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Simulation of an energy efficient single-family house in the area of Smedjebacken to meet Miljöbyggnad's Gold House energy category requirements

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Abstract

Since the building construction area is accounted for high share of energy usage (36 %) in Europe, there is high demand to pay attention to this area accurately. Sweden which is one of the pioneer countries in terms of building energy efficiency plans to reduce this value to 50 % by 2050. To reduce this value there is a need to define a mandatory guideline for builders by the government. So national board of housing, building and planning (Boverket) were given responsibility to define these regulations for builders and house owners. Parallel with that Swedish green building council developed a certification considering the building's energy demand, indoor air climate and environmental impact of building called Miljöbyggnad. While all the existing and new buildings following Boverket's regulations meet this certification's lowest limitations, some ambitious builders tend to fulfil its highest level of limitations called Gold level.

This study aimed to design a house in the area of Smedjebacken to meet Miljöbyggnad's gold house's energy category requirements. To meet the mentioned requirements several parametric studies regarding insulation thickness, windows assembly, heating and ventilation system are done via simulation software called TRNSYS. The result of testing several models show that although windows assembly does not affect this building's energy demand very much, other parameters such as insulation's thickness and type of heating system have a key role.

In addition, a parametric study regarding the impact of thermal mass on the building energy demand is performed. The result shows that the effect of removed massive wood is compensated by replaced additional mineral wool insulation.

In conclusion it is concluded that a single family house located in a cold climate like Smedjebacken using district heating cannot meet Miljöbyggnad's gold level criteria without help of heat recovery ventilation. Furthermore, building with ground source heat pump as its heating system can meet Miljöbyggnad's principals easier than those having district heating. In this case building with 200 mm insulation thickness even with exhaust air ventilation meets certification principals easily.

Keywords: TRNSYS, insulation thickness, ground source heat pump, district heating, heat recovery ventilation, Miljöbyggnad

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Abbreviations

Abbreviation	Description
CLT	Cross Laminated Timber
COP	Coefficient of Performance
DH	District Heating
DHW	Domestic Hot Water
EAV	Exhaust Air Ventilation
GSHP	Ground Source Heat Pump
HPD	Heat Power Demand
HRV	Heat Recovery Ventilation
HVAC	Heating, Ventilation and Air Conditioning
SLV	Solar heat Load

Nomenclature

Symbol	Description	Unit
A_{om}	Total surface area of the building envelope facing the heated indoor air	m^2
A_{temp}	The area enclosed by the inside of the building envelope of all storeys including cellars and attics for temperature-controlled spaces are intended to be heated to more than 10 ºC	m^2
E_f	Building property energy	
E_{kyl}	Bought energy	
EP_{pet}	Building primary energy	
F_{geo}	Geographical adjustment	
PE	Primary energy factor per energy carrier	
PE_{el}	Primary energy factor per electricity energy carrier	
U-value	the effectiveness of a material as an insulator in buildings	W/m^2K
G-value	Solar radiation transmitted through the window	

1 Introduction

1.1 Background

Nowadays with an increase in the amount of energy usage in human daily life in one hand and depletion of energy sources in other hand, a big concern regarding the rate of the waste energy and energy consumption has come up. To find out the main areas of energy consumption and waste energy, several studies have been done in different areas such as building, transport, industry and etc. The results showed that the biggest share of total energy consumption allocates to the building sector with 37% in Europe [1].

Swedish National Board of Housing, Building and Planning (Boverket) has defined a mandatory provisions and general recommendation to reduce building's share of energy usage. In these regulations there is a chapter called energy management that must be followed by builders in Sweden's building market. According to this chapter existing building and new building should be renovated and built respectively in order to have a low rate of heat loss, low heating and cooling demand and efficient electricity usage [2]. In addition, Sweden Green Building Council (SGBC) with a help of government agencies has developed and introduced a specific environmentally-friendly certification for the Swedish conditions and climate called Miljöbyggnad. The main reason of developing this certification was to privilege an environmentally-friendly building with a high rate of efficiency compared to the other building without certification. This certification investigates 16 different indicators such as ventilation, energy sources and light. In three categories of Energy use, Indoor climate and Materials and chemicals which covers three area of energy efficiency, human comfort and environmental aspects respectively. Furthermore, it certifies buildings in three levels: Bronze, Silver and Gold in which Gold level requires the highest level of energy conservations [3].

In order to decrease the building's energy demand, critical areas where energy wasting and overloading take place must be distinguished and be designed to avoid energy loss. As the critical point, building envelope contains surfaces such as external walls, windows, doors, roof, ceilings and floor, which separate the conditioned indoor air climate of the building from the outside, accounts for heat transfer. To reduce the rate of this heat transfer, various promotions such as low U-value windows, adding insulation material and using a building envelope's materials with high thermal properties must be taken into account [4]. For example, natural wood (natural eco cycle) material with high thermal performance, low weight despite of high stability can be used as the building envelope's components [5]. Another explanation of critical point to be called up for promotion and optimization are heating, ventilation and air conditioning (HVAC) systems with an ability of infiltration and overloading. For instance, applying heat pumps using free energy from ambient air, water or ground to heat up the building is an example of energy efficient heating system [6]. Or heat recovery ventilation (HRV) recovers building's heat loss through ventilation system is an energy efficient alternative for exhaust air ventilation.

This study is done with the help of simulation software called TRNSYS. A reference building is developed based on using district heating or ground source heat pump as a heating system in order to fulfil Miljöbyggnad's criteria. While the focus of parametric is on reducing building's energy usage by increasing the insulation thickness, in the models need more energy reduction other developments such as HRV with 70% efficiency and windows with lower U-value of 0.7 (W/m^2K) is used. On the other hand, to increase the energy conservation of the building different control strategies for reference building are applied. Applied control strategies are heating and cooling set points based on home occupancy and sleeping conditions, ventilation rate based on home occupancy and external shading based on indoor temperature.

1.2 Dala Massiveträ

A company called Dala Massiveträ working in an area of wooden building structure conductes the project in cooperation with Chines Company called China-Europe Productivity Centre (CEPC) as an investor to build some energy efficient house in Smedjebacken for sale.

1.3 Aims & Objectives

This study aims to evaluate the requirements on the building structure and heating system of single family house to meet Miljövyggnad's Gold house energy requirements.

The questions to be studied are as the following:

1. What insulation thickness is needed to meet Miljöbyggnad's gold house's energy categories' requirements?

2. What type pf window assembly gives the best resolution (g-value) while it has as lowest as possible U-value and also perform well against overheating during summer?

3. How much is the building's energy use for district heating and ground source heat pump?

4. How much energy saves by applying heat recovery ventilation (HRV) instead of exhaust air ventilation (EAV)?

5. Evaluate required insulation, windows properties, heating and ventilation system to fulfil Milijöbyggnad's gold house's energy categories' requirements.

The thesis' objective is to analyses the impact of different parameters on the building energy demand and the possibilities to fulfil Miljöbyggnad's gold house's energy category's requirements.

In conclusion while building sector accounts for considerable share of energy consumption in Europe, Boverket and SGBC have defined some regulations in order to lead companies and builders to construct and renovate buildings efficiently. To minimize building's energy usage, several energy efficient measures such as high level of insulation, low U-value windows, sealed building envelope and using low energy HVAC systems must be taken into account. This study aims to assess the requirements on the building structure and heating system of single family house in order to meet Miljövyggnad's Gold house energy category.

2 Literature Review

In this chapter relative studies regarding an energy efficient measures in order to fulfill Miljöbyggnad's energy category's gold level principals are investigated. These actions could be in the area of passive design such as insulation thickness, windows assembly and control strategies or active approaches such as heating and ventilation system.

In order to reach the certification's Gold level, Waldron (2017) in his study simulated the impact of electrochromic windows instead of conventional windows on an office building in three area of Stockholm, Umeå and Malmö. The result show that although electromagnetic windows have a significant influence on Solar Heat Load, have not enough effects on building's energy reduction [7].

On the other hand, Dabios (2017) in his study regarding a good daylighting and low energy use in multi-family house in Augustenborg proved that having optimized windows' sizes placed in an appropriate orientation to take advantage of solar heat gain and daylight lead to gold level of certification. in addition, the study shows the demand of external shading to avoid overheating through the larger windows [8].

In addition, another study in regard of a constructing a green building which meet Miljöbyggnad's silver level and up's requirements in the region of Västra Götalands has been done by the Centre for International Climate Research (2017). The result illustrated that applying a passive technologies such as giant insulation thickness, low windows U-value and building orientation can be a solution to attain the goal [9].

A study was done by Li (2015) discussed about the energy performance of five story multifamily building located in Gavle in order to meet certification's energy principals. He concluded that using district heating as a heating system with heat recovery ventilation (85% efficiency) as well as occupancy control strategy would meet Miljöbyggnad's gold level of energy use [10].

As a practical example of a building attained Gold level of Miljöbyggnad, Herrestaskola in Järfälla (2015) can be named. The building has low energy use, based on mechanical heat recovery ventilation and district heating. In addition, rooftop solar cell generates 16.5 kWh electric energy per m^2 annually and the power needs to be purchased provides through solar, wind, hydropower or geothermal sources [11].

2.1 Massive wood building

To investigate the privilege of wooden material on other alternatives such as concrete and steel, a study regarding the environmental and economic impacts of various construction materials has been done by Petersen et al. (2005). In this study they concluded that the amount of greenhouse gas emission avoided by wooden material compare to steel is between 36 and 530 kg CO_2 per m^3, while this value is 93-1062 kg CO_2 per m^3 in comparison with concrete. Furthermore, wood releases less SO_2 emission than concrete and steel while the risk of toxicological of wood on human health is more than alternative materials due to its preservative treated. So it is resulted that wooden material has less environmental impact than other alternatives. From the economical point of view, they claimed that massive wood house is 12 % less expensive than a similar house in concrete and 20 % less than steel structure building which shows wood is competitive on price as well [12].

2.2 Insulation

One of the key parameters to build an energy efficient house is insulation material. This material reduces the heat loss through the wall assembly and as a result decreases building's energy demand. The impact of insulation material on the heat transfer depends on its thermal conductivity.

Apart of the type of insulation material and its properties, increasing the thickness of insulation material causes a declining energy demand of the building by increasing the thermal resistance of the building envelope (R-value) [13].

Furthermore since building sector is responsible for 36% of emitted carbon in Europe [14] the environmental impact of insulation material should be considered as well. For example, although inorganic material such as extruded polystyrene have a very low thermal conductivity and low heat transfer, their environmental impact is high compare to the organic materials such as wood fiber board so the preference is bio-based materials with acceptable thermal characteristics [15]. This can be the main reason of high interests regarding applying wooden fiber insulation material in the market.

In addition, simultaneously "Annual energy cost of the building reduces by increasing building's insulation thickness". This statement has been raised by a study at Pamukkale University (2017) in Turkey regarding the energy cost of the building [16]. Therefore it is expected that optimum insulation thickness is obtained until the cost of insulation material does not exceed the cost for saved energy otherwise it does not have any economic benefit [17].

2.3 Windows assembly

It has been stated that about 20-40 % of heat losses through building envelope is allocated to windows assembly [18]. So the thermal properties of windows (U-value and G-value) become highlighted in buildings energy usage.

While window's U-value accounted for thermal heat transfer, its G-value shows the amount of solar radiation transmitted through the window's glazing. G-value closer to 1 gives more opportunity to take advantage from solar radiation to heat up the house and consequently to reduce the heating demand and artificial lighting. However, the latter feature can be a reason of overheating in summer. So as Grynning et al.(2013) concluded, to select the best choice, the contradiction between visual and energy aspect of the window must be in balanced [19].

2.4 Heating and Ventilation systems

The implementation of energy efficiency is not only restricted to the energy resources and building envelope but also contains active heating, domestic hot water (DHW) and ventilation systems. Hesaraki (2018) stated that nowadays with development of studies and technologies in the area of efficient heating and ventilation systems, many innovative ideas and high efficient systems has been introduced to the market. District heating (DH), ground source heat pump (GSHP) and mechanical heat recovery ventilation can be named as a good example of these systems [20].

District Heating (DH)

Combusting waste materials plus waste heat from industrial areas and renewable sources such as biomass to produce hot water and delivering it through underground pipes to the customers called district heating. Warner (2017) illustrated that having non fossil fuels resources outstands this system as a 100 % energy efficient and environmentally-friendly system among other heating and cooling systems [21]. Also more than 50 % of heating demand of multifamily houses and commercial buildings in Sweden is supplied by district heating and 25 % of it provided by heat pumps which is a main rival of distirict heating [22].

Ground Source Heat Pump (GSHP)

A Ground Source Heat Pump is an energy efficient system that uses moderately constant temperature of earth to heat up the building in winter or cool down it in summer. There are two categories of GSHP: 1) horizontal loop 2) vertical borehole loop. In this system the refrigerant liquid flowing through a pipes gets the heat from the ground and transfers it to the heat pump. Heat pump heat up the transferred heat to the higher temperature by compressing it. Then the high temperature heat is used to provide hot water and heating for the building. This system uses 1 kilowatt-hour electricity to generate three to four kilowatt-hour heat [23]. With dividing the amount of produced heat to the used electricity, the system's coefficient of performance (COP) is calculated. It is concluded that, its COP shows its efficiency and can be vary between three and four or even according to some study five [24] which classified this system as an energy efficient system. It is reported that this value depends on various parameters such as ground properties and borehole heat exchanger which is not relevant to this project to be investigated. Therefore a study has been conducted by the students of Riga Technical University shows that GSHP using ammonia as a refrigerant liquid can reach to the COP of 4 for producing both hot tap water and heating demand [25].

Heat Recovery Ventilation (HRV)

To build a low energy building specially in a cold climate of Sweden, mechanical ventilation systems providing heating, ventilation and air-conditioning (HVAC) is an effective solution. In 2013 Akbari and Oman in their study showed that heat recovery ventilation systems can save 30 $kWhm^{-2}$ energy lost via ventilation annually compare to exhaust air ventilation in Sweden. Moreover, this system can increase building's indoor air quality by removing radon components from air since the ventilation rates can increase without draught and high energy demands. In addition 80% heat recovery ventilation with two fans of supply air and exhaust air consumes 963 kWh energy per year which can be named as its drawback [26].

2.5 Control strategy

Nowadays apart of using energy efficient technologies such as insulation material, heat recovery ventilation, energy efficient windows and etc. Control strategy is another option toward reduction of building's energy consumption. For example, a study has been carried out in the US (2011) for both cold and hot-humid climate shows that applying lower set-point temperature during cold season and higher set-point temperature over the period of the hot season for heating and cooling system respectively resulted in the dramatic reduction on the amount of building's energy usage [27]. Moreover according to a another study at Cambridge University (2012), annual energy saving by turning thermostat set point by 1 degree from 19 °C to 18 °C is 16 TWh [28].

3 Materials and Methods

For modelling and simulation of the house a software called TRNSYS (Transient System Simulation Tool) is used. The software was designed by the University of Wisconsin-Madison in 1975 and has been developed over the last 30 years through collaboration with United States, France and Germany. The newest version is TRNSYS 18, while version 17 is being used for this project [29].

It is a modular system (component-based simulation) and building simulation software in which building components are separated to the series of smaller parts called Types. These types are combined to design, a system model and analyze different type of heating, cooling and ventilation system or to combine them together to build up a hybrid system. Furthermore, there is a type so called TRNBuild (type 56) which provides a possibility of defining building's geometries and thermal properties such as thermal zones and wall layers to evaluate the building's energy performance over the period of the year through the TRNSYS simulation studio. Simulation studio is the main visual layer of TRNSYS software in which the user is able to define a complex project by connecting various components reasonably. In such way, inputs and outputs of different components are determined and connected to each other logically and end up to the output producing plotter or printer Types to show the result. All the components coming from the TRNSYS' library [29].

In this project the whole building has been considered as a single thermal zone and the initial TRNBuild model has been built up based on given data such as buildings geometries and type of insulation material by Dala Massiveträ. As a start point of this work a TRNSYS studio project from a previous study of my supervisor was used as a template.

After defining each model with different insulation thicknesses, windows assembly and external shading as well as control strategy in type 56, it is placed in the simulation studio where heat recovery ventilation system and weather data are defined separately. In addition, in type 56 there is possibility of defining what we need to be showed as a result in simulation studio. For example, since it is needed to evaluate three indicators of energy use, heat power demand and solar heat load, it is asked from TRNBuild to show the relative result to those indicators in simulation studio. Moreover, in the simulation studio the result is printed by type 46b which gives the monthly value of each indicator and plotted by type 65d which provides a possibility of tracking each indicators momentarily over the period of the year. Each result is analyzed individually and compared to the others to find out the best solution for the climate of Borlänge which is fairly close to the Smedjebacken weather characteristics.

Figure 3.1 shows simplified different data exchange with the TRNBuild building model Type 56.

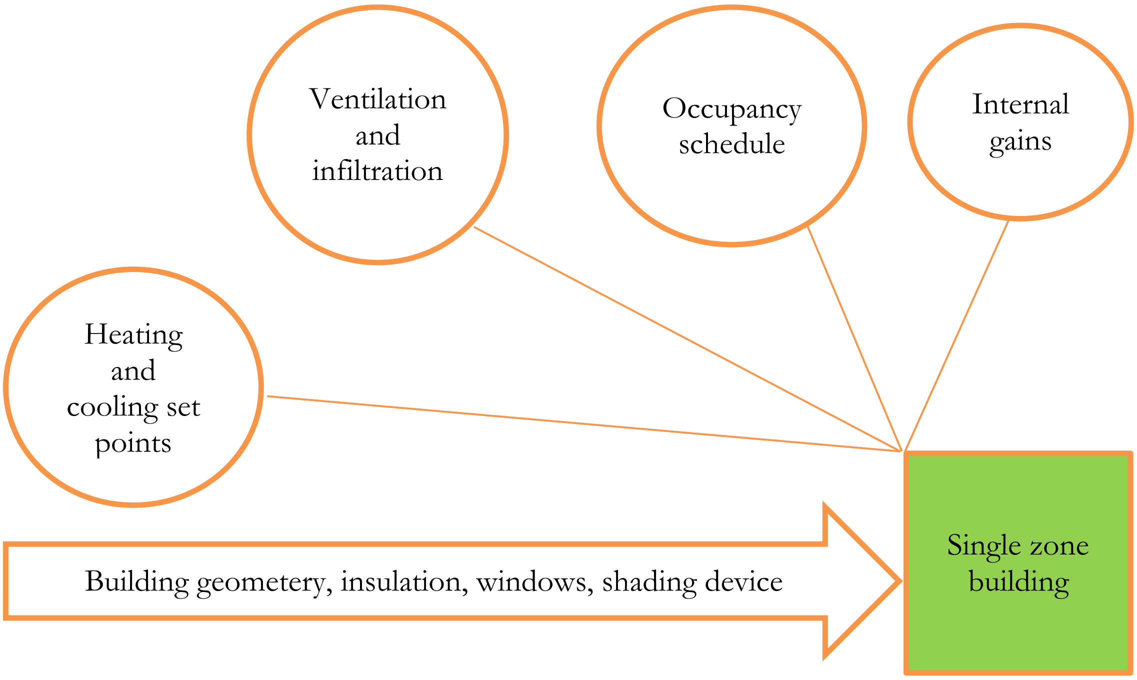


Figure 3.1TRNBuild type 56

3.1 Simulation studio

The studio's components are shown in figure 3.2 where weather data such as ambient temperature and solar radiation is transferred to the TRNBuild model to get processed and to feed type 56's outputs. Weather data selected for the city of Borlänge and has been taken from the Meteonorm in the TMY format. It is a combination of climate database and weather generator of ground measurements and satellite data [30]. At the last stage calculated outputs is displayed and issued through online plotter (type 65d) and printer (type46b) respectively to be investigated. Furthermore, some other outputs such as indoor air climate and ventilation performance rather than building's outputs can be designed in studio to be shown by online plotter. Also simulation studio has been equipped with heat recovery ventilation and shading devices in order to be used when energy reduction is needed. It has to be said that external shading devices is always active to prevent cooling demand over the period of the year.

While all the outputs' performance can be tracked through type 65d momentarily, type 46b gives TRNBuild's outputs monthly which are this project's reference to evaluate building's energy performance.

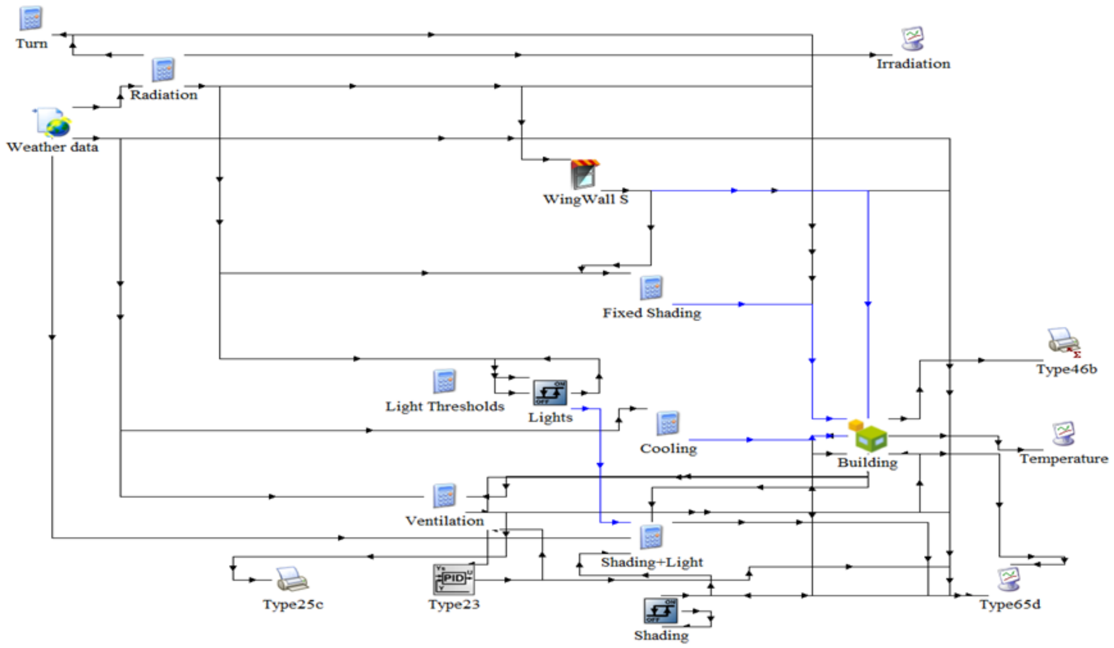


Figure 3.2 Overview of the system model in the simulation studio

3.2 Validation

Since the building has not been constructed yet no measurement data is available. In order to validate of TRNSYS models a qualitative assessment is done which will be expressed in discussion part. Qualitative assessment is performed for the particular model in order to its heating demand be in the range of Milljöbyggnad's criteria.

3.3 Swedish National Board of Housing, Building and Planning (Boverket)

Swedish National Board of Housing, Building and Planning is Sweden's national organization which develop and provide regulations and general recommendations in different areas such as resources management and building construction for those involved in building sector. In the area of building construction it covers several aspects from physical features of building, such as ceiling heights and utility rooms, to energy conservation of the building, such as heating demand [2].

In the energy section the maximum allowed amount of building's energy usage for heating cooling and domestic hot water production is expressed as primary energy, where energy for heating has been corrected with a geographical adjustment factor F_{geo} which is 1.2 for Borlänge and Smedjebacken. The building's primary energy (EP_{pet}) is calculated according to the following formula [2]:

$$EPpet = \frac{\sum_{i=1}^{6}(\frac{Euppv,i}{Fgeo}+Ekyl+Ef,i)\times PEi}{Atemp} \qquad \text{Equation3.1}$$

Where E_{uppv} is required energy for heating (bought electricity to a heat pump, bought district heat or fuel used in boiler), E_{kyl} is supplied (bought) energy used for comfort cooling, E_f is building's property energy, PE_i is primary energy factor per energy carrier and $A_{temp\ is}$ the area enclosed by the inside of the building envelope of all storeys. It has to be mentioned that primary energy for electric energy carrier is PE_{EL} : 1.6 while this value for district heating is PE_{FJV} :1 [2]. According to this formula the maximum allowed building energy usage as a primary energy for a single-family house is 90 kWh per m^2 A_{temp} and year [2].

3.4 Environmental certification system in Sweden

This part gives an overview of a Swedish environmental certification named Miljöbyggnad.

3.4.1. Sweden Green Building Council

Sweden Green Building Council (SGBC) is a non-profit organization established in 2009 opens to all companies and organizations working in the area of building construction who seeks sustainable development for the buildings. It offers customers the environmental building certification at all levels, from litigation support to full-scale certification. Miljöbyggnad is one of the most famous certificate system in Sweden which is accepted by SGBC and is being introduced in following section [31].

3.4.2. Miljöbyggnad

Miljöbyggnad is a Swedish environmental certification which considers the importance of human comfort and energy efficiency of both existing and new buildings. Since it is created for Swedish climate, conditions and regulations, it is the most used certification in Sweden (even more than passive house certification). Miljöbyggnad focuses on three categories of Energy, Indoor Environment and Materials and Chemicals which is sub-divided into 16 indicators such as daylight, acoustic, energy sources and etc. This certification certifies buildings in three levels of BRONZE, SILVER and Gold where BRONZE corresponds to the National Board of Housing, Building and Planning's standard (BBR), GOLD represents the most ambitious buildings and its requirements are most difficult one to be met [31].

In this study only Energy categories' indicators such as energy use, heat power demand, solar heat load and type of energy use for a single family house is investigated. Table 3.1 shows an example of building which rated gold in the category of Energy [7]. The table shows how the grades of energy category's indicators give their aspects to the grade GOLD.

Table 3.1an example of certified building

<table>
<tr><th colspan="2">Indicator</th><th colspan="2">Aspect</th><th colspan="2">Area</th></tr>
<tr><td>Energy use</td><td>GOLD</td><td>Energy use</td><td>GOLD</td><td rowspan="4">Energy</td><td rowspan="4">GOLD</td></tr>
<tr><td>Heat power demand</td><td>GOLD</td><td rowspan="2">Power demand</td><td rowspan="2">SILVER</td></tr>
<tr><td>Solar heat load</td><td>SILVER</td></tr>
<tr><td>Share of renewable enrgy</td><td>GOLD</td><td>Type of energy</td><td>GOLD</td></tr>
</table>

3.4.3. Energy related indicators

In the following sections Miljobyggnad's Energy use's indicators' requirements is expressed [31].

Energy use (Indicator 3)

To achieve the gold level of Miljöbyggnad certification, the building's energy usage has not to be more than 70% of BBR's limit value [2]described in section 3.1. According to the Swedish Energy Agency's report the average demand of energy usage for domestic hot water for single family houses is 781 kWh in Sweden per person and year [32].

Heat power demand (Indicator 1)

The amount of annually required heat in kWh/m^2, A_{om} to provide heating comfort for the occupancies which is equal with multiplication of 15 to the geographical adjustment factor of cities. This factor for Borlänge and Smedjiebacken is 1.2.

The heat output requirement is calculated as heat losses due to heat transmission, air leakage and ventilation for those parts of the building heated to 10 degrees or more (A_{temp}) at the dimensional winter outdoor temperature. The simplified formula to calculate peak demand (PPT) in W/m^2 is shown below:

$$Peak\ power\ demand\ (PPD) = \frac{Ptransmission + Pventilation + Pleakage}{Aom} \qquad \textit{Equation 3.2}$$

Solar heat load (Indicator 10)

The aim of this indicator is to examine the rate of received solar radiation passing through the window in W/m^2 to avoid overheating and to reduce cooling demand. To calculate this value windows G-value and external shading must be taken into account.

Share of renewable energy (Indicator 4)

To privilege buildings using high share of renewable energies with low carbon emission. Which means that more than 80 % of energy used by the building (for heating, cooling and DHW) has to be produced by renewable energy as well as 5% locally generated at building's location. Or instead 95 % of total energy consumption generates by renewable energy. All limitations and regulation is shown in table 3.2.

Table 3.2 Miljöbyggnad's energy category's indicators' limitations

Residential building	***Indicator***	***Gold***	**Unit**	***Explanation***
Energy use	3	≤ 63	kWh/m^2, A_{temp}	
Heat power demand	1	≤18	W/m^2, A_{om}	
Solar heat load	10	≤18	W/m^2, A_{temp}	
Share of renewable energy	4			Mentioned in the section above the table 3.2

3.5 The reference building to be studied

This section describes the building properties such as its geometry, envelope material and the control strategies that have been applied.

3.5.1. Description of simulated building

The modelled house is a massive wooden structure building with two-stories which each has an area of 116.8 m^2. Wood fiber insulation materials called Multitherm 140 and Top 140 are used as the wall and roof insulation materials respectively as well as cellular plastic for the floor insulation towards the ground. It has to be mentioned that Multitherm 140 [33]and Top 140 [34]have an exactly same thermal properties such as same density, thermal conductivity and heat capacity but for different applications. In addition, being environmentally-friendly material is the main reason of applying wooden insulation for roofs and walls. The building's drawings, overview and surfaces' area (m^2) are shown in figuer3.3, 3.4 and table 3.3 correspondingly. The entrance wall is faced to the north and the façade with the most windows facing south.

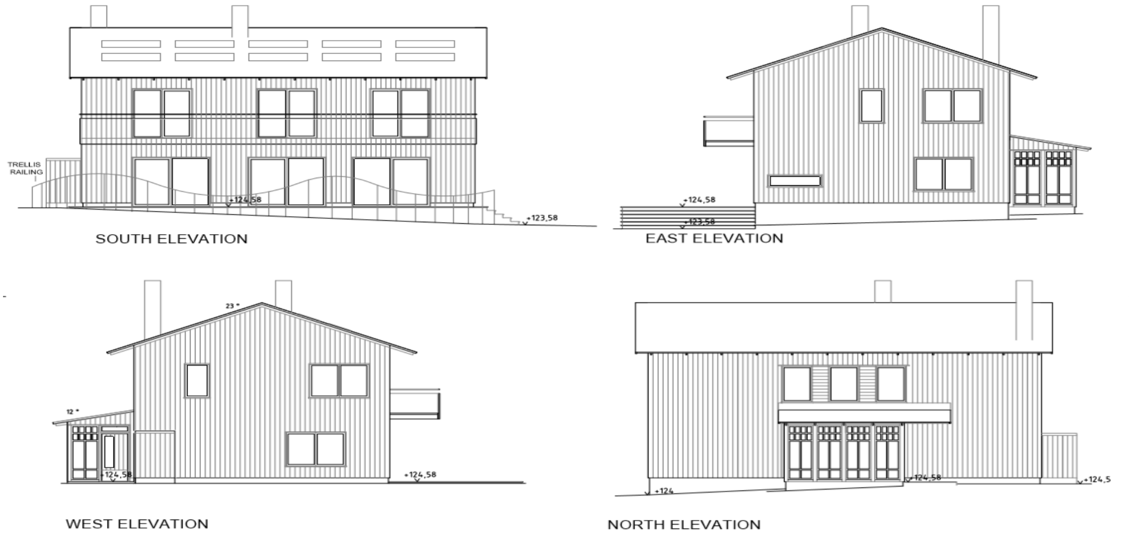


Figure 3.3 Building's drawing, reproduced with permission by Tina Eik architecture

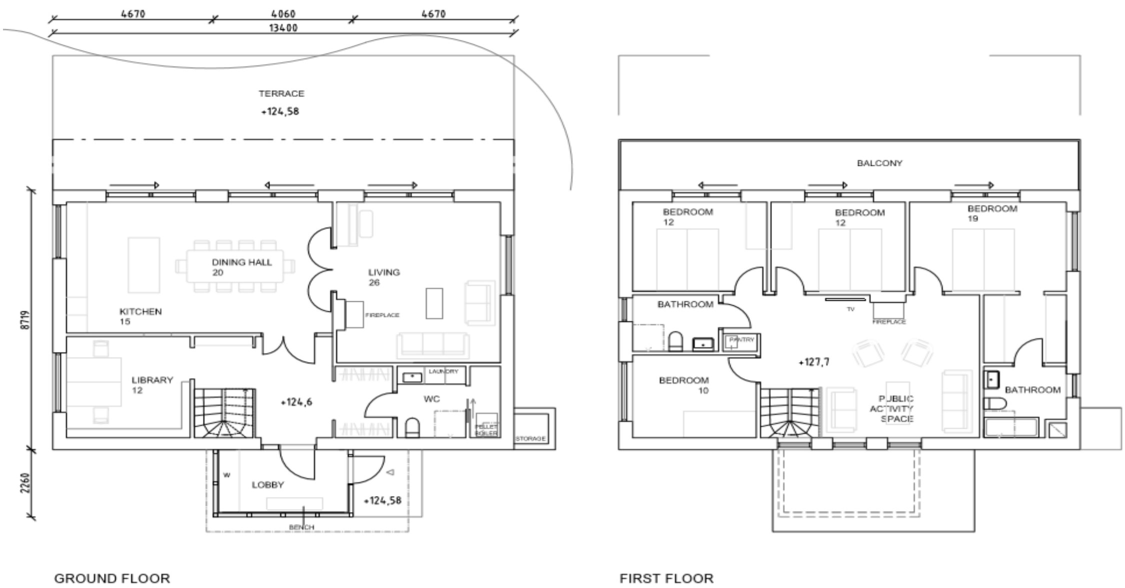


Figure 3.4 Building's ground floor and first floor overview, all units are in mm, reproduced with permission by Tina Eik architecture

Table 1.3 Building surface' area in m^2

Building envelope	***Wall***	***Floor***	***Roof***	**Windows**	***Total (mm)***
North	75.3			7.8	83.1
South	49.3			33.8	83.1
West	46.2			7.8	54.1
East	45.3			8.8	54.1
Pitch roof S			62.8	0.6	63.4
Pitch roof N			63.4		63.4
Floor		116.8			116.8
Intermediate walls		158.4			158.4
Intermediate floors		233.7			233.7
A_{TEMP}		233.6			233.6
A_{OM}	274.3	116.8	126.8		517.9

The concept building is modelled in TRNBuild, assuming one zone with a homogeny air temperature. The base case wall construction consists of 100 mm wood on the inside, 100 mm of Multitherm as an insulation material and 20 mm wood layer is assumed on the outside. The floor has a 140 mm wood layer on the inside placed on 100 mm cellular plastic. In addition, wooden layer covers it with 10mm OAK parquet. Below the floor surface a constant temperature of 10°C is assumed [2].

The roof construction from inside is a 100 mm cross laminated timber (CLT) layer, 100 mm of TOP 140 insulation material, 30 mm wood layer and externally a 20 mm roof-tile. Air gaps are neglected. In addition, the intermediate floor inside the zone is simulated with 95 mm wood layer in the ceiling and 140 mm wood in the floor with an intermediate mineral wool of 95 mm as an acoustic insulation. Heat capacity of internal walls are also taken into account with 100 mm massive wood walls between the rooms and massive bathroom walls of 80 mm thickness. All the materials properties has been taken from Swedish standard SS-EN ISO 10456:2007 [4].

A double glazed window with Krypton gas inside (INS2_KR_6) has been used from the TRNSYS library as a reference window. Its U-value is 1.1 (W/m^2K) with G-value of 0.632. Table 3.4 shows the order of materials used in building envelope, internal walls and floors as well as their thermal properties. In the other models where there is need to take low U-value window, triple glazed window with Krypton inside and U-value of 0.7 (W/m^2K) is applied from the TRNSYS library as well.

It has to be mentioned that the reference model will be adjusted by increasing insulation thickness and using windows with lower U-value. In cases need more energy conservation heat recovery ventilation with 70% efficiency is used instead of exhaust air ventilation. More over all cases with different developments are examined under using DH and GSHP as a building's heating systems.

Table 3.4 Material properties of the reference building model in TRNSYS

Building envelope	***Layer***	***Thickness***	***Density***	***Capacity***	***Conductivity***
		[mm]	***[kg/m³]***	***[kJ/kgK]***	***[kJ/hmK]***
wall	Massive wood	100	500	1.6	0.5
	Multitherm 140	Various	140	2.1	0.144
	Massive wood	20	500	1.6	0.5
Roof	CLT	100	500	1.6	0.5
	Top 140	Various	140	2.1	0.144
	Massive wood	20	500	1.6	0.5
	Roof tile	30	1500	0.84	2.52
Floor	OAK	10	725	1.6	0.648
	Massive wood	140	500	1.6	0.5
	Cellular plastic	Various	144	1.4	20
Windows	***U-value [W/m²K]***	***G-value***			
INS2_KR_6	1.1	0.632			
INS3_KR_1	0.7	0.407			

Table 3.5 shows different scenarios has been considered for a building using DH or GSHP in order to approach to the Miljöbyygand's requirements.

Table 3.5 Different scenarious for a building applying DH or GSHP in order to meet Miljöbyggnad's requirements

Insulation	*Window's U-value (W/m²K)*		*HRV*	*EAH*
	1.1	0.7		
100	✓			✓
	✓		✓	
		✓	✓	
150	✓			✓
		✓		✓
		✓	✓	
200	✓			✓
		✓		✓
	✓		✓	
300	✓			✓
	✓		✓	
400	✓		✓	
450	✓		✓	
		✓	✓	

3.5.2. Building location and climate data

The building is located in a city of Smedjebacken which is 40 km far away from Borlänge in the province of Dalarna. The climate data such as ambient temperature and solar radiation are taken from Meteonorm added to TRNSYS in the format of TMY2. Meteonorm is a climate software provides an hourly weather data for any location in the world based on measured weather data and interpolation [35]. Therefore, Borlänge weather data has been used in the simulation due to not having an access to Smedjebacken climate data on Meteonorm. Borlänge is located at the latitude of 60.433 [°N] and longitude of 15.3 [°E] with an average of yearly sunshine hours of 1680 hours [36].

3.5.3. Initial value

Initial zone temperature and relative humidity are the data that TRNSYS asks to be filled to start modelling the building. Furthermore, the default of TRNSYS software for zone temperature and relative humidity are 20°C and 50% respectively which have been assumed as an initial value for this project as well [29].

3.5.4. Internal gains

The internal heat gains from electric appliances such as computer and lighting calculated by software corresponds to 1674 kWh/year. In addition, the house is assumed to be occupied of totally five persons spending 14 hours a day at home, corresponding to 1845 kWh/year. These values are calculated by the software and are given as an internal gain for all building models.

3.5.5. Thermal comfort

British standard express thermal comfort as a satisfaction condition of mind with the thermal environment and is assessed by subjective evaluation [37]. But still different parameters such as people gender, age and cultures may affect the thermal comfort conditions. In this study thermal comfort only evaluated in terms of air temperature of the zone and while this value for summer comfort range is 23_26 °C and in winter between 20 and 23.5 [38].

3.5.6. Heating

Heating is activated to secure that the room air temperature never falls below 21°C when people are at home and doing some activities such as watching TV while this value is 20 between 24:00 at night and 8:00 at morning when people are normally sleep. In addition, the room temperature is set to be not below 19°C during weekdays when people are not at home between 8:00 AM and 6:00 PM. No specific heating system is simulated, just the required heating is recorded. Domestic hot water production is not considered in the simulation but added to the energy demand afterwards using standard values.

3.5.7. Cooling

Cooling is activated to prevent the room air temperature to exceed 26°C when people attend at home while this value is 30°C for unoccupied time between 7:00 AM and one hour before people get home at 18:00 PM to supply desirable temperature. No cooling system is simulated just cooling demand is calculated by the model.

3.5.8. Ventilation and infiltration

Heat recovery ventilation is modelled assuming 70% temperature efficiency. To minimize cooling demand, bypass of outdoor air is modelled, when indoor temperature rises above 23°C, the bypass is activated to maintain room air temperature to 23°C using a proportional–integral–derivative controller (PID-controller). The minimum supply air temperature during bypass operation is set to 10°C. Furthermore a daily schedule has been defined based on home occupancies, when home is unoccupied ventilation rate is set to be 0.15 air change per hour and 0.5 change per hour when building is occupied(according to BBR, section 6:251 Ventilation flow) [2]. Infiltration losses caused by leakage and open doors and windows is set to 0.05 air changes per hour related to the building volume of 832.4 m3.

3.5.9. External shading devices

External solar shading curtains with a shading factor of 80% is modelled and controlled based on the room air temperature. The curtains fall at room air temperature of 24°C and are rising when the room air temperature goes below 22°C.

3.5.10. Heating demand calculations

The energy use of the building is equivalent with the sum up of heat load, hot tap water, building properties and heat recovery ventilation if used in kWh per m^2 of floor area (A_{temp}). While TRNSYS software simulates the heating and cooling demand of the building, the share of hot tap water, building's properties and HRV should be assumed. According to a the Swedish Energy Agency, estimated annual energy for heating up the water is 781 kWh per person [32] which is equivalent to 3905 kWh per year for a family of five persons. Building's properties energy is mostly used for a commercial building with high rate of electricity consumption for different equipment such as elevator and fountains so it is neglected for a single-family house. Moreover, it is assumed that annual electric energy use of heat recovery ventilation with 70 % efficiency with supply and exhaust fan is 1000 kWh per year which is roughly equal with nominated 80 % efficient HRV's energy use has been discussed in literature review.

To calculate the energy usage for the building heated with district heating, domestic hot water there is only need to sum up all mentioned parameters together. But for a ground source heat pump as a heating system the value of heat load and hot tap water need to be divided by the COP of the GSHP. As it has been discussed previously GSHP's COP varies between 3 and five for a heating system so it is considered to be COP of 3 for heat production and COP of 2 for the domestic water production, since this requires constant temperatures [39]. Moreover the energy consumption used has to be multiplied by 1.6 which is the primary energy factor for an equipment using electricity as an energy carrier [2].

3.5.11. Peak heating power demand

To calculate the peak power demand for heating the outdoor temperature must be put to -23 in simulation studio which correspondent with the coldest temperature of Borlänge in winter [40]. Therefore, all heat gains from lighting, occupancies and appliances must be turned off in type 56 as well as solar heat gain simulation studio. The result issued by printer shows monthly energy usage of the building which has to be the same for each month. But since the number of days are different for each month so the PPD is vary month to month. The energy usage of February is taken as a sample and divided by number hours of this month and surface area to calculate peak power demand in W/m^2.

3.5.12. Solar Heat load (SLV)

Annual passive solar gain (SLV) are calculated by the difference of annual heat load with and without solar radiation. The building model is simulated in (pure darkness) and the difference in annual heat compared to the regular simulation. The result shows the impact of solar radiations passing through the window on the building's heating demand and has not to be more then 18 W/m^2 (Atemp) to meet Miljöbyggnad's requirements.

4 Results and discussion

This chapter shows the results of different scenarios. Based on each insulation thickness, developments are done in order to meet Miljöbyggnad's criteria.

4.1 Validation

In order to do a validation, a model with 100 mm insulation thickness has a windows U-value of 1.1 (W/m^2K) with exhaust air ventilation is investigated. In the first step the energy performance of a model having ground source heat pump is compared with same model uses district heating. The result (figure 4.1) shows while the building has district heating as its heating source needs 131.77 (kWh/m^2A_{temp}) heating annually, same building uses a ground source heat pump as a heating system has lower heating demand up to 43 %. So as it was predicted the required heat of the building uses GSHP is much closer to the Miljöbyggnad GOLD level criteria (63 (kWh/m^2Atemp)) due to have more coefficient of performance (in this project 3) than the model uses district heating with CoP of one.

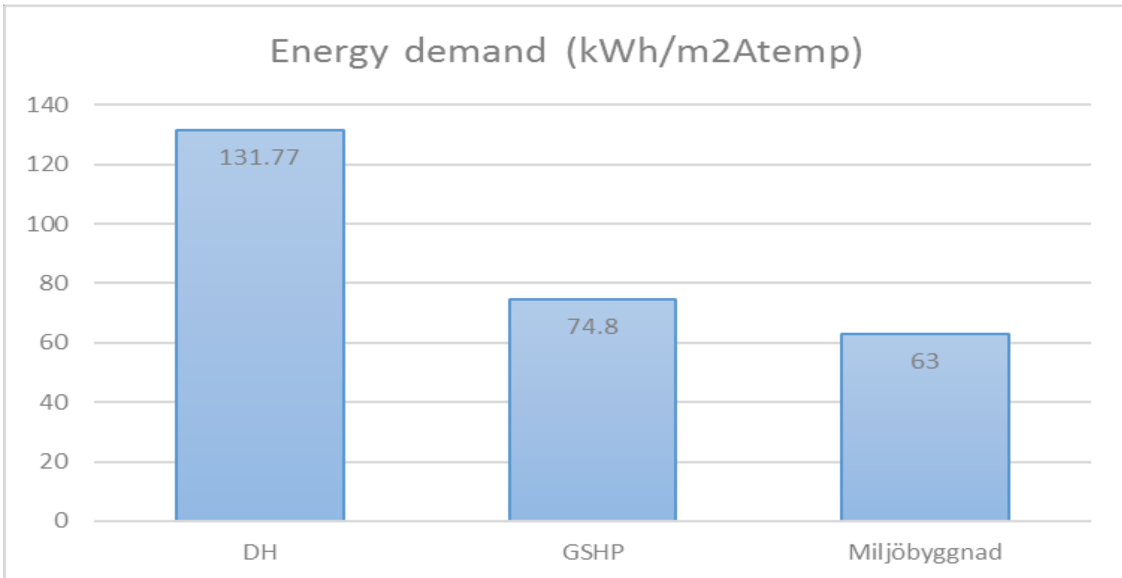


Figure 4.1the energy performance of the building uses GSHP vs DH vs Miljöbyggnad's requirement

In the next step heat recovery ventilation (with 70% efficiency) is applied instead of exhaust air ventilation for the model uses GSHP. As the building's heating demand is strongly influenced by heat loss through infiltration and ventilation the model with heat recovery ventilation has less heat loss and as expected has lower heating demand up to 18% than the other model. This energy reduction leads to fulfilling the certificate GOLD level principals. Moreover, since insulation thickness is not too much and shading device is activated there is almost no cooling demand which is 0.034 (kWh/m^2, A_{temp}) and 0.025 (kWh/m^2, A_{temp}) For model with HRV and EAV respectively.

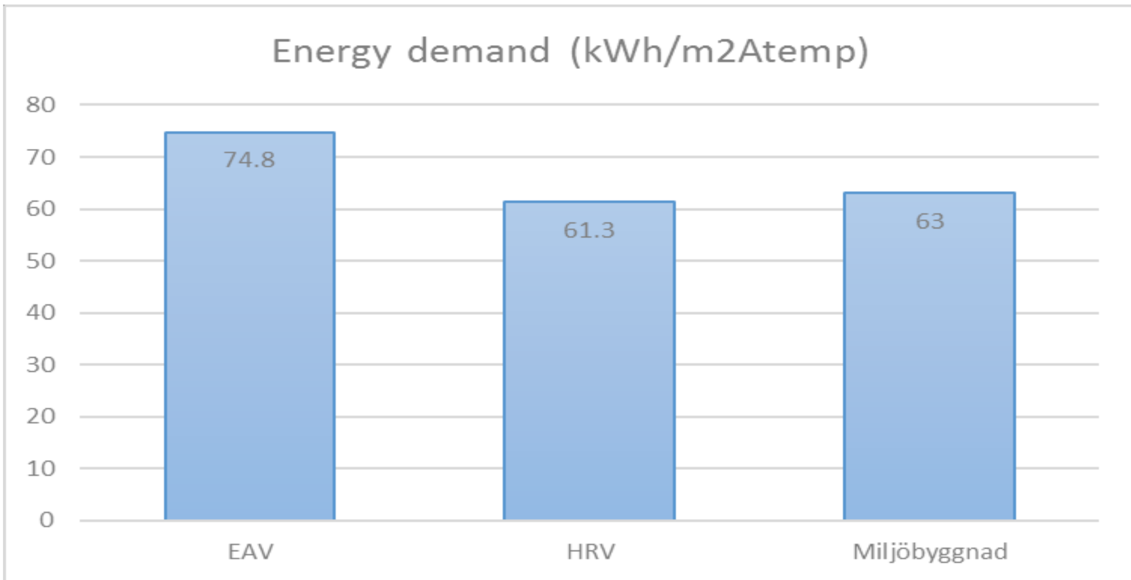


Figure 4.2 the heating demand of the model with HRV vs EAV vs Miljöbyggnad's requirements

In addition, validation of other parameters such as windows U-value and insulation thickness have been done in a similar way and showed a logical result.

4.2 Results

Following figures represent building's energy evaluation of each insulation thickness' scenarios based on Miljöbyggnad's energy's criteria. As it has been discussed with increasing the thickness of insulation the building's energy demand is decreased. But wherever insulation thickness for a certain thickness is not enough to meet the certification's criteria other developments is taken into account.

In the first step the performance of reference building using 100 mm insulation thickness is investigated under using GSHP and DH. Table 4.1 shows the reference building properties using 100 mm insul ation thickness as well as two different windows used for different models.

Table 4.1 Reference building using 100 mm insulation thickness

Building envelope	**Thickness [mm]**	***U-value [W/m²K]***
Wall	270	0.283
Floor	300	0.268
Roof	300	0.275
Windows	**U-value[W/m²K]**	**G-value**
INS2_KR_6	1.1	0.632
INS3_KR_1	0.7	0.407

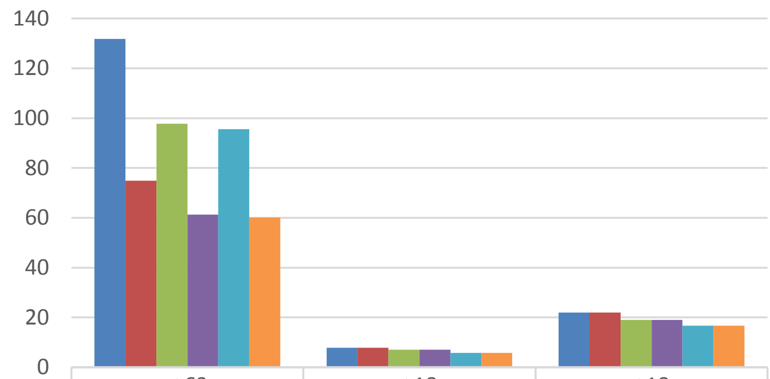
As it can be seen in figure 4.3 three different development scenarios has been examined for the reference building using 100 mm insulation using DH or GSHP.

While the energy uses of the initial state (100 mm insulation, reference window, without HRV) using district heating as a heat generator without HRV is far away from the Miljöbyggnad's target, applying GSHP instead reduces the building's primary energy demand (EPpet) energy use but it is still far from the 63 kWh/m^2 which is the target. In order to reduce the energy consumption HRV is added which makes a dramatic reduction but still not enough for building using DH, however HRV is sufficient with GSHP.

In one hand it can be expressed that since external shading is applied for all models to avoid overheating there is no concern regarding the building's solar heat load limitation which is up to 18 W/m^2 floor area. On the other hand, the ratio of fenestration area (25 %) compared to the floor area which is not too much. So having windows with poor g-value or better does not affect very much.

As it is stated the model with GSHP and HRV with same windows properties as the reference window meets the energy usage's requirements of 63 (kwh/m^2) but not peak heat power demand's principles. Its value is 19.04 W/m^2 which is close to the Miljöbyggnad's peak heat power demand indicator (section 3.2.3) and can be solved by using better windows U-value of 0.7 (W/m^{2}K) than 1.1(W/m^{2}K). The reason that why window with U-value of 0.7(W/m^{2}K) was chosen is due to having limited windows assembly in the TRANSYS' library. So the best windows after U-value of 1.1(W/m^{2}K) is only U-value of 0.7(W/m^{2}K).

So it can be concluded that building envelope with 100 mm insulation cannot fulfill Miljöbyggnad's principles unless ground source heat pump be chosen as heat producer with heat recovery ventilation to reduce the amount of energy use and heat loss through ventilation as well as low U-value windows.



	≤ 63 Energy use(kWh/m2, Atemp)	≤ 18 SVL (W/m2, Atemp)	≤ 18 HPD (W/m2,Aom)
DH+ windows U-value1.1-HRV	131.8	7.8	21.97
GSHP+windows U-value1.1-HRV	74.9	7.8	21.97
DH+ windows U-value1.1+ HRV	97.8	7.1	19.04
GSHP+windows U-value1.1+ HRV	61.3	7.1	19.04
DH+ windows U-value0.7+ HRV	95.6	5.7	16.64
GSHP+windows U-value0.7+ HRV	60.1	5.7	16.64

Figure 4.3 Miljöbyggnad's energy category's evaluation for the reference building envelope using 100 mm insulation thickness and different windows with and without HRV

In addition, the big gap between energy usage of DH and GSHP can be due to COP of GSHP related to the EP_{PET} which is in this project equivalent with three for heating system and two for domestic hot water.

In the next step the energy performance with 150 mm insulation thickness is examined. As it has been expected with increase in the amount of insulation thickness, wall's U-value reduces as well (table 4.2). Furthermore, energy demand decreases but 50 mm insulation is not enough to compensate the impact of HRV on building's energy requirements (figure4.4). So since the GSHP's required energy is close to the target it was decided to reduce the energy demand by using lower U-value window of 0.7 than 1.1 (W/m^{2}K). The result shows that changing windows is not effective enough to reduce energy consumption below 63 (kWh/m^2). In the last step of development HRV is added with the same window as initial state window and as a result building energy demand has met the Miljöbyggnad's principle easily but only with GSHP.

All three developments have been showed in figure (4.4) for both DH and GSHP meet the solar heat load requirement simply.

While the first model with reference window and without heat recovery ventilation does not meet heat power demand, the other developed models fulfill its requirement easily (figure 4.2). As it can be seen in the figure 4.4 the heat power demand for the last two models (150mm insulation, windows U-value 0.7, without HRV) and (150 mm insulation, windows U-value 1.1, with HRV) are 17.46 and 16.96 respectively. It can be stated that lower heat loss and energy demand are the main reason of lower peak power demand.

Table 4.2 Reference building's properties using 150 mm insulation thickness

Building envelope	***Thickness [mm]***	*U-value [W/m²K]*
Wall	270	0.209
Floor	300	0.201
Roof	300	0.205
Windows	**U-value[W/m²K]**	**G-value**
INS2_KR_6	1.1	0.632
INS3_KR_1	0.7	0.407

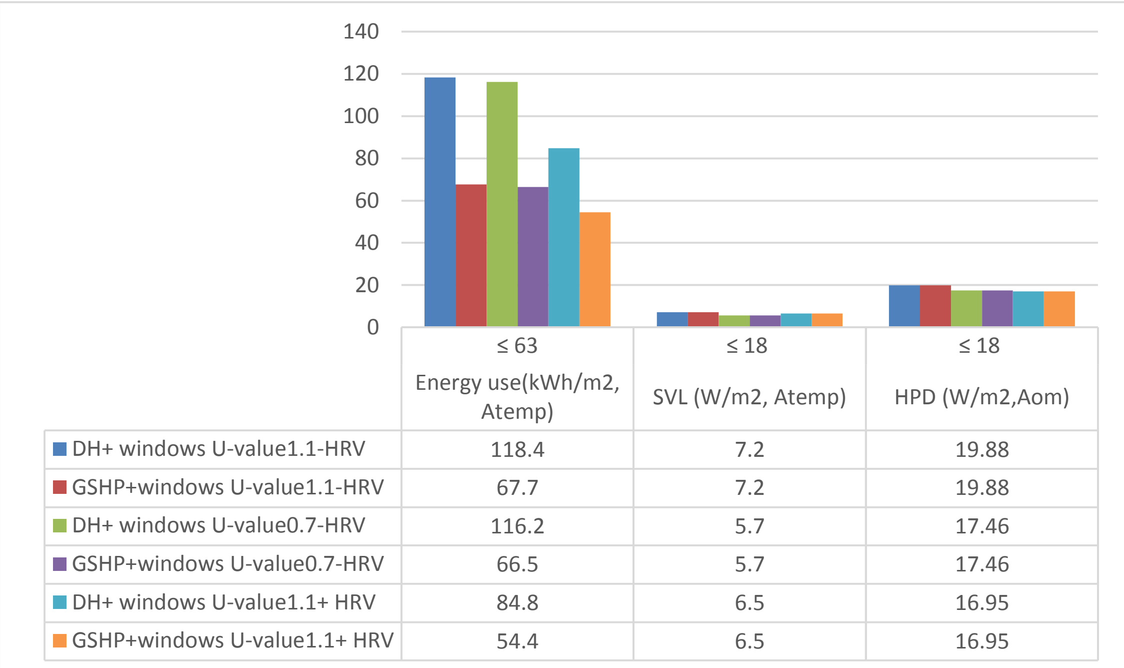
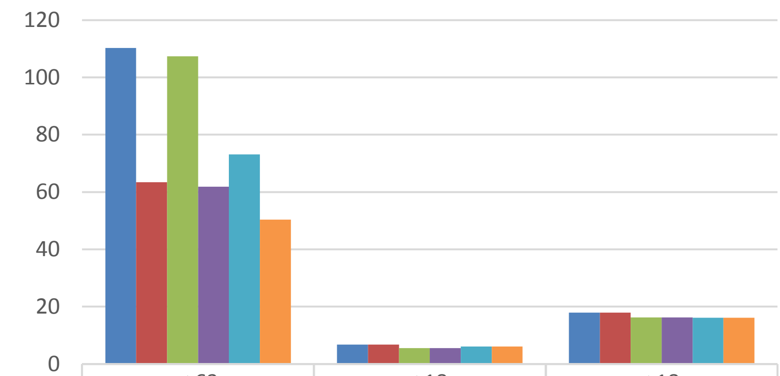


Figure 4.4 Miljöbyggnad's energy category's evaluation's for the reference building using 150 mm insulation thickness and different windows with and without heat recovery ventilation

In the third step 200 mm insulation thickness added to the building envelope and as it is expected GSHP's energy demand (63.4) got very close to the Miljöbyggnad principals but slight development regarding windows assembly with lower U-value required (figure 4.5). Since SVL and peak power demand have met certification's requirements, it can be estimated that with slight increase in the amount of insulation there is even no need to use windows with lower U-value. As before DH energy demand without HRV is still far away from the target but its energy use's value experienced more than 11 units drop with HRV and gets closer to the Miljöbyggnad's energy use demand. Table 4.3 shows building envelope's properties.

Table 4.3 Reference building's properties using 200 mm insulation

Building envelope	**Thickness [mm]**	***U-value [W/m²K]***
Wall	320	0.166
Floor	350	0.160
Roof	350	0.163
Windows	**U-value[W/m²K]**	**G-value**
INS2_KR_6	1.1	0.632
INS3_KR_1	0.7	0.407



	≤ 63 Energy use(kWh/m2, Atemp)	≤ 18 SVL (W/m2, Atemp)	≤ 18 HPD (W/m2,Aom)
DH+ windows U-value1.1-HRV	110.3	6.8	17.86
GSHP+windows U-value1.1-HRV	63.4	6.8	17.86
DH+ windows U-value 0.7- HRV	107.4	5.5	16.22
GSHP+windows U-value 0.7- HRV	61.8	5.5	16.22
DH+ windows U-value1.1+HRV	73.1	6.1	16.08
GSHP+windows U-value1.1+HRV	50.4	6.1	16.08

Figure 4.5 Miljöbyggnad's energy category's evaluation's for the building envelope with 200 mm insulation thickness and different windows with and without heat recovery ventilation

In the fourth and last step the energy performance of building with 300 mm, 400 and 450 (figure 4.6) mm insulation thickness is investigated in order to meet energy requirement of Miljöbyggnad with DH but it is still hard to even get closed to the target without help of HRV. As it can be seen in the figure 4.6 the difference between the building's energy demand with HRV and without HRV is around 40 kWh/m² when 300 mm insulation embedded in envelope. This gap shows the importance of HRV for the building wants to fulfil Miljöbyggnad's energy use indicator without using GSHP.

Table 4.4 Reference building's properties with 300 mm insulation thickness

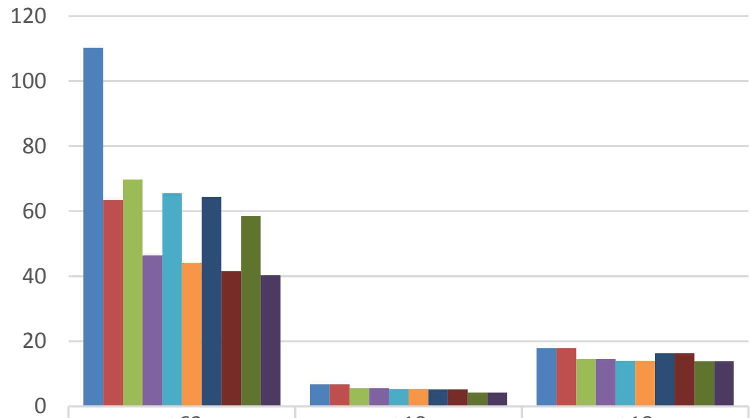
Building envelope	**Thickness [mm]**	***U-value [W/m²K]***
Wall	420	0.117
Floor	450	0.115
Roof	450	0.116
Windows	**U-value[W/m²K]**	**G-value**
INS2_KR_6	1.1	0.632

Table 4.5 Reference building's properties with 400 mm insulation thickness

Building envelope	**Thickness [mm]**	***U-value [W/m²K]***
Wall	520	0.081
Floor	550	0.080
Roof	550	0.081
Windows	**U-value[W/m²K]**	**G-value**
INS2_KR_6	1.1	0.632

Table 4.6 Reference Table 2building's properties with 450 mm insulation thickness

Building envelope	**Thickness [mm]**	***U-value [W/m²K]***
Wall	550	0.091
Floor	600	0.089
Roof	600	0.090
Windows	**U-value[W/m²K]**	**G-value**
INS2_KR_6	1.1	0.632



	≤ 63 Energy use(kWh/m2, Atemp)	≤ 18 SVL (W/m2, Atemp)	≤ 18 HPD (W/m2,Aom)
300mm+DH+ windows U-value1.1-HRV	110.3	6.8	17.86
300mm+GSHP+windows U-value1.1-HRV	63.4	6.8	17.86
300mm+DH+ windows U-value1.1+HRV	69.8	5.6	14.53
300mm+GSHP+windows U-value1.1+HRV	46.4	5.6	14.53
400mm+DH+ windows U-value1.1+HRV	65.5	5.3	13.99
400mm+GSHP+windows U-value1.1+HRV	44.1	5.3	13.99
450mm+DH+ windows U-value1.1+HRV	64.4	5.2	16.34
450mm+GSHP+windows U-value1.1+HRV	41.6	5.2	16.34
450mm+DH+ windows U-value0.7+HRV	58.5	4.2	13.9
450mm+GSHP+windows U-value0.7+HRV	40.3	4.2	13.9

Figure 4.6 Miljöbyggnad's energy category's evaluation's for the building envelope with 300, 400 and 450mm insulation thickness

Experimental study

In addition to the parametric studies, another experimental study is accomplished to examine the impact of thermal mass on building's energy performance. In order to observe thermal mass's influence on building energy demand two scenarios has been run on the model with 200 mm insulation without HRV and with windows U-value of 1.1(table 4.7) and are as follow:

- 80 % of thermal mass' thickness is replaced with mineral wool in order to have same thickness as reference model (Table 4.8)

- Lower massive wood and mineral wool thickness in order to reach same U-value (with 0.001 tolerance) as reference model (Table 4.9)

For the better understanding each scenario is compared with reference model separately:

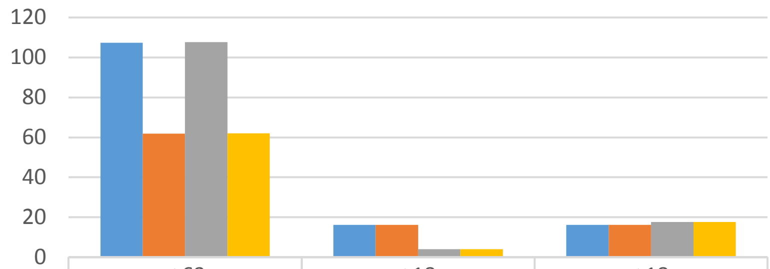
Table 4.7 Reference building uses 200 mm insulation thickness

Building envelope	***Thickness [mm]***	*U-value [W/m²K]*
Wall Floor Roof	320 350 350	0.166 0.160 0.163
Windows	**U-value[W/m²K]**	**G-value**
INS2_KR_6	1.1	0.632

Table 4.8 Same thickness as reference model but lower U-value

Building envelope	***Thickness [mm]***	*U-value [W/m²K]*
Wall Floor Roof	320 350 350	0.132 0.130 0.119
Windows	**U-value[W/m²K]**	**G-value**
INS2_KR_6	1.1	0.632

In one hand energy use of the model with same thickness and different U-value (table 4.7) experienced a slight increase of 0.3 kWh/m^2 despite of higher U-value than the reference model. It can be expressed that in this model the impact of thermal mass is compensated by low U-value of wall assembly as result of using mineral wool with conductivity coefficient (0.1368 kJ/hmK) of lower than massive wood 0.5 (kJ/hmK). Therefore, SLV for the model with same thickness is decreased which can be stated as a lower inside temperature than the reference model. In other word having high U-value can be cause of over temperature inside the building. Then having inside temperature above 24°C activates external shading which prevents solar radiation passing through the window and as result causes SLV reduction. In addition, heat power demand is increased which might be due to having lower heat capacity as a result of lower thermal mass.



	≤ 63 Energy use(kWh/m2, Atemp)	≤ 18 HPD (W/m2,Aom)	≤ 18 HPD (W/m2,Aom)
200mm+DH+Exhaust air ventilation	107.4	16.22	16.22
200mm+GSHP+Exhaust air ventilation	61.8	16.22	16.22
200mm+DH+ same thickness+Exhaust air ventilation	107.7	4	17.66
200mm+GSHP+ same thickness+Exhaust air ventilation	62	4	17.66

Figure 4.7 comparison of the energy performance of the reference building and the building with same insulation thickness and different U-value

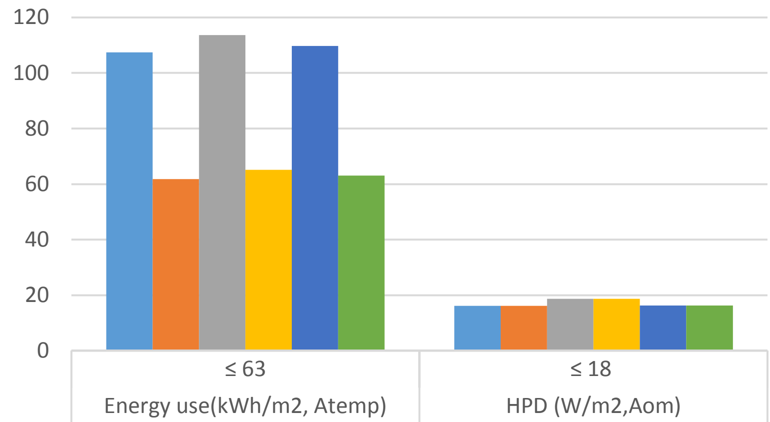
On the other hand, the model with same U-value and different thicknesses (table 4.9) dealt with 5.77% increase of energy use which leads to exceed 63 (kWh/m^2) and disqualification of model from Miljöbyggnad's energy use's gold level. Moreover, its heat power demand increased and go beyond 18 W/m^2. These increase's main reason can be expressed as the impact of lower thermal mass than the reference model. Furthermore, SLV is increased due to having lower inside temperature and as result lower period of activated external shading. In order to compensate the impact of thermal mass a windows with U-value of 0.7 (W/m^{2}K) is replaced with reference windows but despite of meeting HPD, does not meet the energy use's limitation with a small difference of 0.1(kWh/m^2).

Table 4.7 Reference building using 200 mm insulation

Building envelope	**Thickness [mm]**	***U-value [W/m^{2}K]***
Wall	320	0.166
Floor	350	0.160
Roof	350	0.163
Windows	**U-value[W/m^{2}K]**	**G-value**
INS2_KR_6	1.1	0.632

Table 4.9 Same wall U-value as reference model using 200mm insulation with 0.001tolerance and lower thickness

Building envelope	**Thickness [mm]**	***U-value [W/m^{2}K]***
Wall	260	0.167
Floor	268	0.161
Roof	290	0.164
Windows	**U-value[W/m^{2}K]**	**G-value**
INS2_KR_6	1.1	0.632
INS3_KR_1	0.7	0.407



	≤ 63 Energy use(kWh/m2, Atemp)	≤ 18 HPD (W/m2,Aom)
200mm+DH+Exhaust air ventilation	107.4	16.22
200mm+GSHP+Exhaust air ventilation	61.8	16.22
200mm+DH+ same U-value+Exhaust air ventilation	113.6	18.68
200mm+GSHP+ same U-value+Exhaust air ventilation	65.1	18.68
200mm+DH+ same U-value+ windows U-value 0.7+Exhaust air ventilation	109.7	16.26
200mm+GSHP+ same U-value+ windowsU-value 0.7+Exhaust air ventilation	63.1	16.26

Figure 4.8 comparison of the energy performance of the reference building and the building with different insulation thickness and same U-value

4.3 Discussion

This part discusses about the result of parametric study briefly and is an introduction to the conclusion chapter as well. The parametric study was run for reference model with different insulation thickness and windows, equipped with HRV or exhaust air ventilation under applying GSHP and DH as a heating system.

Meeting certification's requirements with district heating as a heating system and without heat recovery ventilation is very hard, so it is strongly recommended to use HRV to reduce energy consumption by saving energy. Figure 4.9 and figure 4.10 shows the impact of HRV on the building using DH as a heat generator. As it can be seen in figure 4.9 building with 300 mm insulation and without HRV is not even close to 63 (kWh/m^2) while figure 4.10 shows a much lower energy demand (69.8 kWh/m^2) for the same insulation thickness with HRV.

In the end building with 450mm insulation, heat recovery ventilation and windows U-value of 0.7 instead of windows U-value of 1.1 could meet the certification's criteria.

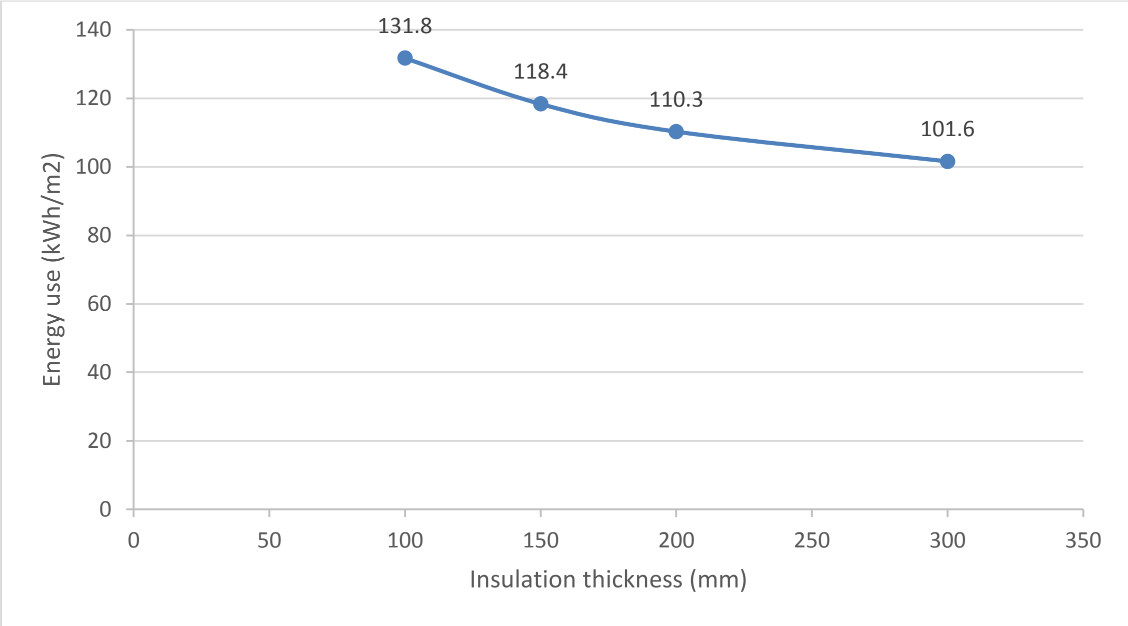


Figure 4.9 Building's energy use with DH and without HRV

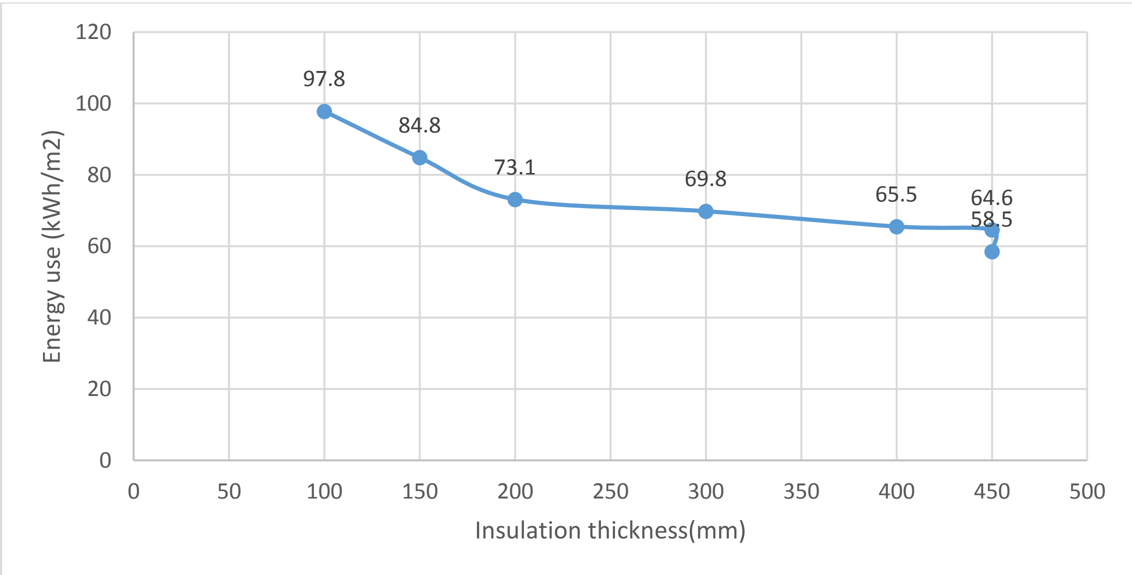


Figure 4.10 Building's energy use with DH & HRV

On the other hand, building using ground source heat pump as the heating system does not deal with the difficulties that DH confronts to meet certification's requirements. In other word GSHP with minimum COP of 3 can even meet certification's principals with 200 mm insulation without help of HRV. The only development needed to meet Miljöbyggnad's principals with 200 mm insulation is using windows with lower U-value than reference model.

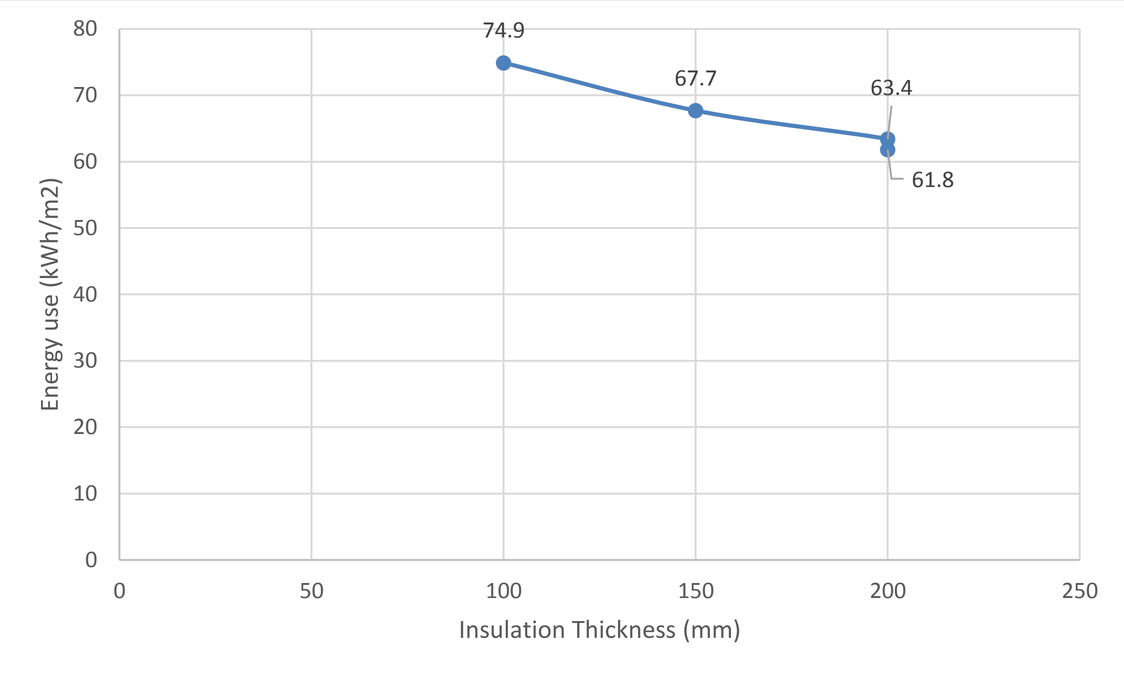


Figure 4.11 Building's energy use with GSHP

Furthermore, if there is an interest to fulfil the certification's principals with lower insulation thickness than 200mm, this two model are suggested:

1. 100 mm insulation thickness+ heat recovery ventilation +windows with lower U-value than 1.1 and low G-value + ground source heat pump
2. 150 insulation thickness + heat recovery ventilation+ windows U-value of 1.1 + ground source heat pump

It has to be expressed that heat power demand is mostly dependent on the heat load of the building which directly correspond with its energy use. So lower energy use, lower heat power demand and as it is obvious from figure 4.3 and 4.4 only three model have not meet heat power demand which all three of them did not meet energy use's limitation as well.

On the other hand, solar heat load was not a big concern at all due to having external shading and low fenestration area.

In addition to fulfil indicator 4 of certification which consider the building's energy resources, 80 % share of total building's energy demand has to be generated by renewable energies such as hydropower, wind power and solar power as well as 5 % locally energy production. Or alternatively 95% from renewable resources. Since building located in Smedjebacken [41], there is a well-developed district heating network in the central part of the city which is fed from renewable resources such as combusting waste materials (in this case waste material counts as a renewable resources in Sweden). But if there is an interest of installing ground source heat pump, the costumer needs to buy electricity as renewable to the house. There is a company called Bävergläntans Fastighets in Smedjebacken delivering electricity produced by solar collectors connected to their wood-chip fired furnace for both residential and industrial area [42]. So builder or costumers can refer to them in order to have electricity produced from renewable energy.

On the other hand, another experimental studies regarding the effect of thermal mass on the building energy demand has been done (figure 4.8). In this study building with 200 mm insulation considers as a reference building and changes has been done regarding thickness of massive wood layer and U-value of building envelope relatively.

In the first study thickness of massive wood layer decreased by 80 % and replaced with mineral wool in order to reach the same thickness as reference model. This makes the U-value decreases from 0.166to 0.132(W/m^{2}K) for walls, from 0.160 to 0.130 (W/m^{2}K) for floor and 0.163 to 0.119 (W/m^{2}K) for roof. The result shows almost no changes on building heating demand which can be due to have less U-value of surfaces that compensates the impact of lower massive wood thickness (thermal mass). Also solar heat load decreased due to have more active shading and heat power demand increased as a result of low building envelope's heat capacity.

In the second study the massive wood's thickness reduced by 80 % but mineral wool added in terms of having same U-values as reference building. This means that the thickness of the wall is reduced from 320 mm to 260 mm for walls, from 350 mm to 268 mm for floor and from 350 mm to 290 mm for roof. The result of energy use went above Miljöbyggnad's requirement by 5.7 %. Moreover, heat power demand went beyond from 18 W/m^2 to 18.68 W/m^2 which is due to having low thermal mass in this case. Solar heat load is increased due to having lower active shading. To compensate the heating demand's, increase a window with U-value of 0.7 is used but still does not meet the certification's limitations.

5 Conclusion

In this project the aim was to design an energy efficient house through the parametric study by the help of the simulation software called TRNSYS in order to meet Miljöbyygnad's energy category's gold level requirements. Miljöbyggnad is a Swedish Building Certification System which is used to evaluate building's energy use, heat power demand, energy resources and solar heat load based on.

The parametric study has been done in order to compare different developments needed to fulfill certification's criteria for a building using district heating versus building using ground source heat pump. The results showed that the building would meet the criteria under various conditions which mention below:

- Having a ground source heat pump as a heating system, heat recovery ventilation and 100 mm insulation thickness as well as windows with U-value of 0.7 (W/m^{2}K)
- GSHP, heat recovery ventilation, 150mm insulation thickness and windows with U-value of 1.1 (W/m^{2}K)
- Having a GSHP as a heating system, exhaust air ventilation and 200 mm insulation thickness with windows U-value of 0.7 (W/m^{2}K)
- Using district heating as heat source, insulation thickness of 450 mm plus HRV and windows U-value of 0.7(W/m^{2}K)

Moreover, the experimental study on the building with 200 mm insulation illustrated that replacing mineral wool as an additional insulation material with wall's thermal mass would compensate the impact of thermal mass on the building's energy usage.

Due to the shortage of time, the simulation of the attached green-house was not done so that its influence on the building energy use could have been possible. Furthermore, the influence of moisture buffering on the energy usage of massive wood buildings has not been considered which could be examined as a future study.

6 Future work

- Future study can be done regarding the effect of the massive wood material on the building energy usage compare to the other materials such as concrete or metal. It would be nice if its energy performance be compared with other building materials to investigate if it is beneficial or not.

- It would be also the next step to see the impact of moisture buffering of massive wood building on the indoor air climate. To examine if the inside air quality is desirable or not. Moreover, to investigate if moisture buffering of massive wood influences on the building energy demand or not.

- In addition, monitoring the performance of other indicators of Miljöbyggnad such as building indoor air quality and thermal climate of the building could be another study to be done in the future.

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