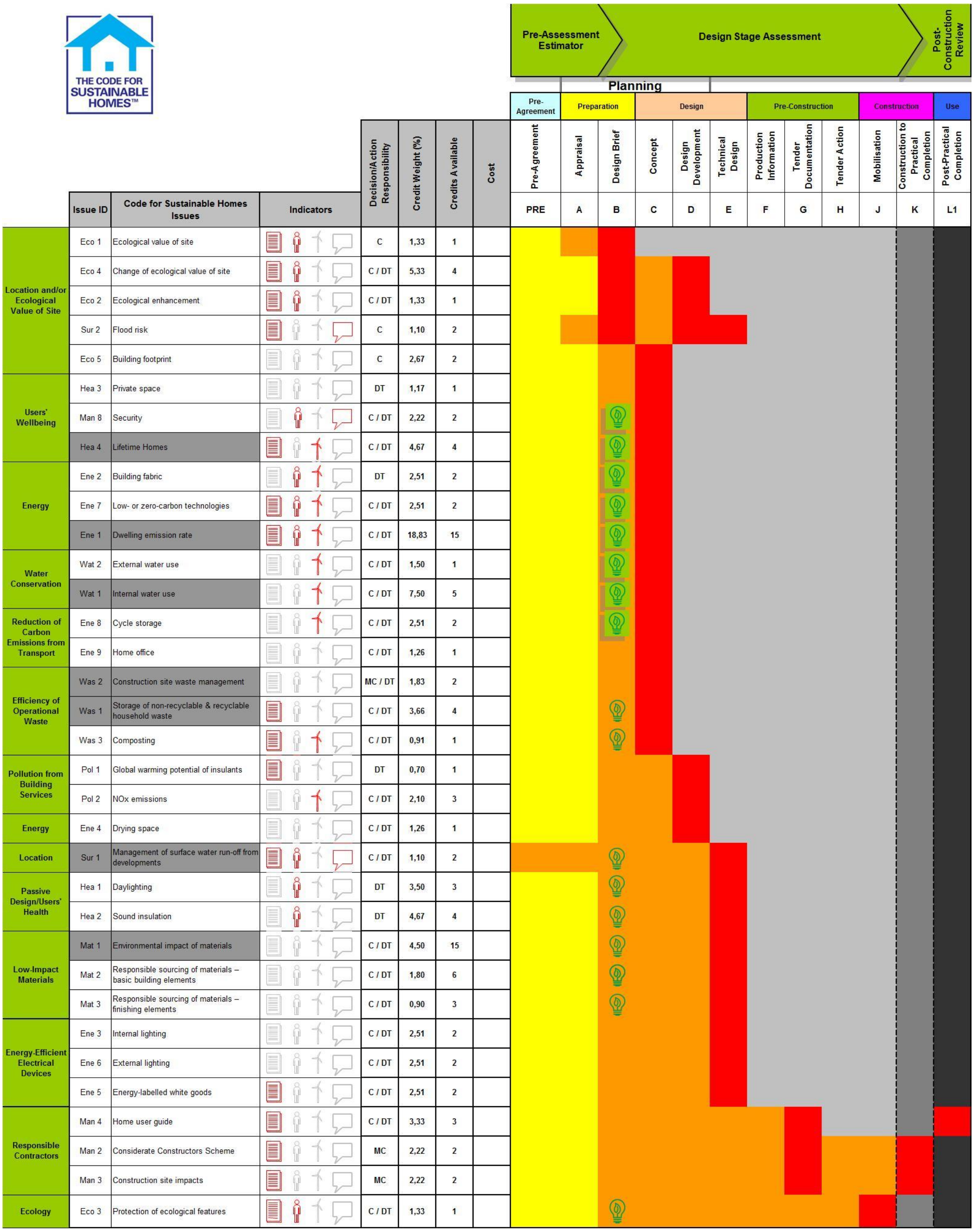
Appendix D- Energikarakterskala: Småhus (Source: Energimerking.no)

Småhus	**Levert energi pr m^2 oppvarmet BRA (kWh/m^2)**						
	A	**B**	**C**	**D**	**E**	**F**	**G**
Oppvarmet BRA (m^2)	Lavere enn eller lik	Lavere enn eller lik	Lavere enn eller lik	Lavere enn eller lik	Lavere enn eller lik	Lavere enn eller lik	
50	109	147	185	261	337	490	Ingen grense
75	98	136	175	250	326	479	Ingen grense
100	93	131	169	245	321	474	Ingen grense
125	89	128	166	242	318	470	Ingen grense
150	87	126	164	240	316	468	Ingen grense
200	85	123	161	237	313	466	Ingen grense
300	82	120	159	234	310	463	Ingen grense
400	81	119	157	233	309	462	Ingen grense
500	80	118	156	232	308	461	Ingen grense



Beregnet levert energi normalisert klima: 88 kWh/m²
Sum andel el/olje/gass av netto oppvarmingsbehov: 42.5 %

Appendix E BREEAM Scorecard for sustainable homes



	Issue ID	Code for Sustainable Homes Issues	Decision/Action Responsibility	Credit Weight (%)	Credits Available	Cost
Location and/or Ecological Value of Site	Eco 1	Ecological value of site	C	1,33	1	
	Eco 4	Change of ecological value of site	C / DT	5,33	4	
	Eco 2	Ecological enhancement	C / DT	1,33	1	
	Sur 2	Flood risk	C	1,10	2	
	Eco 5	Building footprint	C	2,67	2	
Users' Wellbeing	Hea 3	Private space	DT	1,17	1	
	Man 8	Security	C / DT	2,22	2	
	Hea 4	Lifetime Homes	C / DT	4,67	4	
Energy	Ene 2	Building fabric	DT	2,51	2	
	Ene 7	Low- or zero-carbon technologies	C / DT	2,51	2	
	Ene 1	Dwelling emission rate	C / DT	18,83	15	
Water Conservation	Wat 2	External water use	C / DT	1,50	1	
	Wat 1	Internal water use	C / DT	7,50	5	
Reduction of Carbon Emissions from Transport	Ene 8	Cycle storage	C / DT	2,51	2	
	Ene 9	Home office	C / DT	1,26	1	
Efficiency of Operational Waste	Was 2	Construction site waste management	MC / DT	1,83	2	
	Was 1	Storage of non-recyclable & recyclable household waste	C / DT	3,66	4	
	Was 3	Composting	C / DT	0,91	1	
Pollution from Building Services	Pol 1	Global warming potential of insulants	DT	0,70	1	
	Pol 2	NOx emissions	C / DT	2,10	3	
Energy	Ene 4	Drying space	C / DT	1,26	1	
Location	Sur 1	Management of surface water run-off from developments	C / DT	1,10	2	
Passive Design/Users' Health	Hea 1	Daylighting	DT	3,50	3	
	Hea 2	Sound insulation	DT	4,67	4	
Low-Impact Materials	Mat 1	Environmental impact of materials	C / DT	4,50	15	
	Mat 2	Responsible sourcing of materials – basic building elements	C / DT	1,80	6	
	Mat 3	Responsible sourcing of materials – finishing elements	C / DT	0,90	3	
Energy-Efficient Electrical Devices	Ene 3	Internal lighting	C / DT	2,51	2	
	Ene 6	External lighting	C / DT	2,51	2	
	Ene 5	Energy-labelled white goods	C / DT	2,51	2	
Responsible Contractors	Man 4	Home user guide	C / DT	3,33	3	
	Man 2	Considerate Constructors Scheme	MC	2,22	2	
	Man 3	Construction site impacts	MC	2,22	2	
Ecology	Eco 3	Protection of ecological features	C / DT	1,33	1	

Appendix F BREEAM Scoring models and methodology (Source: The code for sustainable homes, UK)

Appendix F-1 Calculation model for dwelling emission rate

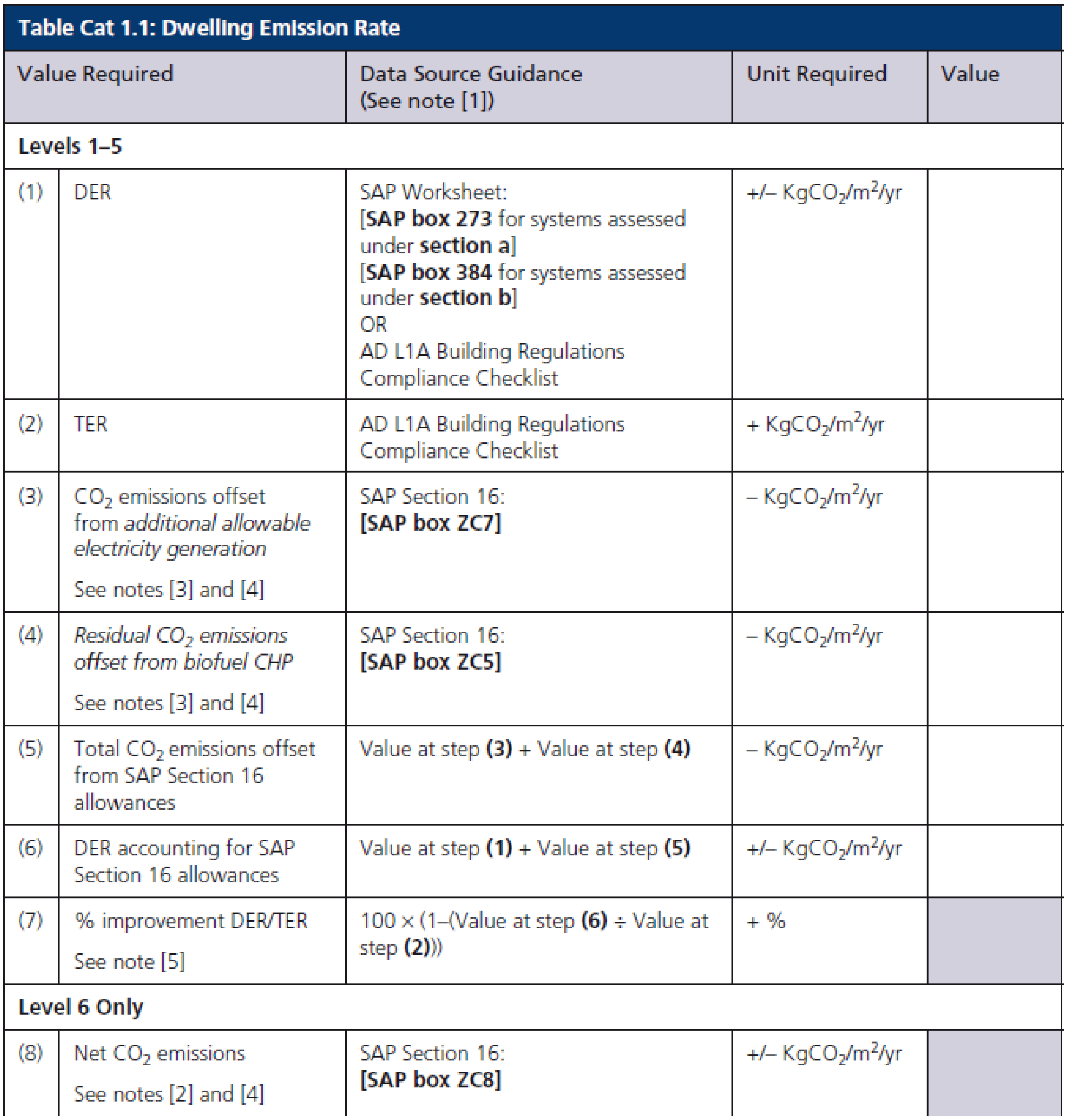


Table Cat 1.1: Dwelling Emission Rate

Value Required		Data Source Guidance (See note [1])	Unit Required	Value
Levels 1–5				
(1)	DER	SAP Worksheet: [**SAP box 273** for systems assessed under **section** a] [**SAP box 384** for systems assessed under **section b**] OR AD L1A Building Regulations Compliance Checklist	+/– $KgCO_2/m^2/yr$	
(2)	TER	AD L1A Building Regulations Compliance Checklist	+ $KgCO_2/m^2/yr$	
(3)	CO_2 emissions offset from *additional allowable electricity generation* See notes [3] and [4]	SAP Section 16: **[SAP box ZC7]**	– $KgCO_2/m^2/yr$	
(4)	*Residual CO_2 emissions offset from biofuel CHP* See notes [3] and [4]	SAP Section 16: **[SAP box ZC5]**	– $KgCO_2/m^2/yr$	
(5)	Total CO_2 emissions offset from SAP Section 16 allowances	Value at step **(3)** + Value at step **(4)**	– $KgCO_2/m^2/yr$	
(6)	DER accounting for SAP Section 16 allowances	Value at step **(1)** + Value at step **(5)**	+/– $KgCO_2/m^2/yr$	
(7)	% improvement DER/TER See note [5]	100 × (1–(Value at step **(6)** ÷ Value at step **(2)**))	+ %	
Level 6 Only				
(8)	Net CO_2 emissions See notes [2] and [4]	SAP Section 16: **[SAP box ZC8]**	+/– $KgCO_2/m^2/yr$	

Appendix F-2 Credit calculation for energy efficiency

Criteria			
Dwelling Type*[1]			
Apartment Blocks, Mid-Terrace	End Terrace, Semi-Detached & Detached		
Fabric Energy Efficiency kWh/m^2/year		Credits*[2]	Mandatory Levels
≤ 48	≤ 60	3	
≤ 45	≤ 55	4	
≤ 43	≤ 52	5*[3]	
≤ 41	≤ 49	6	
≤ 39	**≤ 46**	**7**	**Levels 5 & 6**
≤ 35	≤ 42	8	
≤ 32	≤ 38	9	

Default Cases

None

Appendix F-3 Credit calculation based on LCA performance of various building framework elements

Green Guide Rating	Credits
A+ Rating	3
A Rating	2
B Rating	1
C Rating	0.5
D Rating	0.25
E Rating	0

Appendix F-4 Credit calculation based on material sourcing of basic building elements

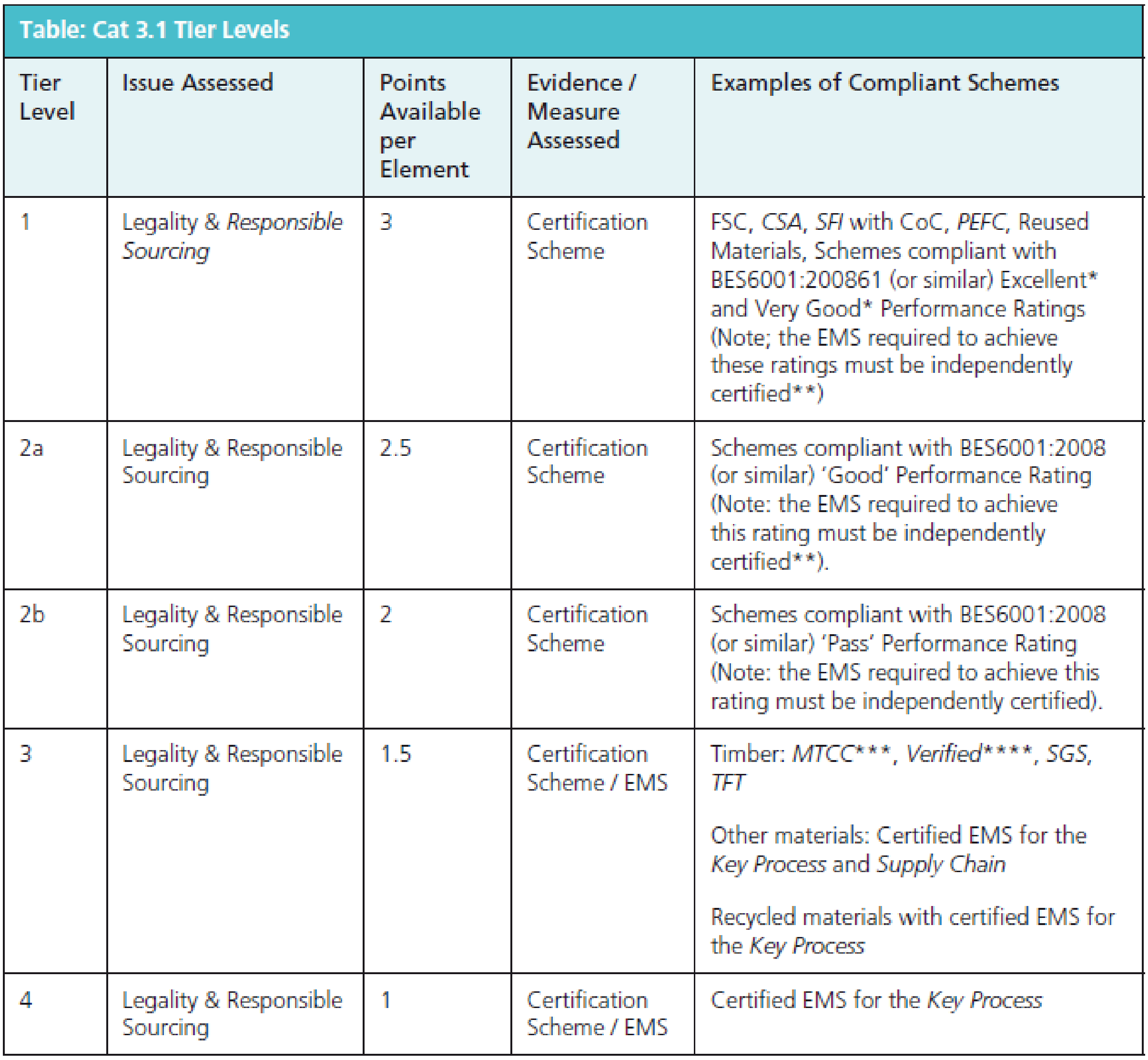


Table: Cat 3.1 Tier Levels

Tier Level	Issue Assessed	Points Available per Element	Evidence / Measure Assessed	Examples of Compliant Schemes
1	Legality & *Responsible Sourcing*	3	Certification Scheme	FSC, *CSA*, *SFI* with CoC, *PEFC*, Reused Materials, Schemes compliant with BES6001:200861 (or similar) Excellent* and Very Good* Performance Ratings (Note; the EMS required to achieve these ratings must be independently certified**)
2a	Legality & Responsible Sourcing	2.5	Certification Scheme	Schemes compliant with BES6001:2008 (or similar) 'Good' Performance Rating (Note: the EMS required to achieve this rating must be independently certified**).
2b	Legality & Responsible Sourcing	2	Certification Scheme	Schemes compliant with BES6001:2008 (or similar) 'Pass' Performance Rating (Note: the EMS required to achieve this rating must be independently certified).
3	Legality & Responsible Sourcing	1.5	Certification Scheme / EMS	Timber: *MTCC****, *Verified*****, *SGS*, *TFT* Other materials: Certified EMS for the *Key Process* and *Supply Chain* Recycled materials with certified EMS for the *Key Process*
4	Legality & Responsible Sourcing	1	Certification Scheme / EMS	Certified EMS for the *Key Process*

Appendix F-5 16 Lifetime Homes Criteria

1. **Where there is car parking adjacent to the home, it should be capable of enlargement to attain 3300mm width.**
2. **The distance from the car parking space to the home should be kept to a minimum and should be level or gently sloping.**
3. **The approach to all entrances should be level or gently sloping.**

4. **All entrances should:**
    a. **be illuminated**
    b. **have level access over the threshold and**
    c. **Have a covered main entrance.**
5. **Where homes are reached by a lift, it should be fully accessible.**
6. **The width of the doorways should conform to 750mm or wider and hallways be 900 mm or wider**
7. **There should be space for turning a wheelchair in dining areas and living rooms and adequate circulation space for wheelchairs elsewhere.**
8. **The living room should be at entrance level.**
9. **In houses of two or more storeys, there should be space on the entrance level that could be used as a convenient bed-space.**
10. **There should be: a) A wheelchair accessible entrance level WC, with b) Drainage provision enabling a shower to be fitted in the future.**
11. **Walls in bathrooms and toilets should be capable of taking adaptations such as handrails.**
12. **The design should incorporate:**
    a. **provision of a stair lift**
    b. **a suitably identified space for a through-the-floor lift from the ground to the first floor, for example to a bedroom next to a bathroom.**
13. **The design should provide a reasonable route for a potential hoist from a main bedroom to the bathroom.**
14. **The bathroom should be designed to incorporate ease of access to the bath, WC and wash basin.**
15. **Living room window glazing should begin at 800mm or lower and windows should be easy to open/operate.**
16. **Switches, sockets, ventilation and service controls should be at a height usable by all (i.e. between 450 and 1200mm from the floor).**

Further details on requirements can be obtained from **lifetimehomes.org.uk**