HALMSTAD UNIVERSITY

Master's Programme in Renewable Energy Systems , 60 credits

MASTER THESIS

Investigations on Energy Efficient Buildings

- the aim to reach zero energy buildings

John Chee

Dissertation in Engineering Energy, 15 credits

Halmstad 2017-02-22

Studie om energi effektiva byggnader - strävan mot nollenergihus

Investigations on energy efficient buildings –the aim to reach zero energy building

John Chee

Master thesis, 15 ETCS

Category	Energy technology

Högskolan i Halmstad
Akademin för textil, teknik och ekonomi
301 18 Halmstad
Telefon 035-16 71 00

Examiner:	Göran Sidén
Supervisor, name:	Jonny Hylander
Supervisor, address:	Högskolan i Halmstad Kristian IV:s väg 3 301 18 Halmstad
Corporation:	Passivhuscentrum Västra Götaland, Stora Torget 3A 441 30 Alingsås
Date:	2016-11-27
Keyword:	Zero Energy Building, *Circuitus*, *Bright Living*, National Board of Housing, Building and Planning, EPDB, energy efficient building

Förord

Detta arbete är gjort i samarbete med Passivhuscentrum Västra Götaland i Alingsås. Först och främst vill jag tacka alla som på något sätt bidragit till att göra detta examensarbete möjligt. Tack till alla anställda på Passivhuscentrum för ett trevligt bemötande och för att ni har tagit er tid att svara på mina frågor.

Ett speciellt tack riktas till min handledare på Högskolan i Halmstad, Jonny Hylander professor i energiteknik på förnybar energi som har varit till stöd vid arbetet med rapporten.

_____

John Chee

Göteborg 2016-11-27

Sammanfattning

Från och med 2021 ska alla nya byggnader i Europa vara nära nollenergibyggnader. EU:s direktivet om byggnaders energiprestanda (EPBD) medför krav på att Sverige ska utgöra nationella handlingsplan för nära-nollenergibyggnader (NNE). Definiera vad NNE innebär – kvantitativa riktlinjer - krav på hur byggnaders energiprestanda ska beräknas med avseende på den valda systemgränsen. Boverket fick enligt en regering beslut den 9 januari 2014 i uppdrag att förslå vad svensk tillämpning av nära nollenergibyggand innebär i form av krav på byggnaders energiprestanda. Boverket föreslår att systemgränsen levererad (köpt) energi ska användas med viktningsfaktor. För att uppfylla energiprestandadirektivets avsikt att främja användning av förnyelsebar energi som är producerad på plats eller i närheten, föreslås att inte ingår i den mängd energi som energiprestandakravet ställs på. Förslagen om att tillgodoräkna av förnyelsebar energi som är producerad på plats eller i närheten, om val av system gräns gör det möjligt att kompensera det specifika energibehovet. Risken är att oenergieffektiva byggnader kan använda förnyelsebara energitekniker på plats för att kunna reducera den levererade energin till 80 kWh/m^2, år (det förslagna energiprestandakravet för NNE). Detta i följd till hög energianvändning med stora investeringskostnader i förnyelsebara energitekniker på plats, eller begäran av att använda fossil bränsle för att komplettera höga energi toppar. Båda beräkningsobjekt *Circuitus* och *Bright Living* är NNE enligt den svenska tillämpningen av NNE. Den mest signifikanta skillnaden är att *Circuitus* har bättre värmeväxlare samt klimatsskal än *Bright Living*.

Nyckelord: Nollenergibyggnad, *Circuitus*, *Bright Living,* Boverket, EPDB, energi effektiva byggnader

.

Abstract

The European Parliament Buildings Directive (EPBD) obliges Sweden to develop plans to enhance the amount of NZEB. Define what NZEB for them exactly constitutes - technical definitions and system boundaries for energy performance calculations. The National Board of Housing, Building and Planning in Sweden has received an assignment from the Swedish government to propose the definition and quantitative approach on energy requirements for NZEB. NBHBP suggest the system boundary should be the delivered (bought) energy. The delivered energy divide into two different energy form. The set system boundary to calculate the specific energy performance with the introduced weighted factor. Makes it possible to compensate the specific energy performance by using renewable energy generators on site. The risk is inefficient buildings can use renewable energy technologies on site to compensate the delivered energy to achieve the 80 kWh/m^2, year (the proposed energy requirements for NZEB). This results to high energy cost along with large investments in renewable technologies on site, or the need to add fossil fuels to make up the high-energy demand. The both reference houses *Circuitus* and *Bright Living* are NZEB, per the Swedish definition proposal of NZEB from NBHBP. The most significant difference is *Circuitus* has better heat exchanger and building envelope than *Bright Living*.

Keyword: Zero Energy Building, *Circuitus*, *Bright Living*, National Board of Housing, Building and Planning, EPDB, energy efficient building

Table of content

1. Introduction 1
1.1 Motivation 1
1.2 Purpose 1
1.3 Limitations 2
2. Background 3
3. Theory 6
3.1 System scope and boundaries 6
3.2 Building requirements 7
3.3 The basic principle for energy efficient buildings 12
3.4 Energy passive house 13
3.5 Building envelope and structural system 14
3.6 Ventilation and heat system 22
3.7 Economy 27
3.8 Solar cells technology 28
4. Method 28
5. Results of the investigation 30
5.1 Results of *Circuitus* 30
5.2 Results of *Bright Living* 35
5.3 Comparison between *Circuitus* and *Bright Living* 39
6. Discussion 41
6.1 Discussion concerning the building requirements 41
6.2 Discussion concerning the results 42
6.3 Method 42
6.4 Future research possibilities 43
7. Conclusion 44
8. Referenser 46

1. Introduction

The EU´s 20-20-20 goal is to improve 20 % in energy efficiency, 20% reduction of greenhouse gas emissions (from 1990 levels) and 20 % of EU energy from renewable energy sources by 2020. The European Parliament Buildings Directive (EPBD) is the EU´s main legislation when it comes to help citizens to reach the EU´s 20 % reduction target on primary energy consumption of buildings. [1]

Under the EPBD, all new private buildings must be "nearly zero energy building" (NZEB) by 31 December 2020 and include an environmental impact assessment. The Directive obliges the 28 member states to develop plans to enhance the amount of NZEB and "zero carbon" buildings, and to set reasonable minimum energy standards for new and existing buildings. [2]

Today the residence and service sector in Sweden consume approximately 40 percent of total energy production in Sweden and nearly 60 % goes to heating. The National Board of Housing, Building and Planning (NBHBP) is central government authority affiliated under the ministry of enterprise and innovation of Sweden, who issues the building regulation (BBR). [3] [4]

1.1 Motivation

The interest in energy efficient buildings began since the oil crisis 1970, but have lately increased terrifically in Sweden in correlation to the increased energy prices and the ongoing global climate debate. The EPBD obliges Sweden to set a national definition on NZEB and national roadmaps to enhance it. This will increase the interest in "low energy buildings" even more in the future. The Swedish authorities NBHBP and Energy Agency have allocated a total of 120 million SEK for the years 2014 to 2016 to encourage initiatives for low energy construction. [5][6]

The thesis will be based on two chosen existing private low energy houses. The "passive house" certified "*Circuitus*" in Växjö which have a unique round building envelope. The pilot house "*Bright Living*" in Stockholm which uses climate- and energy efficient solutions, it was built to create climate friendly buildings such as wood houses to open the market for "low energy buildings".

1.2 Purpose

The purpose of the thesis is to investigate the proposed definition of nearly zero energy building from National Board of Housing, Building and Planning, and if the houses *Circuitus* and *Bright Living* can achieve these requirements with its design and system configurations.

The thesis will investigate the basic principle for energy efficient buildings to enhance the sustainable construction, and how it can be applied in the planning phase to build a "low energy building". The results emerging from the investigation will present the differences between the houses *Circuitus* and *Bright Living*. The consequences from the proposed definition of nearly zero energy building from NBHBP in an environmental perspective.

Investigation Questions
Are the proposed energy requirements from "National Board of Housing, Building and Planning" along the given system boundary for "nearly zero energy building" sufficiently analyzed and reliable?

What is the most significant difference between *Bright Living* and *Circuitus*, regarding energy performance?

1.3 Limitations

The thesis will not study the building requirements that is not related to *Circuitus* or *Bright Living*. A sufficient analysis on the proposed definition of NZEB will not be done. The cost will exclude the surplus sold micro produced electricity from the solar cells.

2. Background

It is increasingly significant that sustainable buildings and constructions contribute to achieving the EU´s environmental, energy and climate goals. There is many different definition under the title low energy building, such as zero energy building (ZEB), plus energy building and passive house. For the scope of this thesis, the thesis will focus on the concept of passive house and NZEB (very efficient buildings which require very low amount of energy).

"Zero Energy Building" is defined as a building that has a high-energy efficiency with zero net energy consumption; generate the same total amount of renewable energy on site, or in other definition, the renewable energy sources nearby are equal to the annual energy use. The ZEB concept highlight different aspects of sustainability, such as implementation of renewable energy source and help the citizen's engagement to reach the EU´s 20 % reduction target for primary energy consumption. However, the sustainable buildings can only help to achieve the EU´s target if it allows to function within the global ecological boundaries. [7]

Sweden is working on the national plan to increase the amount of NZEB in the country; the definition and regulations of NZEB, and the roadmap till 2021. NBHBP have set a proposal for utilization of NZEB about the definition of the energy performance and quantitative guideline to the government mandate. [8][9]

The work of this thesis is collaborated with the environment center in Sweden, "Passivhuscentrum Västra Götaland". An organization of expertise working to encourage energy efficient construction and renovation through education, development project, and preferably "passive house" (PH). [10]

The house Circuitus

The *Circuitus* is an international certified passive house, and its named in Latin means "what goes around comes around" after the recycled materials that has been used, and its cylindrical shape. It is used as a private residence for a family and as a pilot house. The passive house experts Kreutzer S. and Wesslund T. built and developed the house *Circuitus* together with the architect Sandahl N. The couple Wesslund T. and Kreutzer S. lives in this house today. The builder and consultants involved in this project are all educated passive house builder or developer.

The couple moved in *Circuitus* 12th November 2015 in Vikensved, Växjö. Their objective was to build an energy efficient building, which uses environmental friendly and maintenance free materials – as much as possible with a reasonable budget. See figure 1. [11]

Figure 1 shows the house Circuitus, the glass veranda, the balustrade made of orange colored, transparent solar cells and beside the house is a double carport. [11]

The house *Bright living*

The house *Bright Living* was built for the pilot project *One Tonne Life*. The aim of the *One Tonne Life* was to create a climate friendly household by trying to reduce the average carbon dioxide emission for a "typical" Swedish family that consume around 7,3 ton CO_2/(year and person) to one ton CO_2/(year and person) without compromising the living comfort. The family of 2 adults and 2 youths succeeded at least during one week consume an average of 1.5 ton CO_2/ (year and person), by reducing the use of CO2 on transportation and on the household management.

The energy efficient house *Bright Living* was built 25th January 2011 in Stockholm by A-Hus, designed by the architect Gert Windgårdh. The company A-Hus wants to build sustainable constructions by building wood houses with climate- and energy efficient solutions. Their goal is to create climate friendly wood houses to open up the market for low energy buildings. See figure 2. [12]

Figure 2 shows the solar panels on the roof of the carport, black solar cubes inbuilt in front of the windows and a white porch in front of the entrance door. [12]

3. Theory

The theory will first describe the energy performance calculations and the building requirements for NZEB. Then the basic principle to achieve as a low energy building with today's climate- and energy efficient solutions.

3.1 System scope and boundaries

The system boundary in a building is a systematic way to map the energy flow. The system boundaries are the boundary in or around the building that define the energy performance calculations and building requirements.

The choice of the system boundary decides how the total energy use of the building is defined. The basic energy balance is shown in the figure 3.

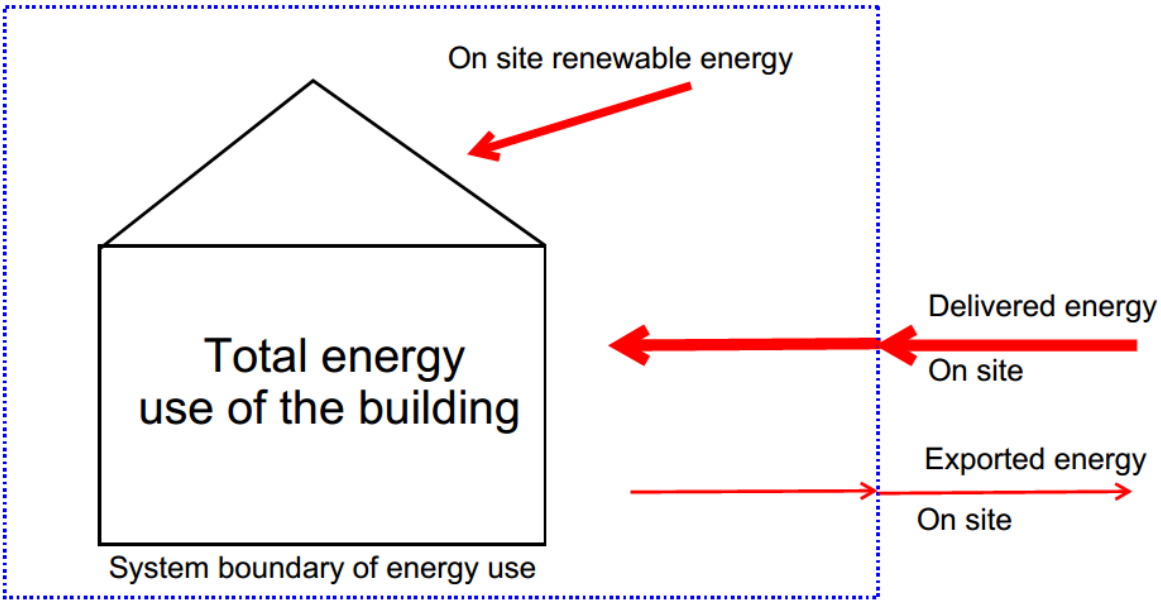

Figure 3 shows the basic system boundary for on site assessment.

System boundaries for on site assessment do not considered on site production as part of delivered energy on site. The system boundary of energy use of building technical system has direct connection to the building; system boundary of delivered energy is the bought energy to the building, exported energy on site is the sold energy, and the extensive use of microgeneration technology for renewable energy on site is taken into account so that it reduces the amount of delivered energy needed or be exported if cannot used in the building.

The benefits with the basic system boundary is the bought energy shows how much the delivered (bought) energy is. But cannot calculated the total energy use of the building without crediting the produced renewable energy on site. The definition of different kind of energy is not defined, e.g. electricity and thermal energy.

The set of detailed system boundaries for delivered and exported energy that define the different energy form have its benefits to give different energy ratio, such has the renewable energy ratio, see figure 4. [13]

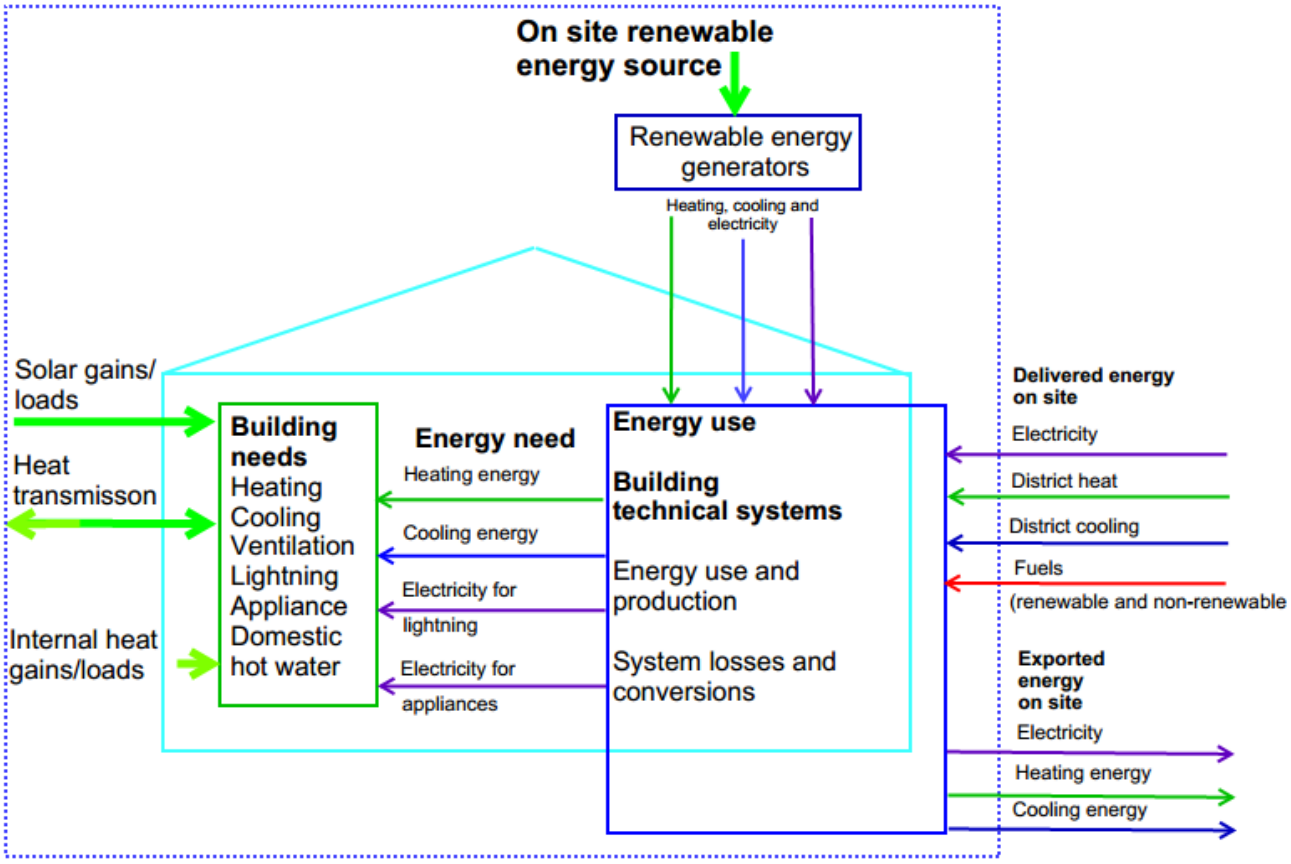

Figure 4 shows the building site boundary; detailed system boundary of delivered and exported energy on site, and two other system boundaries; the buildings needs and energy use. System boundary of energy use to calculate the renewable energy ratio. Renewable source from geo-, aero-, hydrothermal energy source of heat pumps, sun, wind and free cooling.

3.2 Building requirements

The aim of the BBR is all building envelopes should be design to limit the energy demand by minimize heat losses, use of cooling and efficient use of electricity. The regulations from BBR are divided into 4 different climate zones in Sweden with different minimum requirements on the specific energy usage, average heat transfer coefficient and average airtightness.

The regions that belongs to climate zone III are Jönköpings, Kronobergs, Östergötlands, Södermanlands, Örebro, Västmanlands, Stockholms, Uppsala, Gotlands county and Västra Götalands county except the municipalities Göteborg, Härryda, Mölndal, Partille and Öckerö. See table 1. [14]

Table 1 shows the energy requirements in the climate zone III, Sweden for a house that are bigger than 50m^2 from BBR22.

	The building specific energy demand [kWh/m^2 and year] (Maximum)	Average heat transfer coefficient [W/ (m^2*K)] (Minimum)

House, Area> 50 m^2	90 (Heating from other source than electrical heating)	0.40
House, Area> 50 m^2	55 (Electrical heating)	0.40

The requirements should be verified partly from the calculated energy performance, average heat transfer coefficient during planning phase, partly from measuring the energy demand in the finish built building. The measuring data should be measured over a continuous 12 month. [15]

The proposed Swedish definition of NZEB

EPBD wants from the Member state to define what NZEB for them exactly constitutes. There is various definition of NZEB. But EPBD wants technical definitions and system boundaries for energy performance calculations on NZEB. That are based on assumption of an introduce energy requirements, which are more ambitious than what in the short term is equivalent to cost optimal levels. The directive requires that the energy performance of building should include an energy performance indicator and a numerical indicator for primary energy consumption.

NBHBP has received an assignment 9 January 2014 from the Swedish government to propose the definition and quantitative approach on energy requirements for NZEB. NBHBP has set the system boundary based on the basic energy balance but has also defined the delivered (bought energy) on site into two energy form (delivered electricity and other energy form), see figure 5.

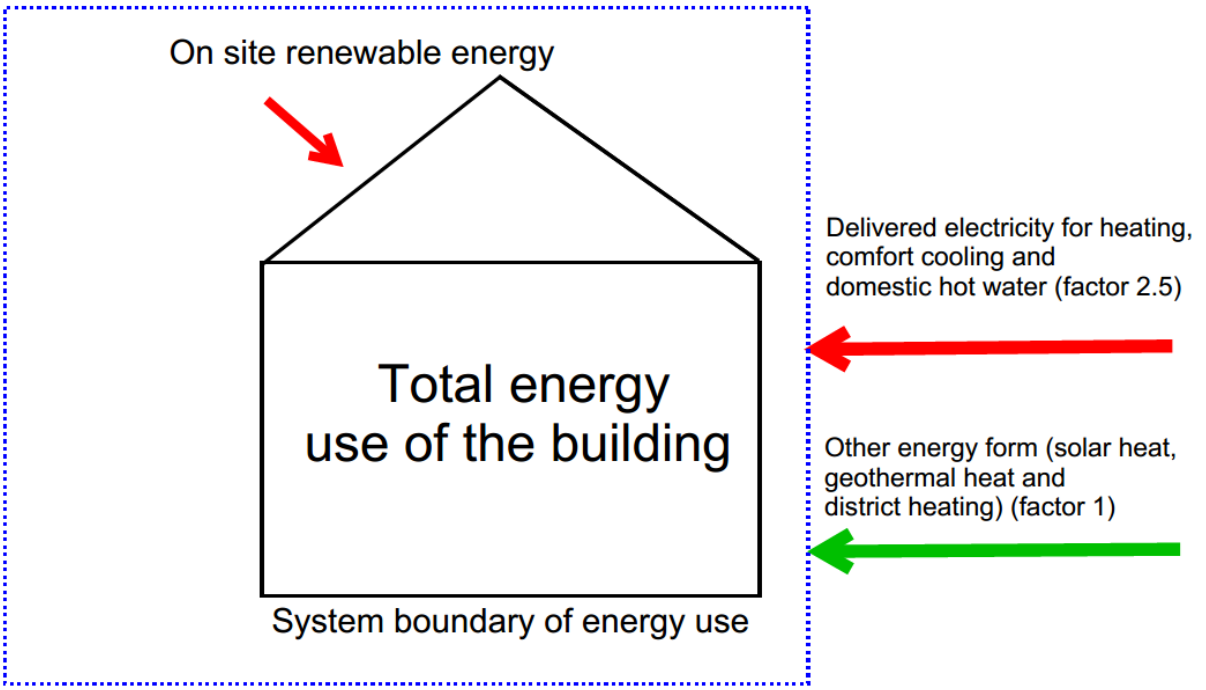

Figure 5 shows the delivered electricity for heating, comfort cooling and domestic hot water can be as a factor 2.5, and other energy form (solar heat, geothermal heat and district heating) with a weighted factor 1.

NBHBP proposes the weighting factor should be applied. The weighted factor for electricity is brought forth in the foundation to avoiding the use of electricity for heating or cooling, and that the weighted factor can be used as primary energy indicator to meet the EPBD meaning and regard. The specific energy performance can be calculated according to equation 1.

$$E_{spec} = \frac{(E_{el,heat} + E_{el,vw} + E_{el,cool}) * 2.5 + E_{el,ser} + E_{heat} + E_{vw} + E_{cool}}{A_{treated}} \quad (1)$$

$E_{el,heat}$ *is electricity for heating* $[kWh/year]$

$E_{el,vw}$ *is electricity for domestic varm water* $[kWh/year]$

$E_{el,cool}$ *is electricity for cooling* $[kWh/year]$

$E_{el,ser}$ *is electricity for building technical system* $[kWh/year]$

E_{heat} *is other than electricity for heating* $[kWh/year]$

E_{ww} *is other than electricity for domestic varm water* $[kWh/year]$

E_{cool} *is other than electricity for cooling* $[kWh/year]$

A_{treat} *is treated floor area* $[m^2]$

For a building in Zone III to achieve as a NZEB the proposed specific energy performance can maximum be 80 kWh/m^2, year.

NBHBP define the delivered energy as the bought energy, and allows the extensive use of solar energy technology on the roof to reduces the amount of delivered energy need or be export if cannot use in the building. Energy to building technical system is excluded from the total energy use of the building.

The proposal from NBHBP are based on analysis of what is the possible level of energy requirements for NZEB from experts´ and participants´ assessments which are active in construction and real estate. The methods that have been in used are the "TEQUILA-method", "RegSweDyn", "TIMES-Sweden" and interviews. These methods are design to estimate of the possible levels of the participants, analysis of the socio-economic effects of political decisions, and analysis of the environmental impact of more stringent energy requirements and on the Swedish energy system. [9],

Passive house Institute

The passive house institute (PHI) is an independent research institute working on the development of the passive house concept, issues the international passive house certification and distribute the planning software tool "passive house planning package" (PHPP). [16]

The international passive house certificate is a strict professional passive house certification offered worldwide. The criteria for residential passive house buildings is characterize by high level of thermal comfort with minimum energy demand, and for all climate worldwide. The verification of compliance with the criteria shall be provided from the PHPP. See table 2.

Table 2 show the criteria for passive house standard. The heating, cooling, airtightness and renewable

primary energy. [17]

			Criteria[1]			Alternative Criteria[2]
Heating						
Heating demand	[kWh/(m²a)]	≤	15			-
Heating load[3]	[W/m²]	≤	-			10
Cooling						
Cooling + dehumidification demand	[kWh/(m²a)]	≤	15 + dehumidification contribution[4]			variable limit value[5]
Cooling load[6]	[W/m²]	≤	-			10
Airtightness						
Pressurization test result n_{50}	[1/h]	≤	0.6			
Renewable Primary Energy (PER)[7]			Classic	Plus	Premium	
PER demand[8]	[kWh/(m²a)]	≤	60	45	30	±15 kWh/(m²a) deviation from criteria...
Renewable energy generation[9] (with reference to projected building footprint)	[kWh/(m²a)]	≥	-	60	120	...with compensation of the above deviation by different amount of generation

To apply for passive house certificate from PHI, documents need to be submitted to verify the parameters and the results, such as the airtightness test to ensure requirements are met, calculation of heat transfer coefficient and the air quantities. [18]

3.3 The basic principle for energy efficient buildings

Zero- or plus energy buildings are often based on the extensive use of microgeneration technology on site that are meant to turn homes into micro power producer, and have low-end energy buildings techniques. These building can simply be self-sufficient if their energy demand is very low. By design and build energy efficient buildings can create comfort indoor climate, high energy efficiency performance and reduce the consumption of CO_2 emissions. [14]

The basic principle for an energy efficient building can be illustrated by the "Kyoto pyramid" that was created from the largest independent research institute in Scandinavia, Norwegian Sintef, in affiliation with" Kyoto Protocol" from the "United Nations Framework Convention on Climate Change" (UNFCCC) 1997. Kyoto pyramid is a pedagogic design strategy method that show the energy efficient way to structure low energy building design. See figure 6. [19]

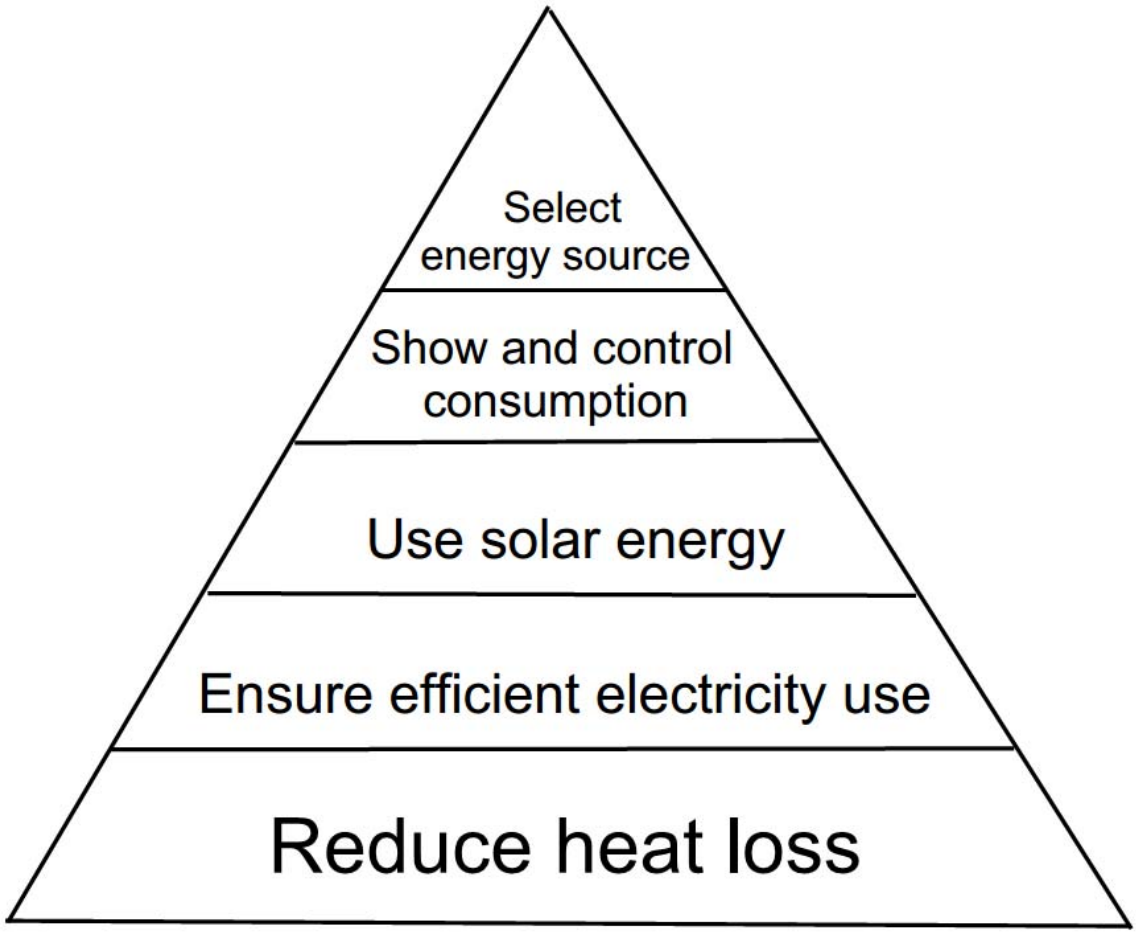

Figure 6 shows the Kyoto pyramid that is a pedagogic tool in a structure order to reduce the energy consumption in the most effective ways.

The Kyoto pyramid consist of 5 general steps (from the bottom of the pyramid to the top) reduce the heat losses, reduce the electricity usage, utilize solar heat, display and control the

energy consumption and choose energy source. There are different versions how the Kyoto pyramid can be applied, but for designing low energy dwellings, the steps are:

1. Reduce the heat losses by minimize the heating demand: super insulated- and air tight building envelope, minimized the thermal bridge and use effective heat recovery ventilation.

2. Reduce the electricity consumption to avoid energy waste by exploitation of sunlight to take advantage of solar heat and -light, use energy efficient electric devices: lights, pumps or fans, and low pressure drops in the pipes or ventilation air paths.

3. Utilize the "free" solar heat and -light by optimum the window and building orientation, proper use of thermal mass, solar collectors and -cells.

4. Show and control the energy usage by using use-and-control devices, "smart" technologies: energy watch to show the correlation between the electricity usage and the resident living style, different profile schedule to control heating demand, ventilation system, lightning and electrical equipment when it is needed.

5. Choose local energy source and carrier: E.g. district heating, natural gas, biomass and geothermal heat pump. [20]

The method will not only reduce the energy demand but improve the understanding of living more sustainable and be more cost effective. Buildings that are based on the extensive use of microgeneration technology on site that neglecting the building envelope efficiency, and focusing only on renewable inevitably results to high energy cost along with large investments in renewable technologies on site, or the need to add fossil fuels to make up the high-energy demand.

By control and reduce the energy demand will make it more cost effective to invest in renewable technologies while curbing the energy price volatility and safeguarding economic, social, and environmental welfare. [17]

3.4 Energy passive house

Planning and design

The passive house reduces the energy demand by passive measures. Approximately 70-75 % of the heating in a passive house comes from solar radiation, human activities and electronic devices. The solar energy, buildings techniques, heating systems, energy demand are very depended on the local climates. In this theory, the cool climates like Sweden will be described.

The passive buildings are designed and oriented to exploitation the solar gain and light by facing the most of the glass area and building area to the south. The choice of the color and materials for the façade are often based on the solar absorption. dark-colored absorb more solar radiation than light-colored, and some light-colored facades can even be reflective. The orientation can also facilitate the implementation of solar panels or -cells on the roof.

The shape and the size of the building are designed to be compact, and have as little outer area as possible to reduce the heat loses and the indoor heating volume, e.g. traditional

quadrangular buildings have longer outer wall circumference than cylindrical shaped.

All the rooms are design and position to minimize the length of the ventilation ducts, and are installed inside the building envelope to avoid temperature- and pressure drop. The challenge increase with the number of floors. [6]

Building materials and components
The most important to build an energy efficient building is to have proper construction techniques with proper materials and components, which mostly discerns from commercial buildings. Material or component of a building that have a better quality can be verified and be found from different verification certifications e.g. PHI.

Certification for high quality components allow users to verify the parameters of the product or material, such as good insulating windows frame, high efficient heat pump, ventilation unit etc. The criteria from PHI are climate independent based on two categories the comfort criteria and energy performance, and is expressed by tested methods and measurable quantities. See figure 7. [16]

Figure 7 shows a certified triple glazing window from Passive house institute.

LCA is a tool to assess environmental impacts associated with a product life cycle of a material. The stages from cradle to grave (the transportation, repair, maintenance and disposal or recycling). In an ecological perspective, the choice of building materials should be made from a life cycle assessment of a material or a product. For an example the production and transport of a timber wall in houses emits three times less CO_2 than an equivalent concrete wall in a cradle-to-gate perspective. [21]

3.5 Building envelope and structural system

Thermal bridge and air leakages
Parts of the building envelope where the heat can easily pass through broken, and “unbroken” construction elements such as walls, edges, corners, connections and penetrations than the rest of the building is known as thermal bridge. One of the most efficient energy savings measures is to prevent the thermal bridge and air leaks.

By having as airtight building envelope as possible will also reduce the risk of structural- and moist damage. That can be obtained through proper planning, construction and installation. The test of the air tightness for a building envelope is performed by measuring the pressure drop while the building envelope is under 50 pascals positive or negative pressure. The advantage with an under-pressure test is to identify potential air leakage by using a thermographic camera. [17]

Heat transfer coefficient

An energy efficient building has materials or assemblies of materials with a low heat transfer coefficient, U-factor. Proper use of different thermal mass and moist buffering material to contribute better indoor climate by stabilizing the indoor temperature and humidity.

The U-factor describe the rate of thermal transmittance, see equation 2.

$$U = \frac{1}{\alpha_v} + \sum_{i=1}^{i=n} \frac{\delta_i}{\lambda_i} + \frac{1}{\alpha_k} \qquad \left[\frac{W}{m^2 * K}\right] \tag{2}$$

α_v, α_k *are the heat transfer coefficientsdepend on both convection and radiation on each side of the wall*

λ *is the material's coefficient of thermal conductivity*

δ *is thickness of the homogeneous matrial*

Specific heat capacity (c) is the measurable physical quantity that show the thermal inertia of the material. The ratio of storing or losing thermal energy to resulting temperature change on a material or object. See equation 3.

$$c = \frac{Q}{\Delta t} \qquad \left[\frac{J}{K}\right] \tag{3}$$

Q is heat energy
Δt is temperature differences

Building materials that have high specific heat capacity are clay and concrete. It is energy efficient to have high heat capacity materials inside the building envelope to a certain extent during the winter to store the heat during the day and unload during the night, and vice versa during the summer. Airtight building with proper thermal mass is generally easier to keep cool compared to a building built mostly by massive materials. [22]

Roof, foundation and wall

Energy efficient building has a low average U-value to reduce heat losses. The construction of the building envelope can vary depend on the building requirement, materials, design and financial. The given examples will show how a proper construction can be done.

The recommended minimum U-value is 0.10 W/m^{2}C on the foundation from the PHI. This can be achieved in different construction. An example of such a construction is at the bottom filled with 150-250 mm layer of rubble, 150 mm vertical foam, three layer of 100mm foam and on top of that diffusion- and radon barrier. See figure 8.

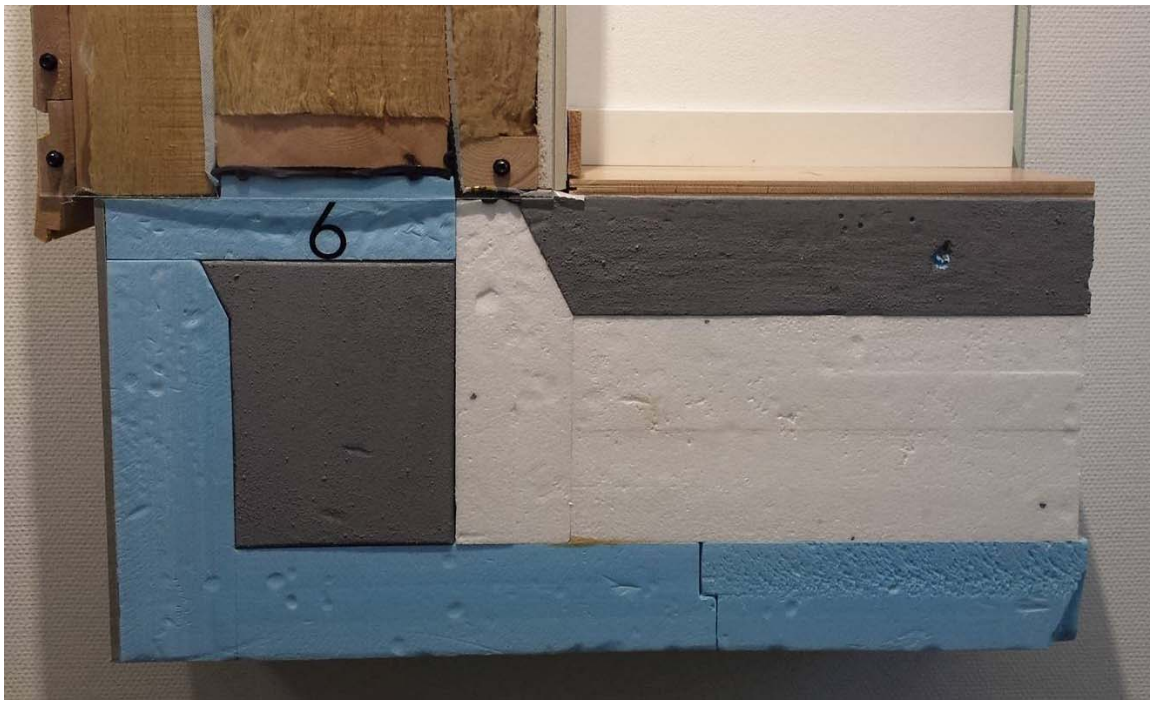

Figure 8 shows the foundation of a building that have a U-value of 0.1W/m²C.

A wall with U-value of 0.10 W/m^{2}C can have from outside in 100 mm insulation, variable moist barrier, 200 mm insulation with framework, variable moist barrier, 70 mm insulation with frame, diffusion barrier and plasterboard. See figure 9.

The inner walls are mainly designed for sound isolation and privacy area. The joists of the roof should have an U-value of 0.08 W/(m^{2}K), an insulation of approximately 500 mm. See figure 9.

Figure 9 shows the construction of a roof with 500 mm insulation.

The choice of structural system is depended on the building requirements that are based on the stability of building. The structural system can in the planning phase be designed to avoid or minimize thermal bridge. There is no requirement of the choice of materials but wood has lately been popular in Sweden considering environmental- and climate impact. [6]

Window and door

The windows are the building components with the lowest thermal insulation. In cool climate, the quality of the window need to be highly insulated to reduce the thermal bridge. Windows with a low U-value have good isolated frame, opening mechanism and triple or quadruple glazing to ensure that the heat or cold are isolated. Windows that simultaneously allow as much day light as possible shine indoor. See figure 10.

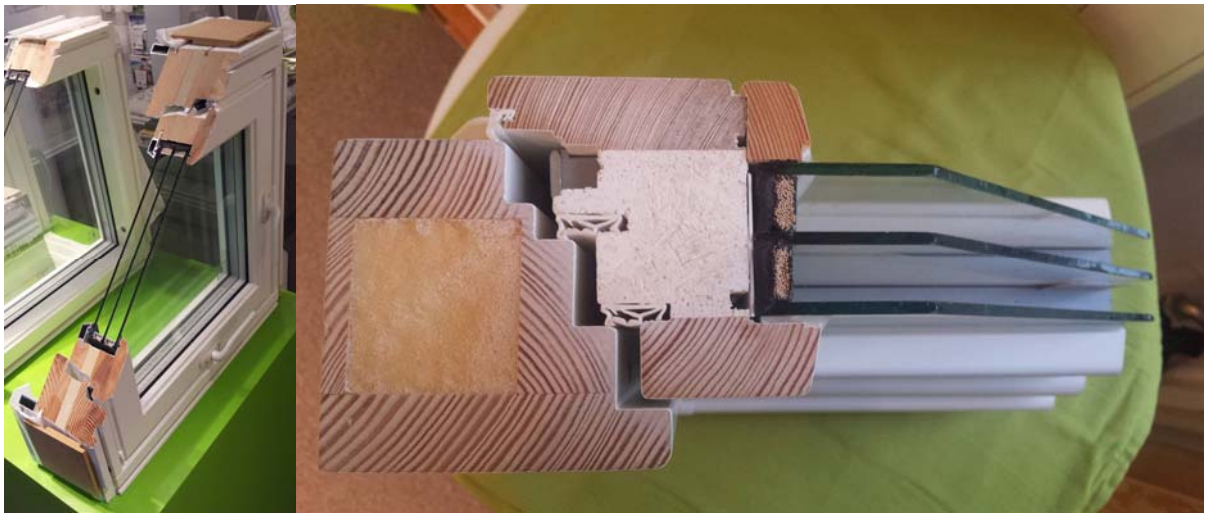

Figure 10 shows triple glazing window with a U-value of 0.72 (measured inbuilt in the building).

An incorrect installation of a window can easily create energy leaks. But by a proper installation in the insulation layer, edge sealing, and extending the insulation to make it possible to overlap the connections in the window frame minimize the thermal bridge. See figure 11.

Figure 11 shows the extend insulation from a window to overlap the connections in the window frame.

In thermographic picture, it is possible to see energy leaks. The differences with and without frame insulation, and where in the wall the windows is installed. See figure 12.

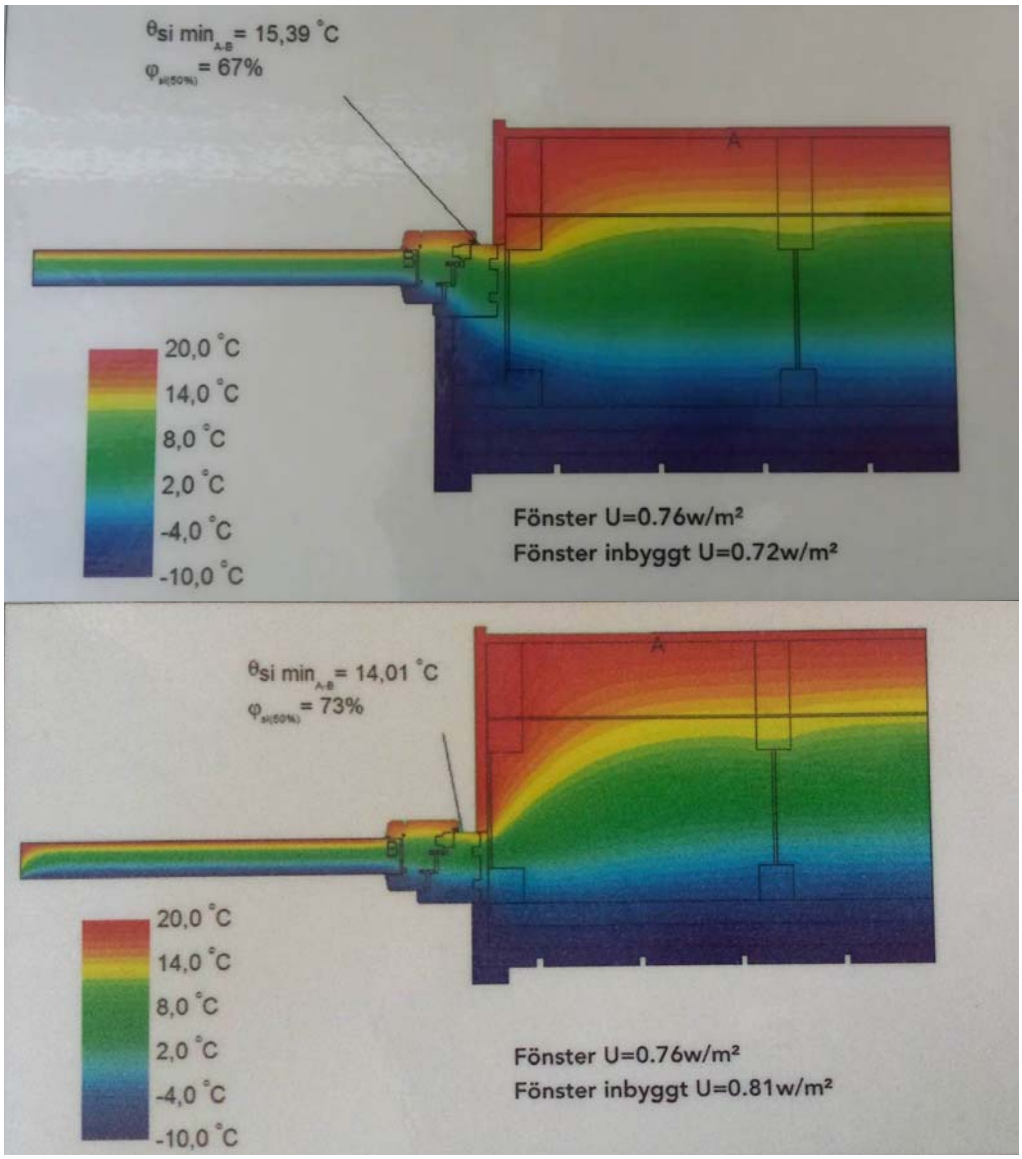

Figure 12 shows the windows temperature with and without frame insulation and the thermal bridge.

The consequences for an airtight and good isolated building has bigger risk for overheating during warm summer periods. The emphasis lies on limiting solar gains by using internal and external shadings. See figure 13. [17]

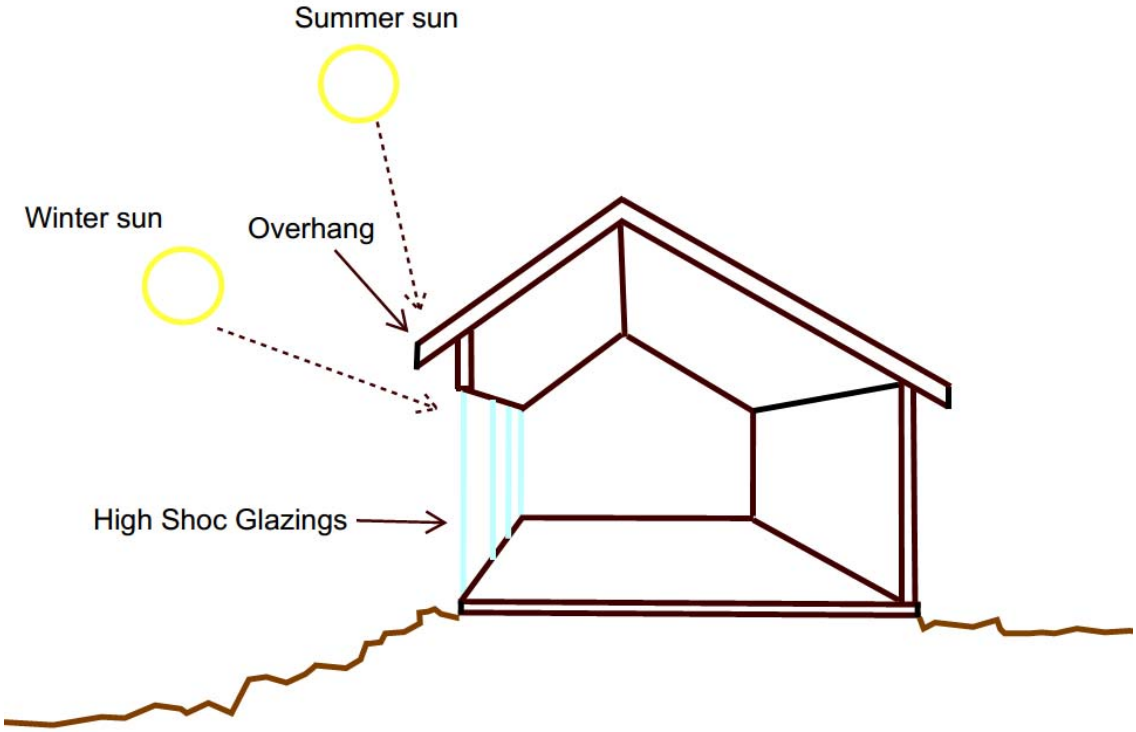

Figure 13 shows the low sun during winter and high sun during summer.

Another solution to minimize the overheating is by using “solar cube” in front of the windows. The cube works like an external shading during the summer solstice, when the sun is at its highest path through the sky. During the winter solstice that allow the sunlight shine through the cube and window to heat up the building. The cube creates a micro climate around the window that protects from cold wind, rain and snow. See figure 14. [12]

Figure 14 shows the designed solar cubes from Bright Living which are used as external solar shading during the summer. [12]

Doors and windows that are hinged in a frame to open inwards are more airtight than sliding doors. The closing mechanism pulls the door tight against the frame. The advantage compare to outward doors are that the hardware is inside the building envelope to increase the life time, and entering the building with the air flow that can reduce big amount of warm indoor air. See figure 15. [23]

Figure 15 shows the door hinged in a frame to open inwards and the hardware inside the building envelope.

Another solution to reduce the heat losses while enter-or exiting the building is using isolated porch. An isolated porch creates a weather protection and climate right outside the main door. It preheats the outside air while entering. The double door, the porch- and the main door prevent big amount of warm air to escape while opening the door to reduce the heat losses. See figure 16.

Figure 16 shows the porch from Bright living designed to avoid big amount of indoor air to escape while opening the main door. **[12]**

Insulation

The insulation has different materials and thickness to achieve a low U-value. In cool climates, the cost optimal insulation thickness for external wall and roof is around 240 mm insulation assuming a thermal conductivity of 0.036 W/(m*k), and cost effective thickness is 320 mm. This resulting even more energy effective in the long run and better independence from the energy price volatility. [17]

3.6 Ventilation and heat system

Ventilation

Heat recovery ventilation (HRV) systems are often used in cold climates to be able to exchange the heat from the stale air (exhausted air) and pass to the fresh cold air (supplied air). The ducts are leak proof and isolated from each other. Se figure 17.

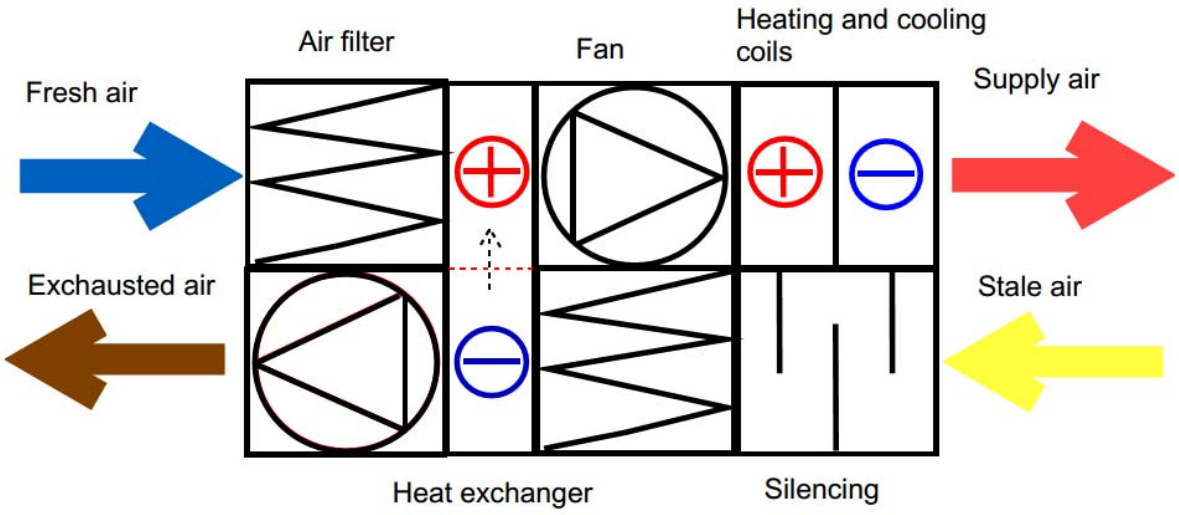

Figure 17 shows the main components of a ventilation unit from a HRV-system; air filter, heat exchanger, fan, silencing, heating- and cooling coils.

HRV is the most energy efficient ventilation system compare to mechanical, natural, mixed mode (hybrid) ventilation and infiltration. HRV system usually called balanced ventilation because of there is no pressure differences in the building envelope, but make it sensitive to air leaks. The airtightness needs to be as tight as possible to make the best combination with HRV. Depend on the outdoor temperature, heat exchangers can have its best efficiency over 90 %, and can eventually during hot summer work to a certain extent in reverse.

HRV is often combined with an open plan to facilitate the heat distribution throughout the supplied air. The supply air vent is often placed in the living room and bedroom. Extract through vents placed in rooms where moisture and odours build up, e.g. the bathrooms, kitchen, laundry room and storeroom, see figure 18. [17][24]

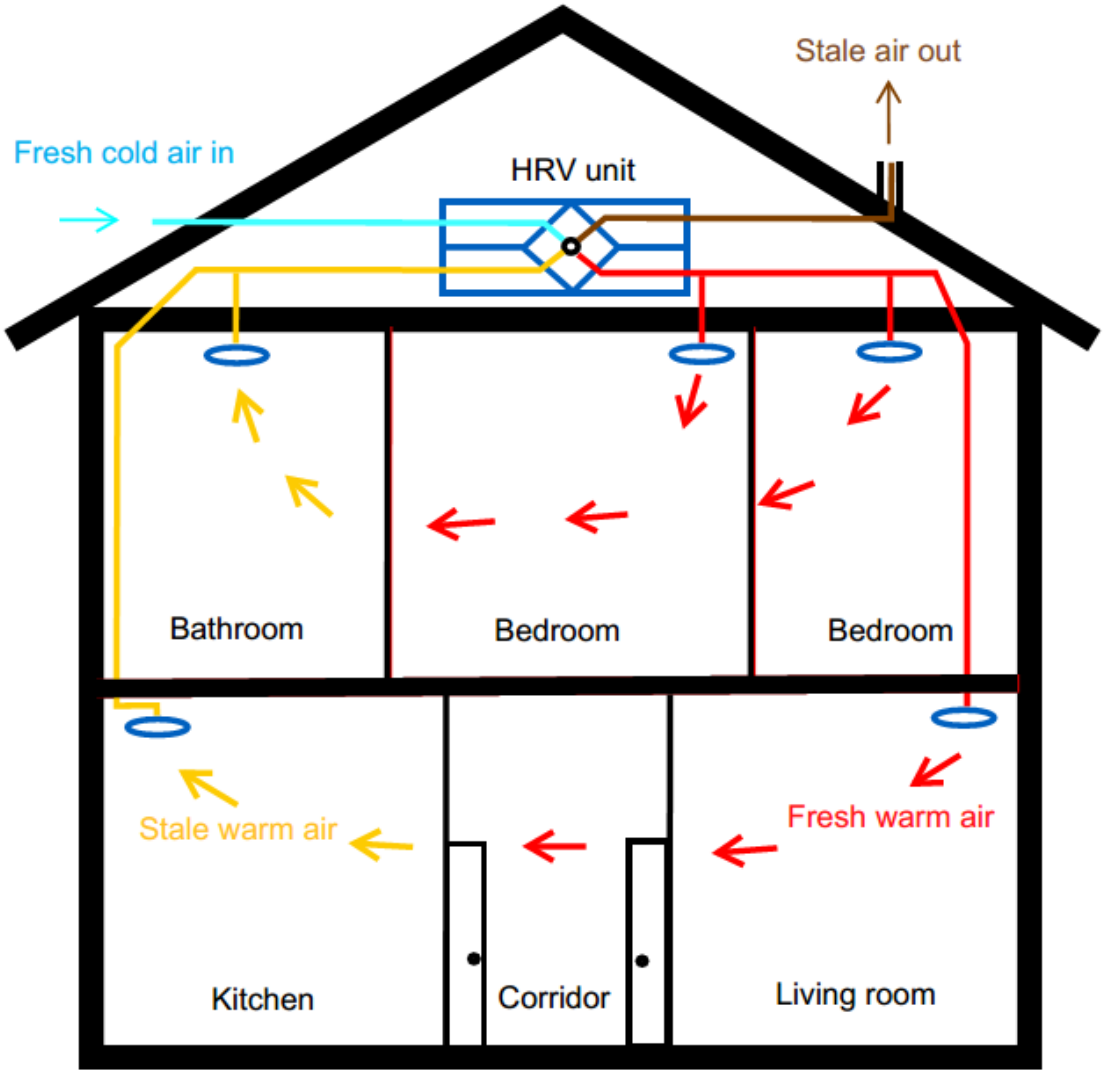

Figure 18 shows the air circulation in a house through air transfer zones and openings that are integrated in the door frame.

To be even more energy efficient, instead of extract the heated air from cooking the air can be charcoal filtered in a recirculating cooker hood to minimize the heat losses and ducting pipes.

The supply air vent is design to reach a strong air throw to minimize the unventilated zones and can be help with the “Coanda” effect. The effect occurs when the air jets from vents or opening are placed near a surface when the air in the room cannot be pulled together, instead

suck the air jet against the celling. See figure 19. [24]

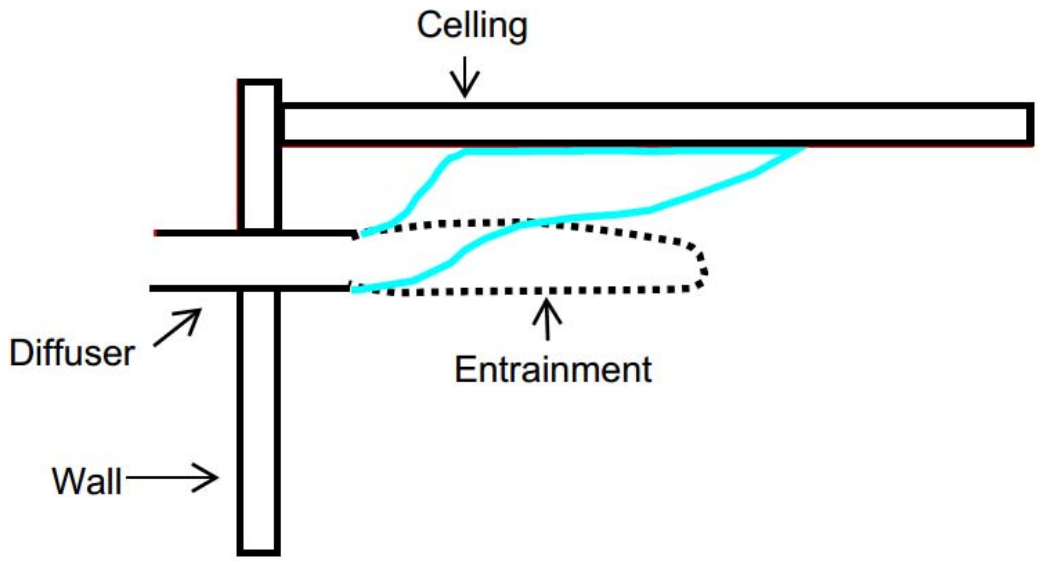

Figure 19 shows the air jet sucks against the celling, also known as the Coanda effect.

Heating system

In energy efficient buildings the heating distribution is often integrated with the HRV system. Heat pumps that is combined with coils in the ventilation unit. The heating coils and eventually cooling coils are used during peaks. When the high demand of heating or cooling is needed during cold winter or hot summer. The coils make up the remaining heating or cooling demand after the air has pass through the heat exchanger. It is energy saving to place the heating coil in front of the heat exchanger to preheat the fresh air, prevent the heat exchanger to freeze and increase thermal efficiency.

The heating system combined with the ventilation, hot water supply and storage in one system is an energy efficient and cost effective solution. The heat source can be produced from e.g. geothermal- or solar energy with the help of heat pump. See figure 20. [17][24]

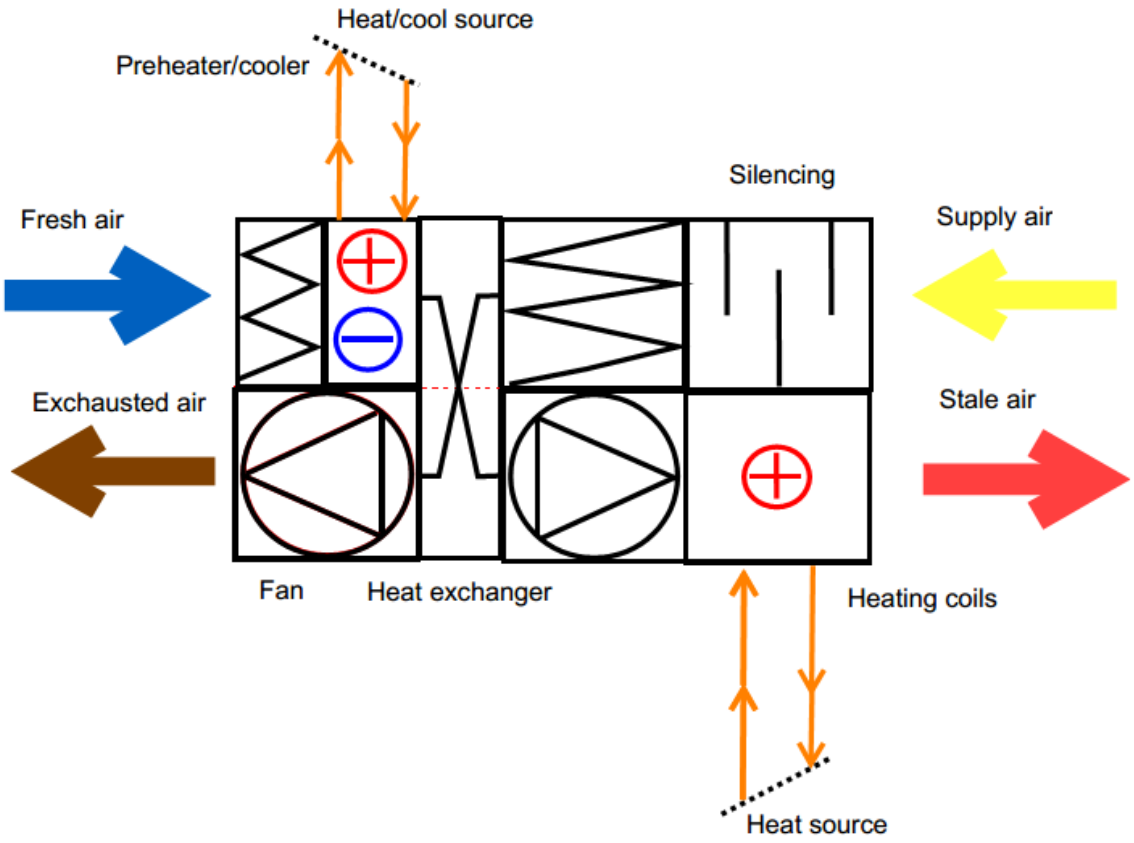

Figure 20 shows a ventilation unit with preheater and -cooler to prevent the heat exchanger to freeze and increase thermal efficiency

Heat pump

Heat pump is adaptable for a multitude of heating application relating to efficient end-use and efficient use of renewable energy sources. Inside a simple heat pump, circulating a fluid known as refrigerant around the four main components: high temperature condenser, low temperature evaporator, compressor and expansion to transfer the heat from low temperature source to the high temperature sink. See figure 21 and 22.

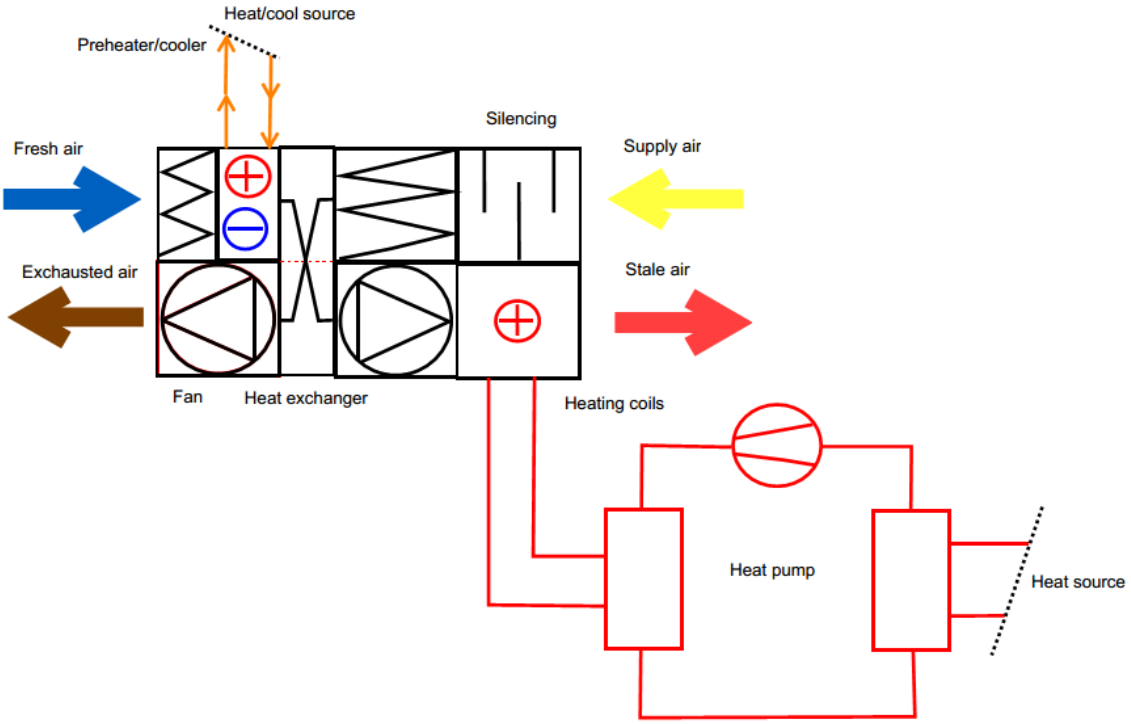

Figure 21 shows how the heat pump is connected to the heating coils in the ventilation unit.

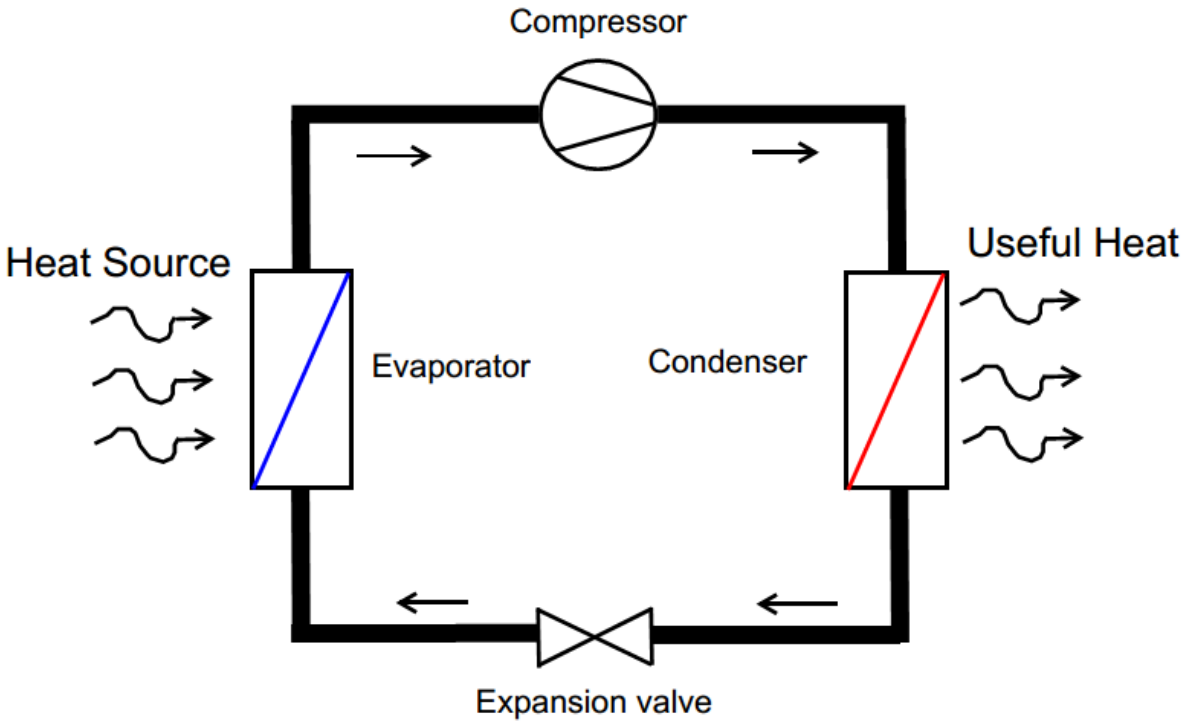

Figure 22 shows the four main components for a simple heat pump; evaporator, compressor, condenser and expansion valve.

The refrigerant enters the evaporator with a low-temperature and low pressure liquid to absorb the heat from the heat exchanger, and leaves as a vapor. The compressor is the only required electrical driven main component to increase the pressure in tandem with the

temperature. The high temperature and pressure vapor will condense when it has been cooled down or transferred the useful heat in the condenser, and leave as a high temperature liquid. On its return pass the expansion valve to the evaporator the refrigerant will have the same condition from the beginning of the cycle.[25]

The efficiency of the heat pump know as coefficient of performance (COP), is defined as the ration, ε between the transferred heat from the condenser, the useful heat or cooling from the evaporator, P_a, and the required drive energy, P_c. See equation 4.

$$\varepsilon = \frac{P_a + P_c}{P_c} \tag{4}$$

P_a is drive energy
P_c is useful energy

Geothermal heat pump brings the heat from the stored geothermal energy in the earth through pipes dug into deep borehole into the ground. This can only work if the geothermal conditions are appropriate. The heat source can be combined with other sources such as solar energy collectors or bought energy from district heating. [24]

3.7 Economy

In comparison of a conventional building with 85.6 kWh/(m^2*year) and a low energy building with 49 kWh/(m^2*year) have shown in a Life Cycle Cost Analysis (LCCA) that the additional investment is approximately 6.5% larger in relation to total production cost. The capital costs, maintaining and operation costs for energy efficient buildings is generally cost less over their lifetime than conventional counterparts. It is in a larger perspective more cost optimal to approach for energy efficient building. [27]

Life Cycle Cost Analysis (LCCA) is a process of evaluating the economic performance of i.e. a building or a building system over its lifetime. The process also known as “whole cost accounting”, “total cost of ownership”, or just life cycle cost, and can be implemented at any level of the project process, even on existing buildings. LCCA is based on assumptions on different building design option that achieve acceptable performance, and these options provides different “first costs” (design and construction expenses), operating, maintenance, and disposing cost.

LCCA has a significant impact on the principle of making informed decisions at the project level, and to secure the funds or rarely extend ongoing operation costs in the future it is important to pay attention to the whole cost cycle of a building. These costs can significant reduce the total cost of building ownership compare to shortsighted decisions which is often happened in the public sector that is often just based on their initial cost.

The use of LCCA is more prolific in the private sector compare to the public sector as there need to be more responsible to defend financial investment needs and the decision-making process. [28]

3.8 Solar cells technology

Solar cell or photovoltaic (PV) cell is an electrical device that transform the solar radiation or artificial light into electricity by physical and chemical phenomenon called the photovoltaic effect. PV cells have three generation; first generation is the most common type of semiconductor technology, mono-/polycrystalline silicon PV panels, second is thin film PV that is still in the development stage and latest third generation is the nanotechnology cells, Gräzel. [26]

The yearly energy production from solar cell can be calculated by the equation 5.

$$W_{year} = W_0 * A * \eta * K_1 * K_2 * K_3 * K_4 \quad (5)$$

W_0 is heat energy
A is solarcells area
η is solarcells efficiency
K_1 is slope factor
K_2 is orientation angel factor
K_3 is battery factor
K_4 is converter factor

4. Method

Feasibility study

The background and the purpose of the thesis have been formed from the motivation to work for a sustainable development and the EU´s environmental, energy and climates goals that are taken from the Europe Commission strategies.

Reviewed on UNFCCC report, Kyoto protocol and publications from EC have been done to identify the strategies to achieve the goals and the EPBD requirements on NZEB in Sweden. The chosen buildings have been done through communication with Passivhuscentrum to find suitable comparison objects, internet searching and contact with the house owner concerning the possibilities.

The theory has been based on the chosen buildings system configurations, climate- and energy efficient solutions from a literature study. Primary from independent research publications and directive protocols, and secondary from association, interviews and seminars. In addition, the thesis has been cooperated with Passivhuscentrum to provide in-depth knowledge of research in energy-efficient construction, and an insight how companies works with the energy challenge.

The thesis investigation questions have been formed after the feasibility study to be able to investigate a very specific question.

The investigation

The investigation was to see how Sweden develop plans to enhance the amount of NZEB, the Swedish definition of NZEB and quantitative approach on energy requirements for NZEB: s. EPBD requirements have thereby been reviewed to investigate on how the Swedish building

authority been working to meet their requirements.

The information about the chosen houses have been taken from the house owners or builders website, seminars and direct contact, such as the building construction, architect drawings, energy performance, verification, economy and experience.

The Swedish proposed definition of NZEB from NBHBP have been studied to be discussed and compared to analysis if it is reliable with today's technology, knowledge, climate- and energy efficient solutions. Thereby answering the thesis investigation questions.

5. Results of the investigation

5.1 Results of *Circuitus*

Architecture
The single storey house has 176.5 m^2 treated floor area. The house has big windows facing to the south, and all the rooms in the house shows in the figure 23.

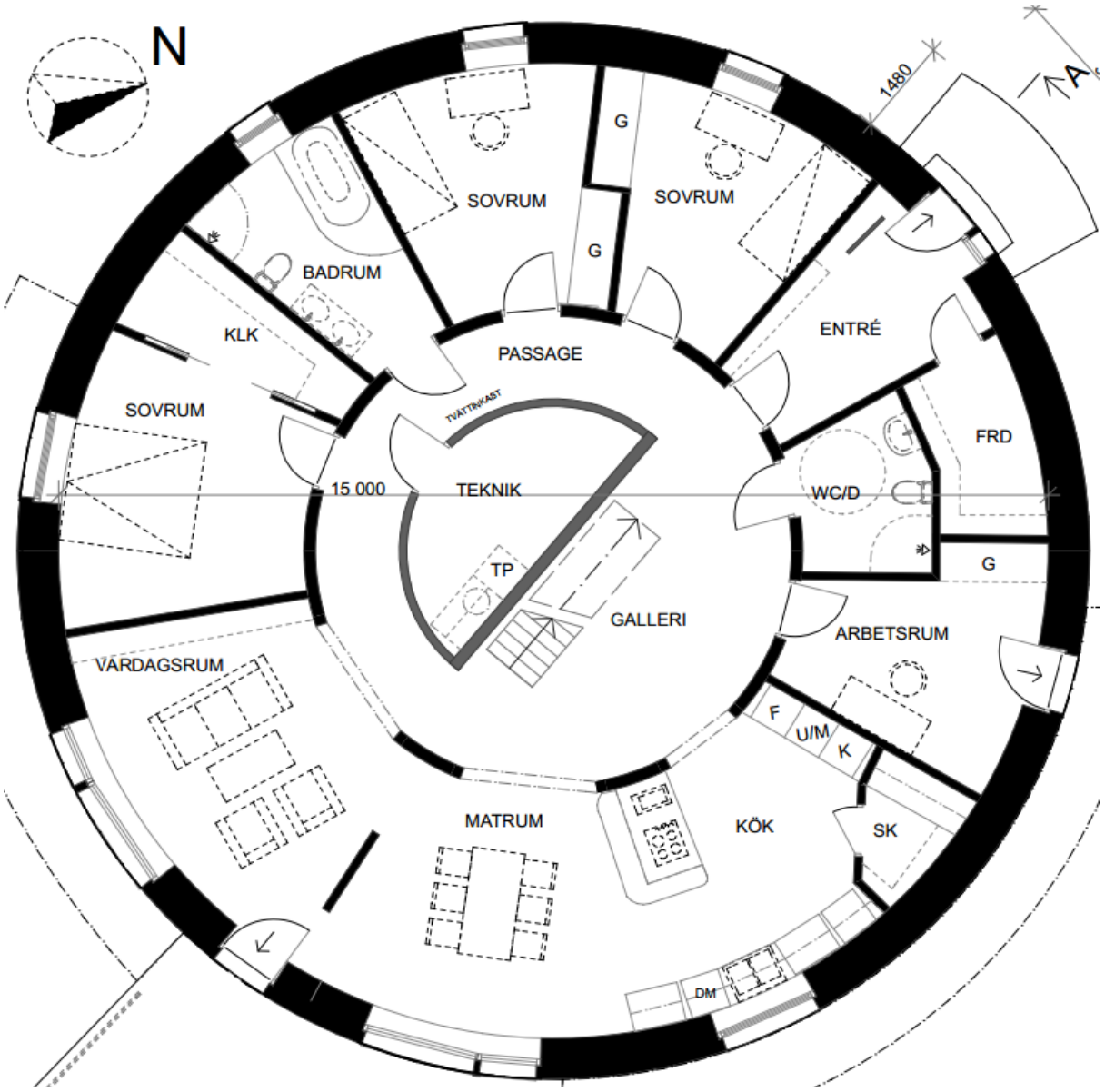

Figure 23 shows the first floor with 3 bedrooms, 2 water closet, office, technical room (that also work like a laundry room), gallery with a stairway, entrance, storeroom and an open family room (kitchen, dining- and living room).

The glass veranda on the second floor is outside the building envelope, has an area of 35 m^2 and around the veranda a roof terrace. See figure 24.

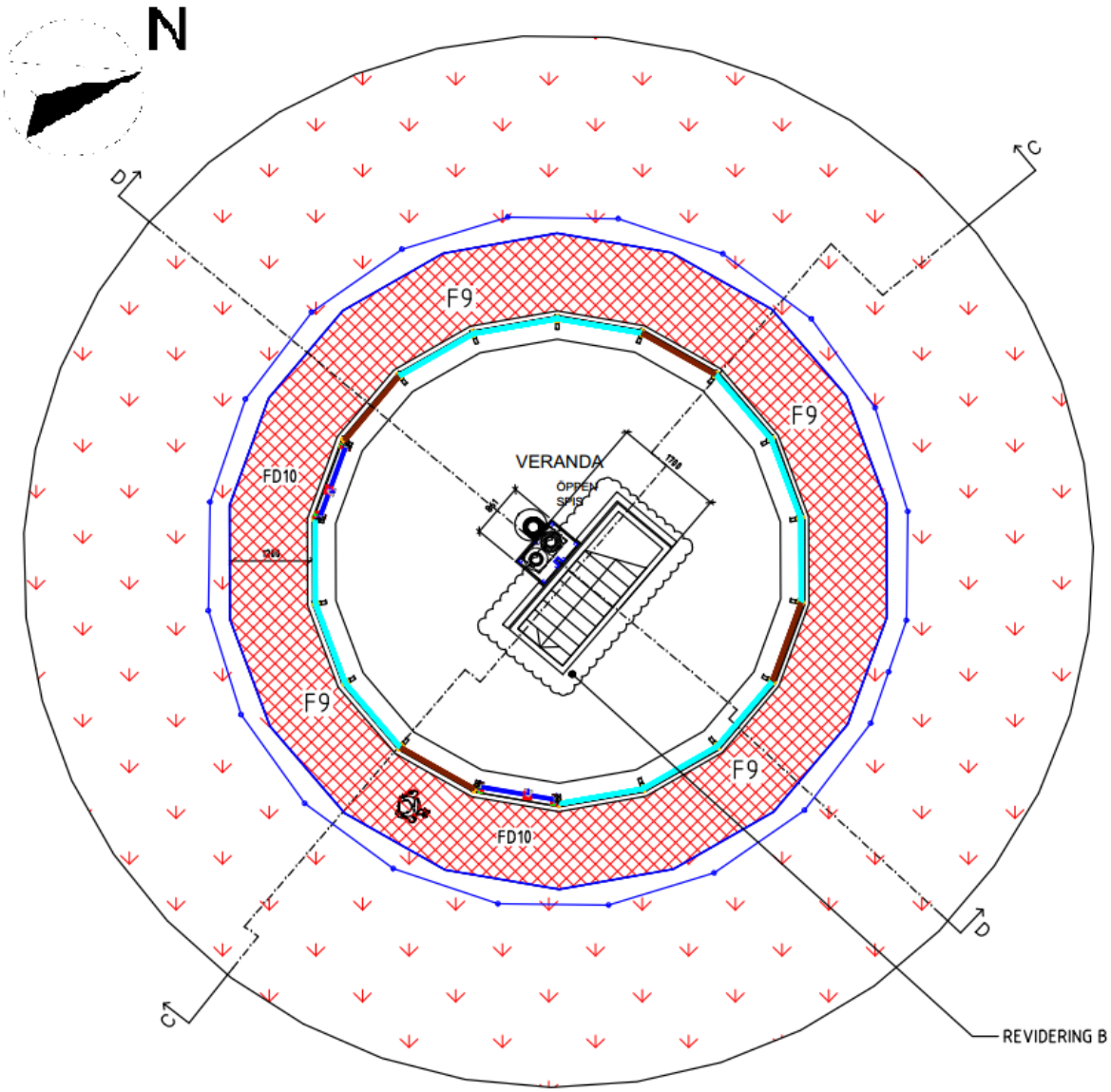

Figure 24 shows the "second" floor, the glass veranda, terrace, the balustrade, the glass door above the stairs and an open woodstove.

The Choice of material

The house has partly used recycled building and environmentally friendly materials. The exterior is made of modified softwood that undergoes a patented process with bio-based liquid to enhance the sustainability. The interior in the inner circle walls are made of airbricks with a layer of clay polish. The deck around the house is made of fossil wood which is free from the toxic biocides, and the glue that have been in used is also environmental friendly.

Building envelope and structural system

Roof and building foundation

The roof has U-value 0.07 W/m^{2}C made of, from inside out, plasterboard, 500 mm loose cellulose fiber insulation, wind protection barrier, airgap, wood panels, water proof rubber membrane, layer of wood chips and on top of that 2-3 cm sedum. See figure 24 and 25.

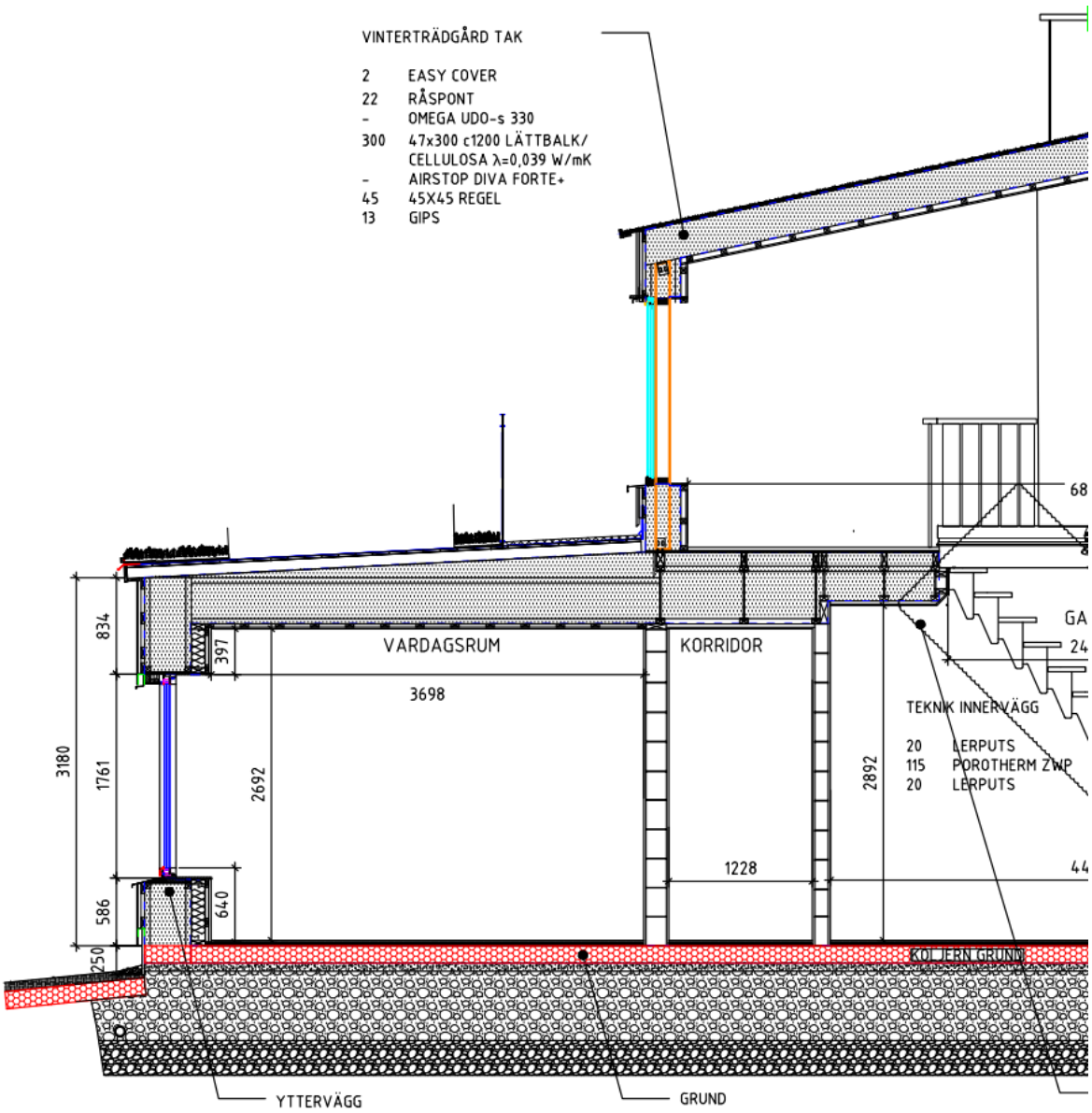

Figure 25 shows section of Circuitus, the roof covered with rubber membrane, sedum, the balustrade and the horisontal glass door above the stairs.

The orange safety glass on the roof is used as a balustrade which is integrated with silicon cells to transform the solar radiation into electricity. On the roof of the veranda is covered with black solar cells.

The foundation has an U-value of 0.11 W/m^{2}C made of 600 mm glass foam insulation, layer of rubble, radon protection barrier, layer of sand, 150 mm isolated cellular glass panels, wind protection barrier, 30 mm fiberboard and on top of that laminate floor.

Insulation

The outer wall has U-value 0.08 W/m^{2}C. The airtightness is 0.05 l/s, m^2 with a 50 Pascals pressure. The house has two frames, one outer frame that is made of 45x120 joist to construct the frontage and lift the roof, and one inner frame to lift the veranda. The outer wall is made of wood panel, furring and within the joist wood fiber insulation. Thereafter 400 mm joist, wind protection barrier, one open and one sealed vapor barrier with moisture variable vapor membrane, and within the barrier 400 mm cellulose fiber insulation.

Window and door

All windows and the entrance door are PH certified. The total window area is 26.5 m^2. The window frame is made of wood and aluminum with a U-value between 0,61 - 0,73 W/m^2 C depend on the size of the windows.

The entrance door, patio door and windows open inward to the house. The windows are assembled with marginal into the exterior wall and provided with sunshades both internally and externally. The internal are blinds and external fixed louvres. See figure 26.

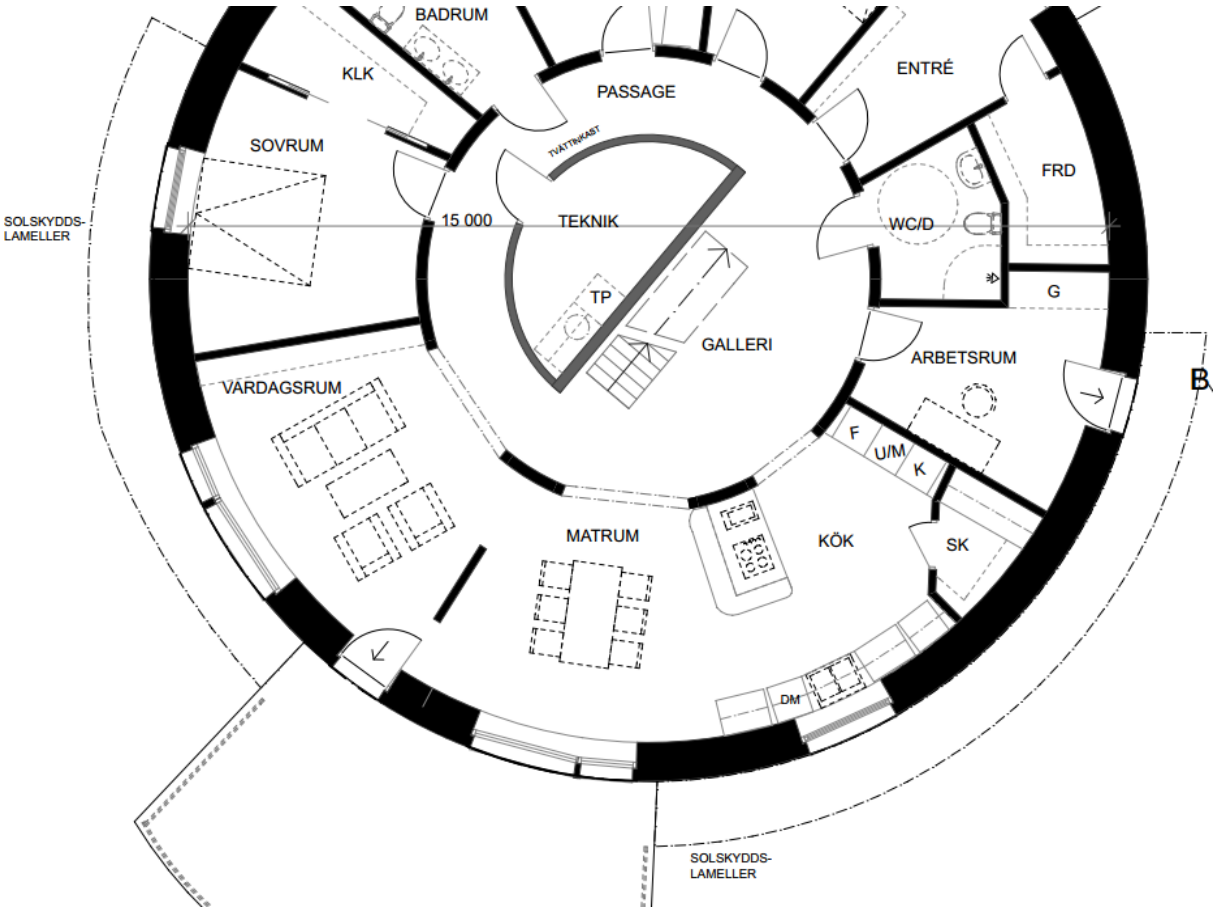

Figure 26 shows the external fixed louvres and the outer doors opens inwards.

Ventilation- and heating system

The ventilation is a HRV-system combine with geothermal heat pump. The heat exchanger is PH certificated and has an efficiency of 85-94 % depended on the outside temperature. The exhausted air transport from the toilets, bathroom, store room, and the kitchen to the heat exchanger where the fresh air preheats or precool, and continues to the living room, bed rooms and the office. The kitchen has a charcoal filter with a fan above the kitchen range. See

figure 27.

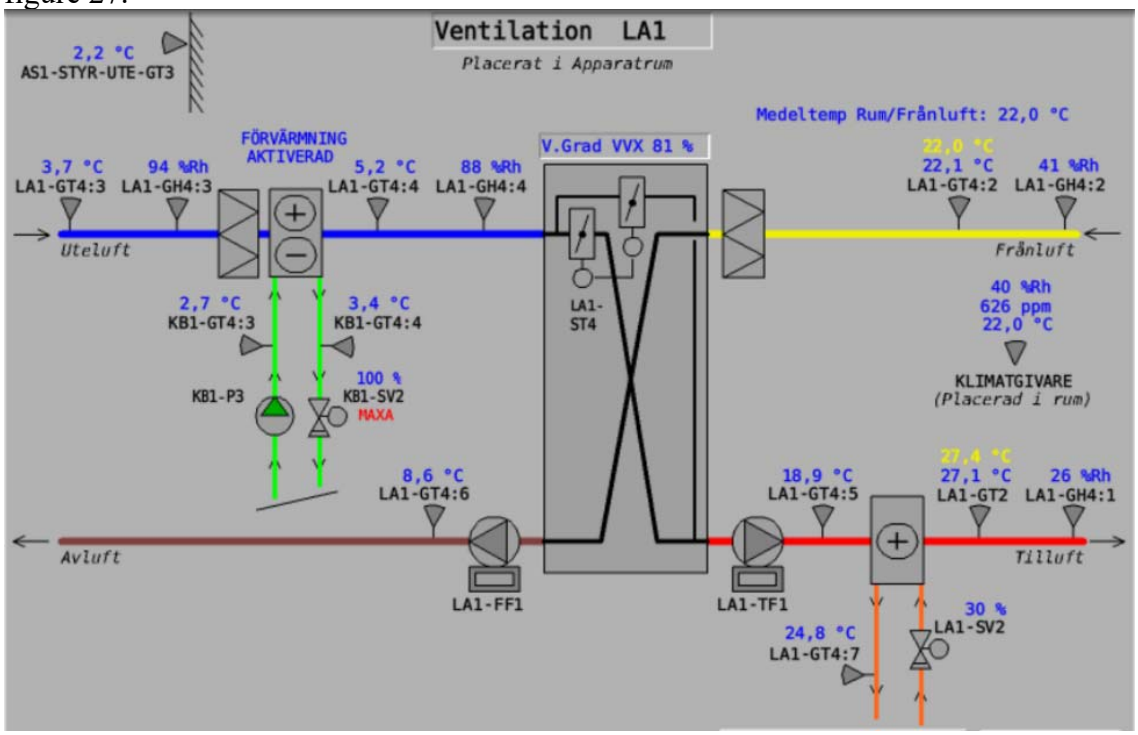

Figure 27 shows the ventilation unit in Circuitus and the air flow temperatures, date 2016-11-17.

The 3.5 kW heat pump supply the heat water in a small storage tank, and generates additional heat to the supplied air when it is required from the 90-meter depth ground loop. The supplied air has an air temperature of around 25 C out from the vents and directed under the roof to create a Coanda effect. The heat pump can also work as a passive cooler to a certain extent, e.g. when it is 30 C outside the indoor will be cool down to around 23 C. The house has two underfloor water heaters for comfort reasons, one in the bathroom and one in the kitchen floor.

Energy performance

The total annual energy demand from November 2015 to November 2016 is 48.3 kWh/m^2 without the produced electricity from the solar cells, and with the solar cells that have been in operation since September 2016, 36.3 kWh/m^2. See table 3.

Table 3 shows annual energy performance for Ciruitus divided in 4 different category.

Electricity for household	2395 kWh	13.6 kWh/m^2
Electricity to the technical systems of the building	3 864 kWh	21.9 kWh/m^2
Hot water and heating demand	2272 kWh (5906 kWh without the heat pump)	12.9 kWh/m^2 (33.5 kWh/m^2)
Solar cells (6 month)	2129 kWh	12.0 kWh/m^2

According to equation 1 the specific energy performance is 22.7 kWh/m^2 and year without the produced electricity. This result to that Circuits can be achieved as a NZEB, 80 kWh/m^2

according to the proposed Swedish definition of NZEB from NBHBP.

Economy
The total cost for the building *Circuitus* is 24,000 SEK/m^2. The geothermal heat pumps system combines it with and heat recovery ventilation system cost 250,000 SEK, photo voltaic 150,000 SEK, the external weather protection that was in use during the construction 270,000 SEK. See table 4 for more information.

Table 4 shows the total cost of the building Circuitus

Earthwork	700,000 SEK
Construction work include solar cells	3,192,500 SEK
Water- and drain system	190,000 SEK
HRV ventilation system	55,000 SEK
Electrical system	120,000 SEK
Sum of the construction cost	**4,250,000 SEK**

The geothermal heat pump used 12.9 kWh/m^2 year for an average indoor temperature of 22 Celsius, 23 Celsius in the WC and around 75 l hot domestic water per day. The heat pump system cost 130,000 SEK, has an average COP 2.6 that equal to 5906 kWh/year for the heating and will have a payoff time for around 15 years.

5.2 Results of *Bright Living*

Architecture
Bright Living is a 2 storey house with 5 rooms and a kitchen. The first floor has 78.5 m^2, the second 78.5 m^2 and the total threated floor area is 157 m^2. The living room can be used as an extra multiroom. See the figure 28.

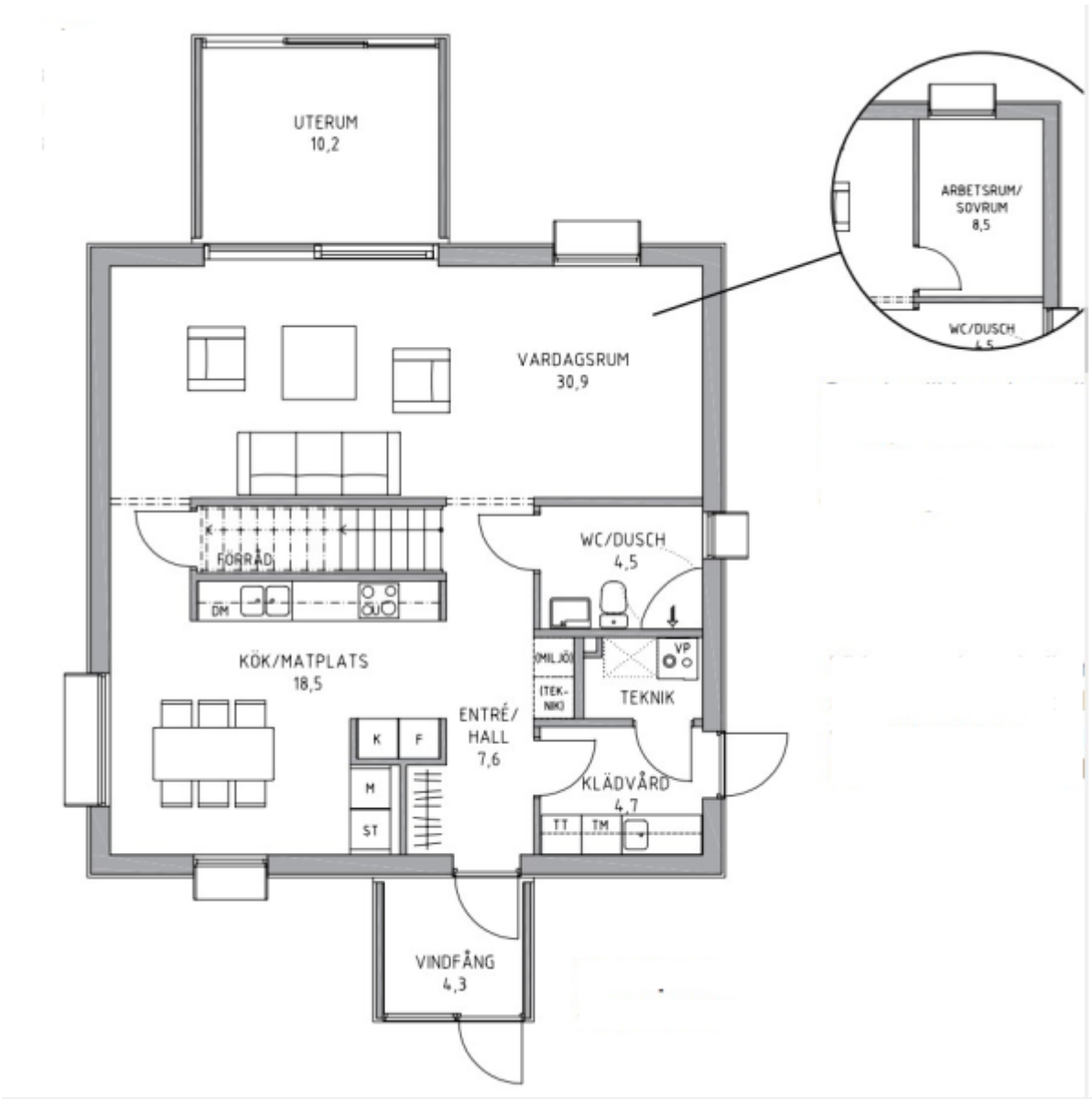

Figure 28 shows the first floor and the living room that can be used as an extra working or sleeping room.

On the second floor, there are three bedrooms, a bathroom and a walk-in-closet. See figure 29.

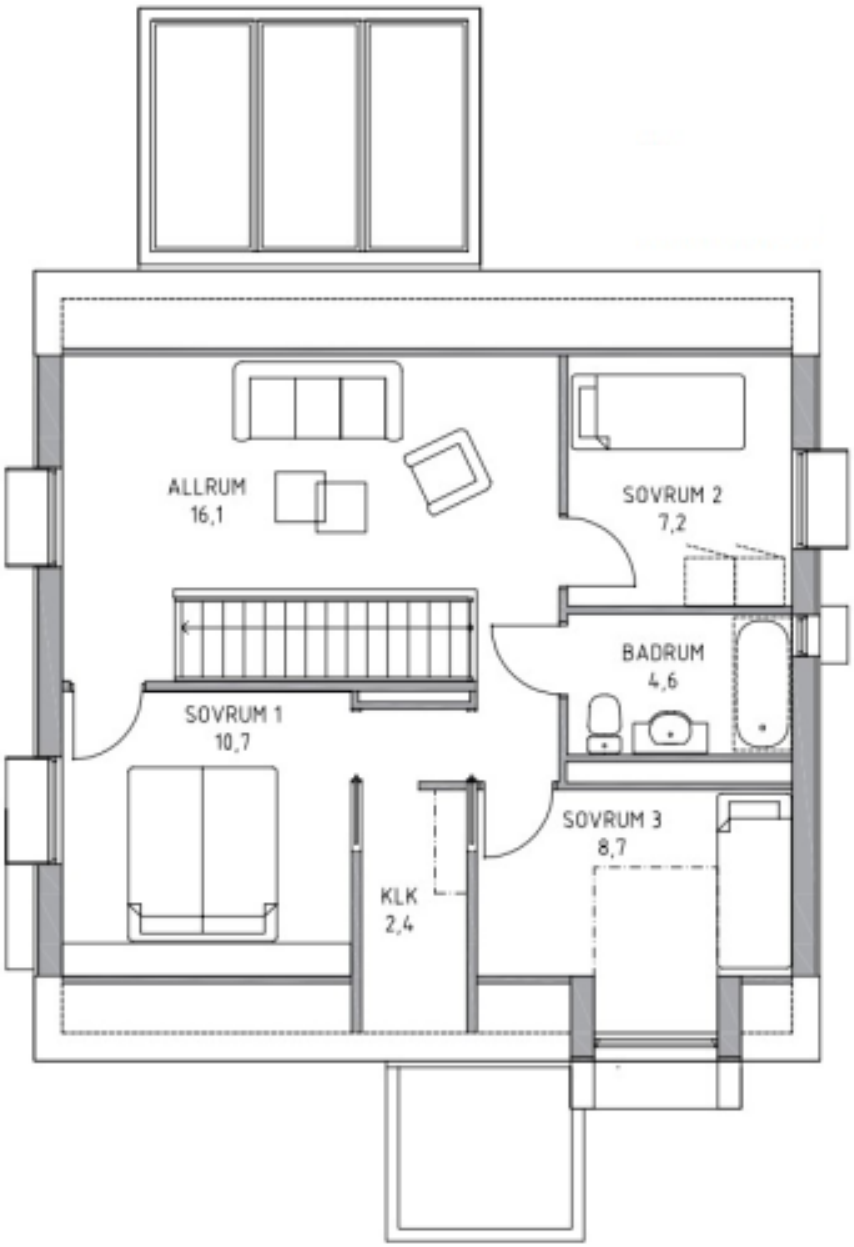

Figure 29 shows the second floor, the three bedrooms, bathroom and walk-in-closet.

Building Envelope and structural system

Roof and foundation

The roof has U-value of 0.098 W/m^{2}C made of 445 mm joist with mineral wool insulation and plasterboard. The solar panels are installed on the roof facing to the south. The foundation to1 meter depth has U-value of 0.116 W/m^{2}C.

Insulation

Outer wall has U-value of 0.136 W/m^{2}C that is made of 80 mm mineral wool, two joist, one 170mm and one 70 mm, wood panel and plasterboard. The airtightness is 0.07 l/s, m^2.

Window and door

The total windows area in the building is 25.3 m^2, 80% is glass area and have a U-value of 0.6, 0.8 or 1.2 W/m^2 C depend on the size of each windows. There are 6 windows and 2 doors, both door have the u-value of 0.8 W/m^2 C.

All the windows and doors are assembled with a solar cube in front of it, except the entrance door where a porch is used instead. See figure 30.

Figure 30 shows the house Bright living, the black solar cubes in front the windows and the white porch to the entrance door.

The cubes and the porch are for creating a micro climate around the windows and doors, and as an external sun shading during the high summer solstice. The internal sun shading are blinds. See figure 31.

Figure 31 shows the view on solar cubes inside-out of the building, and as it allows the sunlight shine through the cube during the low winter solstice.

Ventilation- and heating system

The ventilation system is a HRV-system combine with heat pump. The heat exchanger has an average efficiency of 79.6 %. The supplied air flow is 56 l/s with a minimum temperature of 20 C.

The heat pump use the 8.8 m^2 solar panels as a heat source during April to October, otherwise from district heating when it is needed during cold weather and low solar radiation for heating the supplied air and the domestic hot water.

Energy performance
The total annual energy demand is 67.4 kWh/m^2 without the produced solar heat, and with 51.0 kWh/m^2. See table 5.

Table 5 shows annual energy performance for Bright Living divided in 4 different category.

Electricity for household	5,611 kWh	36.2 kWh/m^2
Bought energy for heating	2,893 kWh	18.6 kWh/m^2
Bought energy for hot water	2,077 kWh	13.4 kWh/m^2
Solar energy	2,570 kWh	16.56 kWh/m^2

The specific energy performance is 35 kWh/ (m^2 and year). This result to that *Bright living* can be achieved as a NZEB according to NBHBP.

Economy
The total production cost for the house *Bright living* is 4,025,960 SEK or 25,500 SEK/m^2.

5.3 Comparison between *Circuitus* and *Bright Living*

Table 6 shows the differences between Circuitus and Bright Living.

	Circuitus	*Bright Living*
U-value, roof	0.07 W/m^2C	0.098 W/m^2C
U-value, foundation	0.11 W/m^2C	0.116 W/m^2C
U-value, wall	0.08 W/m^2C	0.136 W/m^2C
U-value, windows and door	0.61 – 0.73 W/m^2C	0.6 – 1.2 W/m^2C
Threated floor area	176.5 m^2	157 m^2
Windows area	26.5 m^2	25.3 m^2
Airtightness	0.05 l/s	0.07 l/s
Efficiency, heat exchanger	85-94 %	79.6 %
Temperature of the supplied	Average 22 C	Minimum 20 C

air		
Energy performance without the generate energy on site	48.3 kWh/m^2 and year	67.4 kWh/m^2 and year
Generate solar energy on site	12.0 kWh/m^2 (6 month)	16.56 kWh/m^2 and year
Specific energy demand (equation 1) without the generate solar energy on site	22.7 kWh/m^2 and year	35 kWh/m^2 and year
Total construction cost	4,250.000 SEK	4,025,960 SEK

6. Discussion

6.1 Discussion concerning the building requirements

Since the EPBD does not give a minimum or a maximum energy building performance on the requirements on NZEB, as well as details of energy performance calculation framework. It is up to the Member states to set the system boundaries as well as
how ambitious they want to be.

LCCA and LCA
Nowadays, the project of the cost is often based upon project initial cost. The long-term cost; maintenance-, operation- and disposal cost are often overlooked and leads to a short-term decision. Studies have shown that energy efficient buildings in a LCCA is regularly cheaper price choice than a conventional one. Nevertheless, this analysis may not be easy for a residence to comprehend. The lack of knowledge can be the reason why the interest in LCCA is not that attractive and these long-term costs may not be of interest by entrepreneurs, because they do not usually pay it.

From an ecological perspective, the most price effective solution is not always the most environmental friendly choice. The core of "sustainability" is a balance between human concerns (the quality of life) and environmental concerns (ecological footprint). The EPBD requires an environmental impact assessment on the development plans to enhance the amount of NZEB. One way to assess environmental impacts associated with the products or materials life cycle is to do a LCA, and from there find a balance to achieve the most sustainable solution.

Energy requirements for NZEB
An estimate of the possible energy requirements for NZEB can be set by comparing todays existing green building certification that already have different realistic requirements, such as *Green building*, *BREEM*, *LEED*, *Miljöbyggnad* and *Passive house*. These are the certifications that usually have routines in controlling the energy requirements, and are designed by experts in efficient energy buildings.

The energy requirements from NBHBP on the proposed NZEB is 80 kWh/(m^2*year). Compared to the classic passive house standard for all climates, PHI have divided the energy requirements; the heating demand to 15 kWh/(m^2*year) and the renewable primary energy to 60 kWh/(m^2*year) seem reasonable for a NZEB on today's technology and solution. However, the criteria from PHI is characteristic for all climate worldwide which makes it more challenging in cold climates, such as in Sweden.

Another challenge is how to verify the planning buildings are, and if they achieve the requirements that is being asked for. BBR wants the requirements to be verified partially from the calculations and from the measurements. The problem is that the theoretical aspect will never be the same in the practical terms, and if it is correctly calculated and very close to the measured value, it is often based on long mathematical formulas or many different factors. By using simulation program and systematic measure during the building process will make it easier and more accurate to get to the total measured energy performance.

NBHBP introduced proposal is a start to develop plans to enhance the amount of NZEB and

thereby ZEB. I see an advantage in stricter requirements on the heating- and the electricity demands associated to the proposed system boundaries. I can also see advantages how NBHBP are trying to enhance the technical solutions to integrate renewable energy in the buildings.

6.2 Discussion concerning the results

The specific energy demand for *Circuitus* is 22.7 respective *Bright Living* 35 kWh/m^2 and year. That is at least 35-55 % less energy than the energy requirement for newly built standard house in the climate Zone III from BBR22, see table 1. However, the produced solar cells have only been in operation for 6 month and the specific energy demand will be even lower when it has been in operation for a whole year for *Circuitus*. The first year for a new built building is always a test year to understand and adjust the buildings technical systems to optimize the performance, and the comfortness.

It is a challenge to build an energy efficient house; often due to of lack of knowledge, even if the passive house concept has been here for more than 25 years and still many people do not actually know what it is. There is myth about passive houses e.g. all windows must face to the south, it is expansive, the airtight building get moldy, complicated, needs to compromise the living quality etc. The challenge, theoretically and practically, to build an airtight and thermal free building and to find the right workers with such knowledge i.e. craftsmen who have the knowledge that can do an airtight installation that differ from commercials buildings, architects and constructors who can plan and design a thermal free and airtight building, as well as developers who can order the right building components, materials etc. There are reasons why the Swedish government gave the task to the Swedish building and energy authorities to improve the knowledge concerning low energy building, and to set a reasonable Swedish definition of NZEB.

The house *Circuitus* was built and is own by experts in passive houses. Experts that have the experience on how to find the right material, how to build an airtight and thermal bridge free building, They are involved in developing the concept of passive house through education, sharing and networking between energy efficient building experts, manufactures, as well as entrepreneurs that have made this project possible and costs 24,000 SEK/m^2. The house *Bright Living* was built by A-hus for 25,500 SEK/m^2 who offered to build similar houses for their client. It is not necessary expansive to build an energy efficient building than similar commercials buildings that can cost 18,000 – 28,000 SEK/m^2, and from a LCCA perspective.

6.3 Method

A closer contact with the house owner, the people from NBHBP who is involved in the proposed definition and the people from EPDB would facilitate the work of the investigation and give a better insight on how companies works with the energy challenge. As a student, it is difficult to get the attention from different companies and often get down prioritized with waiting a long time.

Be involved in an active building project would improve the feasibility study and the investigation questions to form even more specific questions and conclusion that can raise the quality of the thesis.

The selection of references has been done with care. The material for the investigation has mostly and primary been taken from independent research publications, EU directive protocols and Swedish authorities to keep up-to-date when it comes to the requirements and discarding old or wrong information. The information taken from electronic references is mainly from different research institute and house owners or builders website.

6.4 Future research possibilities

It is unnecessary for entrepreneurs or construction companies to do a LCCA to calculated the maintenance, operation and disposal cost because they usually do not pay it, as well as life cycle assessment because there are no any direct requirements. At the same time, both methods are not simple to understand or use for homeowners to decide or invest in a cost effective and environmental friendly project.

Political provisions of different requirements must consider different interests, and are often formed after how the interests are prioritize. Usually this involves a balance between the socio-economic effects and the environmental impacts, how strict energy requirements can be set to reduce the environmental impacts with a good national economy and energy system.

7. Conclusion

The most significant difference is that *Circuitus* has better heat exchanger and building envelope; lower U-value and better airtightness which results to better energy performance without counting the solar energy on site than *Bright Living*. Both houses are NZEB, per the Swedish definition proposal of NZEB from NBHBP,

The system boundary that NBHBP have set to calculate the specific energy performance with the introduced weighted factor. That is used as primary energy indicator to meet the EPBD meaning and regards, and to avoiding the use of electricity for heating and cooling. That makes it more possible to compensate the specific energy performance by using renewable energy generators on site, see equation 1. The crediting of renewable energy may accelerate the achievement of EU 20-20-20 goals. Nonetheless in the long term to achieve EU future goals – to make newly ZEB buildings may postpone the challenge to reduce the high energy- and resources demand. However, the effect of more stringent energy requirement should be set based on a longer term to move forward to a sustainable development. This system boundary cannot map the energy flow within the boundary or calculate the total building needs, total energy needs and renewable energy ratio. The risk is that buildings with inefficient technical system, and bad building envelope can use renewable energy technologies on site to compensate the delivered energy to achieve the 80 kWh/m^2, year (the proposed energy requirements for NZEB). This results to high energy cost along with large investments in renewable technologies on site, or the need to add fossil fuels to make up the high-energy demand.

I believe that the NBHBP should set a more detailed system boundaries for example like figure 4, and follow the strategy method, Kyoto pyramid when it comes to set stricter building requirements. Before the use of renewable energy generators on site to reduce the consequences. Firstly, stricter requirement on the airtightness, thermal bridge, heat transfer coefficient. Secondly, ensure efficient technical system; ventilation system, heat exchange and heat pumps. At last the total renewable energy ratio to the building. The primary energy indicator should be more related to the total renewable energy ratio (energy from renewable energy generators on site and delivered (bought) renewable energy on site) to be able to compare.

The concept of ZEB can be interpreted to be more ambitious in renewable energy technologies or in energy efficient measures to achieve as a ZEB. It is interesting to study how far we should go with energy efficiency measurements and when we should we start the implementation of renewable energy technologies in context of sustainability and finances.

My opinion on NBHBP proposed introduction of energy requirements based on the NZEB's analysis is that, it is not consequent enough to make a full assessment yet. Due to the method that has been used to analyze the choice of system boundary makes it possible to compensate the specific energy requirements by using renewable energy. However, the proposed energy requirement for NZEB with its proposed system boundary seems like a reliable requirement, compared to the results from *Circuitus* and *Bright Living.*

The living style of the resident is the most significant factor for the total carbon dioxide emissions, which is mostly caused by transportation and household activates. From efficient energy and intelligent building solutions, such as compact building (minor heating volume)

and by making rooms more versatile, can significantly reduce the carbon dioxide emissions - the demand of natural resources and energy. By focus more on making efficient compact buildings such as tower blocks, condominiums and dormitories etc. and not on individual family buildings can reduce the carbon dioxide emissions even more by sharing common surface, materials, building components etc. This will noteworthy reduce resources- and the energy demand. However, all the energy requirement and criteria are based on energy per treated floor area, (kWh/m^2) when we actually should be comparing the energy per treated floor area and person, $kWh/(m^2 * person)$ with limitations. It does not seem sustainable for a single person to live in a ZEB by him/herself.

8. Referenser

[1] Anon, 2020 climate & energy package - European Commission. Available at: http://ec.europa.eu/clima/policies/strategies/2020/index_en.htm [Accessed November 16, 2016b].

[2] European Union, 2014. SIXTH NATIONAL COMMUNICATION AND FIRST BIENNIAL REPORT FROM THE EUROPEAN UNION UNDER THE UN FRAMEWORK CONVENTION ON CLIMATE CHANGE (UNFCCC). In *required under the United Nations Framework Convention on Climate Change and the Kyoto Protocol*. Luxembourg. Available at: http://ec.europa.eu/clima/policies/strategies/progress/monitoring/docs/ec_6nc_en.pdf [Accessed November 16, 2016].

[3] Energimyndighet, 2015. Energiläget 2015. In Bromma. Available at: https://www.energimyndigheten.se/contentassets/50a0c7046ce54aa88e0151796950ba0a/energilaget-2015_webb.pdf [Accessed November 16, 2016].

[4] Anon, About Boverket. *Boverket*. Available at: http://www.boverket.se/en/start-in-english/about-boverket/ [Accessed November 16, 2016c].

[5] Energimyndigheten, 2014. Energimyndighetens arbete med näranollenergibyggande. Available at: http://www.energimyndigheten.se/globalassets/energieffektivisering/program-och-uppdrag/programbeskrivning-nne.pdf [Accessed November 16, 2016].

[6] Lars, A. & Lars, T., Passivhus--en handbok om energieffektivt byggande. *AB Svensk*.

[7] Crawley, D. et al., 2006. Zero Energy Buildings: A Critical Look at the Definition; Preprint. In California : National Renewable Energy Laboratory;U.S. Department of Energy. Available at: http://www.nrel.gov/docs/fy06osti/39833.pdf [Accessed November 16, 2016].

[8] Hermelink, A. et al., 2013. Towards nearly zero energy buildings - Definition of common principles under the EPBD. In Köln: Ecofys. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/nzeb_full_report.pdf [Accessed November 16, 2016].

[9] Boverket, 2015b. Förslag till svensk tillämpning av nära nollenergibyggnader. I. Karlskrona: Boverket. Available at: http://www.boverket.se/globalassets/publikationer/dokument/2015/forslag-till-svensk-tillampning-av-nara-nollenergibyggnader-2.pdf [Accessed November 16, 2016].

[10] Anon, Detta är Passivhuscentrum Västra Götaland | Passivhuscentrum. Available at: http://passivhuscentrum.se/kontakta [Accessed November 16, 2016e].

[11] Anon, Villa Circuitus | Det runda passivhuset Circuitus som var med i SVT Husdrömmar. Available at: http://circuitus.se/ [Accessed November 16, 2016j].

[12] Anon, One Tonne Life - Bli klimatsmart. *Open graph site name &*. Available at: http://www.a-hus.se/om-a-hus/vara-projekt/one-tonne-life [Accessed November 16, 2016i].

[13] Anon, Technical definition for nearly zero energy buildings: REHVA. Available at: http://www.rehva.eu/publications-and-resources/rehva-journal/2013/032013/technical-definition-for-nearly-zero-energy-buildings.html [Accessed January 31, 2017d].

[14] Boverket, 2011. Boverkets byggregler (föreskrifter och allmänna råd), BBR. In Boverket. Available at: http://www.boverket.se/contentassets/a9a584aa0e564c8998d079d752f6b76d/konsoliderad-bbr-2011-6-tom-2016-6.pdf [Accessed November 16, 2016].

[15] Boverket, 2015a. Boverkets föreskrifter om ändring i verkets byggregler. In Boverket. Available at: https://rinfo.boverket.se/BBR%5CPDF%5CBFS2015-3-BBR-22.pdf [Accessed November 16, 2016].

[16] Passive House Institute, Passivhaus Institut. Available at: http://www.passivehouse.com/01_passivehouseinstitute/01_passivehouseinstitute.htm [Accessed November 16, 2016].

[17] House, P., 2014. *Active for more comfort: Passive House*, Rheinstraße: International Passive House Association.

[18] Passive House Institute, 2016. *Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard*, Darmstadt.

[19] Mysen, M., 2008. Oppdragsrapport: Energireduserende tiltak i Husarveien 26. In *SINTEF Byggforsk*. Billingstad: SINTEF Byggforsk, p. 20.

[20] Andresen, I., Kleiven, T. & Knudstrup, M.-A., 2008. *State-of-the-Art Review. Methods and Tools for designing integrated building concepts* P. Heiselberg, ed., Aalborg, Denmark : Aalborg University.

[21] Ingemarsson, A. & Lisle, K., 2012. *What contributes most to sustainable development; Timber framed or concrete houses?* Master fo Science. Chalmers University of Technology. Available at: http://publications.lib.chalmers.se/records/fulltext/203521/203521.pdf [Accessed November 16, 2016].

[22] Alvarez, H., 1990. *Energiteknik. D. 2*, Studentlitteratur.

[23] Anon, Door - Energy Education. Available at: http://energyeducation.ca/encyclopedia/Door [Accessed November 17, 2016f].

[24] Dahlblom, M. & Warfvinge, C., 2010. Projektering av VVS-installationer. *Lund: Studentlitteratur AB*.

[25] Stefan, P., Invest in heat pumps. Available at: http://www.veoliawater2energy.com/en/references/heat-pumps/ [Accessed November 16, 2016].

[26] Anon, 5 fakta om solenergi som du inte vill missa | GreenMatch.se. Available at: http://www.greenmatch.se/blogg/2014/08/5-fakta-om-solenergi-som-du-inte-vill-missa [Accessed November 17, 2016a].

[27] Andersson, K. & Chiaussa, T., 2007. *Life Cycle Cost analysis of small houses – a comparison of Boverket´s energy requirements and energy efficient houses*. Master of Science. Chalmers University of Technology . Available at: http://documents.vsect.chalmers.se/CPL/exjobb2007/ex2007-116.pdf [Accessed November 16, 2016].

[28] University, S., 2005. *GUIDELINES FOR LIFE CYCLE COST ANALYSIS*, Standford.

Har som mål att jobba för en hållbar utveckling
genom klimat- och energitekniska lösningar
som kan påverka människans livskvalité, därmed människans levnadssätt.

HALMSTAD UNIVERSITY

PO Box 823, SE-301 18 Halmstad
Phone: +35 46 16 71 00
E-mail: registrator@hh.se
www.hh.se