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Simulation of energy consumption for passive house

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DESCRIPTION

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Abstract

There are a lot of different ways and technologies of saving energy. But if the idea is to minimize costs for energy consumption, the best solution is to find out how to make the whole building energy smart and improve not the energy efficiency of some system or equipment but improve the building`s energy efficiency in a complex way. One of the modern ways of improving the energy efficiency in general is a passive house technology. The idea of a passive house is the economic minimization of heating energy demand during the wintertime and minimization of cooling energy demand in summertime with providing good indoor climate, comfort conditions and good indoor-air quality.

The aim of the thesis is to find out how to make energy consumption of the building as small as possible with the lowest E-value and net purchased energy. There are lot of factors which has an effect on the energy consumption and it is difficult to take into account all them then calculations are carried out manually. In this case computer simulation can be applied.

In this bachelors thesis single-family house with the floor area 150 m^2 with the smallest possible E-value will be planned and designed using simulation tool IDA ICE 4. First the main features and aspects of passive house design will be defined in the theoretical part of the thesis using the articles and literature. When the concept of low energy building will be shown and study cases will be described.

After that according to computer simulation the best solution for one-family house with as low E-value as is possible to achieve will be found using IDA ICE simulation tool out by changing

- shape of the building
- air tightness
- area and direction of the windows (area of the windows 12 – 20 % of floor area)
- glazing type
- solar shading (shadings around the site and in windows)
- heat source
- type ofheating systems

Finally the resulting E-value of the best-case building will be compared with the several energy certificates and the recommendation for the passive house and low-energy building design will be given

Subject headings, (keywords)

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CONTENTS

1 INTRODUCTION

Since the price for energy growing up, people have started to think about energy efficiency to save the money. Electricity and fuels, especially oil and gas, become more and more expensive, so energy for heating and cooling is always limited. Nowadays it so that we pay for the energy which we used, if we use a lot of energy, than we pay a lot of money, and vice versa: then the amount consumed energy is low, than we can save the money. So people should think how to reduce energy consumption.

There are a lot of different ways and technologies of saving energy. But if the idea is to minimize costs for energy consumption, the best solution is to find out how to make the whole building energy smart and improve not the energy efficiency of some systems or equipment but improve the building`s energy efficiency in general. One of the modern ways of solving this problem is a passive house.

The idea of a passive house is the economic minimization of heating energy demand during the wintertime and minimization of cooling energy demand in summertime with providing comfort conditions and good indoor-air quality. In other words the heating and cooling energy should be as low as possible. This concept is based generally on the reducing the heat losses of the building, making the envelope air-tight and utilizing external heat gains such as solar radiation. Also the internal heat gains should be utilized if possible.

From the ecological point of view, passive house is a great step for reducing CO_2 emissions which has an effect on the climate changes. It is so because in Europe buildings consume even more energy than transport and industry, the energy consumption of the buildings is 40% from total energy consumption. In that case minimizing the heat losses of the building is clever decision. In the new buildings construction, high-quality thermal insulation is one of the most cost effective methods for reducing the energy demand.

There are a lot of design aspects which are important from the energy consumption point of view such as shape of the building, its orientation, the area and orientation of the windows which allows using the solar energy for reducing heating energy demand with the good U-values of windows and other parts of building envelope. Also the high-efficient heat recovery unit in ventilation system is an essential way to save significant amount of energy for heating supply air. Overheating in summer time should be also taken into account, so the solar shading is also important factor for preventing uncomfortable high temperatures in summer time and reducing the cooling energy demand.

All these factors making the energy consumption of the passive house much lower than for the ordinary building. So the operational costs which are including the prices for energy and the electricity are significantly lower.

On the other hand investment costs for passive houses are rather big. But these extra costs will be compensated during the life cycle of the building in the first years because the operating and life cycle expenses for passive house are remarkably lower than for a ordinary building.

It is difficult to think about building`s life cycle before it is built. We cannot be sure, how much energy it will consume, what will be the indoor climate of the building according to design outdoor temperatures and HVAC systems and what kind of problem can occurs. But nowadays computer technologies can help us to solve this problem. The energy consumption which depends on the different factors can be simulated with all these factors taken into account. We can study the energy consumption and indoor climate as well in a design phase, so the best solution can be found and a lot of problems can be prevented.

Computer simulation is a good opportunity to prove efficiency of passive house and we can be sure that it is more reasonable to have higher investments in the building with lower operational costs after that during the operation and maintenance of the building. So we will know the energy consumption and indoor climate conditions and the best properties of the building such as shape, orientation, etc. can be found. By means of computer simulation we can calculate the energy efficiency based on several factors such as outdoor air temperatures, type of the heat source, type heating and ventilation system and so on.

In this Bachelors Thesis the definitions of the passive house and different ways of making building energy-smart will be given, passive house concepts and important aspects of passive house design will be described. And finally computer simulation of energy consumption of the single family house which is performed according to several passive houce concepts VTT (Technical Research Centre of Finland) passive house concept will be done and results will be compared with the values given in energy sertificate which will be valid from 2013 and gives the requirements for residential buildings energy demands.

In the simulation process the best solution for single family house concepts will be found by changing several factors: shape of the building, its orientation, the area and direction of the windows and solar shading. Finally standardized one-family house which has as low energy consuption as possible will be defined.

2 AIMS AND METHODS

2.1 Aims

The main idea of the thesis is to make energy consumption of the building as small as possible with the lowest E-value or net purchased energy. A lot of factors have an effect on the energy consumption and it is difficult to take into account all them when calculations are carreid out manually. That`s why computer simulation can be applied.

Using the computer technologies we can think about the energy consumption and indoor climate of the building in the design stage. It is important for passive houses which has bigger investment costs compare to the ordinary building. If the design is done properly this houses will make a benefits for users such as lower operational and maintenance coasts.

In this bachelors thesis single-family house with heated net area 150 m^2 with the smallest possible E-value will be designed using simulation tool IDA ICE 4.

This single-family house will be designed and simulated according the requrements of VTT (Technical Research Centre of Finland) Passive House Concept which represents the requrements for passive house and achieving low energy consumption. After that values of the best simulation case will be compared with requirements of energy sertificate which gives the classification for buildings according to the primary energy consumption.

The one family house will be located and simulated in real area. Walls and roof constructions are wooden frames. Simulation will be done with standard use of building (according to D3 2012) and the simulation weather is Helsinki-Vantaa 2012 weather data.

2.2 Methods

First the main features and aspects of passive house design will de defined in the theoretical part of the thesis using the relevant literature. Then the concept of low energy building will defined and study cases will be described.

When in the simulation part according to computer simulation the best solution for one-family house with the lowest possible E-value will be founded using IDA ICE simulation tool by changing:

- shape of the building
- air tightness
- orientation of the building
- area and direction of the windows (area of the windows 12 – 20 % of floor area)
- glazing type
- solar shading (shadings around the site and in windows)
- heat source

All these factors has a big effect on the energy consumption and indoor climate of the building, and it is important to choose correct properties and the best possible location of the building, using the maximum benefits such as solar radiaton for compensation part of the heating power and so on.

First the best shape of the building will be defined in order to achieve the lowest net purchased energy. Five cases will be studied:

- U-shape
- T-shape
- rectangular shape
- one-store square shape
- two-store square shape

After that for the best shape with the lowest heat losses another factors will be simulated. Recommendations for achieving the lowest E-value will be given as a single family house concept.

For studing all these factors IDA ICE 4 simulation tool will be used. It is dynamic multizone simulation application for accurate study of thermal indoor climate of individual zones as well as the energy consumption of the entire building. IDE calculates total energy consumption, energy demands for heating and cooling systems, temperature variations during the simulation period, heat losses through the building envelope also with the thermal bridges.

According to the output similation results energy consumption of the building will be estimated.

3 BACKGROUND

The term “Passive house” refers to achieving the low energy consumption and high level of energy efficiency. In this chapter we will go through basic definitions of energy consumption such as energy consumption of heating system, energy consumption of cooling system, electricity consumption and look what it consists of and after that some basic things about energy calculations and energy efficiency will be described.

Also some general things about computer simulation of building performance and the simulation tool which will be used in the simulation part of the thesis will be given.

3.1 Purchased energy

Energy consumption depends on the climate and weather conditions. The weather effects on the energy usage in heating systems, ventilation, cooling and lightings. So the energy consumption is proportional to the temperature difference between indoors and outdoors.

Buildings` net energy needed in general consists of the energy need for heating, cooling and electrical energy for lighting and different equipment.

Calculations of total energy consumption according to the regulations are based on the standard use of the buildings, so time of occupancy, number of people, internal heat gains, specific consumption of domestic hot water and ventilation air flow rates depends on the type of the building (residential building, office building, school, etc) and values are given in table 3 and table 4 from National Building Code of Finland D3. Energy management in buildings /1/.

3.1.1 Heating system purchased energy

Heating energy need for building according to National Building Code of Finland D5. Calculation of power and energy needs for heating of buildings, equation 6.7 based on energy required for heating spaces, heating domestic hot water and heating supply air in ventilation system /2/:

$$Q_{heating} = \frac{Q_{heating\ spaces} + Q_{heating\ vent} + Q_{heating\ DHW} - Q_{solar}}{\eta_{production}} \qquad (1)$$

$Q_{heating}$	energy consumption of heating system,	kWh/a
$Q_{heating\ spaces}$	energy consumption of heating spaces,	kWh/a
$Q_{heating\ vent}$	energy consumption of ventilation system,	kWh/a
$Q_{heating\ DHW}$	energy consumption of heating domestic hot water,	kWh/a
Q_{solar}	domestic hot water produced with solar collectors,	kWh/a
η_{prod}	efficiency of heating energy production,	-

η_{prod} is the efficiency of each part of the system which takes into account losses in every part of the system like:

- losses in production (boiler system)
- losses of heat storage (water tank)

Energy consumption of heating spaces according to equation 6.1 from National Building Code D5 is calculated as /2/:

$$Q_{heating\ spaces} = \frac{Q_{heating\ spaces,net}}{\eta_{heating\ spaces}} + Q_{distribution,out} \qquad (2)$$

$Q_{heating\ spaces\ net}$	net energy needed for space heating,	kWh/a
$Q_{distribution\ out}$	heat loss into a non-heated room in heat distribution,	kWh/a
$\eta_{heating\ spaces}$	heating system efficiency in heating spaces,	-

$\eta_{heating\ spaces}$ takes into account losses in space heating system like:

- losses in heat distribution
- losses in the heat emitters
- losses in control system

Heating system efficiency in heating spaces depends on the type of heating system, from example radiator heating and floor heating has a different efficiency. Efficiency of heating system will be described in chapter 5.7.

Energy consumption of domestic hot water system is calculated according to equation 6.4 from D5 /2/:

$$Q_{heating\ DHW} = \frac{Q_{HDW\ net}}{\eta_{HDW}} + Q_{HDW\ storage} + Q_{HDW\ circulation} \quad (3)$$

$Q_{heating\ DHW}$	energy consumption of heating domestic hot water,	kWh/a
$Q_{HDW\ net}$	net energy needed for domestic hot water,	kWh/a
$Q_{DHW\ storage}$	heat losses from storage,	kWh/a
$Q_{DHW\ circulation}$	losses from domestic hot water circulation,	kWh/a
η_{HDW}	efficiency of domestic hot water transfer,	-

Energy for producing hot domestic water $Q_{heating\ HDW}$ does not depend on the weather conditions.

Energy consumption of ventilation system according to National Building Code D5, equation 3.10 is calculated as /2/:

$$Q_{heating\ vent} = \rho_i \cdot c_{pi} \cdot t_d \cdot t_v \cdot q_{v,supply} \cdot (T_{sp} - T_{recov}) \cdot \Delta t/1000 \quad (4)$$

$Q_{heating\ vent}$	heating energy need for ventilation system,	kWh/a
ρ_i	density of air,	1.2 kg/m^3
c_{pi}	air specific heat capacity,	1 kJ/(kgK)
t_d	ventilation system`s mean daily running time ratio,	h/24
t_v	ventilation system`s weekly running time ratio,	days/7
$q_{v,supply}$	supply air flow,	m^3/s
T_{sp}	supply air temperature,	˚C
T_{recov}	temperature of air after the heat recovery,	˚C
Δt	time period length,	h

Calculations of total energy consumption always include:

- Weather data from the design documents
- Indoor Climate conditions
- Standardized use of the buildings: time of occupancy, number of people, internal heat gains etc. /1/

3.1.2 Cooling system purchased energy

In order to provide comfort indoor temperatures and avoid overheating of spaces and rooms in summer, cooling system can be required. Energy consumption of cooling system based on the cooling energy of ventilation cooling battery, cooling energy of the room units and properties of cooling system. According to equation 8.1 from National Building Code D5 annual energy consumption of cooling system is /2/:

$$Q_{cooling} = (1 + \beta_{sca}) \cdot Q_{ca} + (1 + \beta_{scw}) \cdot Q_{cw} \qquad (5)$$

$Q_{cooling}$	annual energy consumption of cooling system,	kWh/a
Q_{ca}	annual cooling energy of ventilation cooling battery,	kWh/a
Q_{cw}	annual cooling energy of room units,	kWh/a
β_{sca}	factor of air-side losses,	-
β_{sca}	factor of water-side losses,	-

3.1.3 Electrical purchased energy

Electricity is needed in building for operation of auxiliary devices in HVAC systems: pumps, automation, for domestic appliance and equipment: TV`s, computers, and for lighting.

Calculations of electrical purchased energy for HVAC systems are also based on D5. For heating system auxiliary devices according to equation 6.3 electricity consumption is /2/:

$$W_{spaces} = e_{spaces} \cdot A \qquad (6)$$

W_{spaces}	electricity consumption of heating system auxiliary devices,	kWh/a
e_{spaces}	specific consumption of auxiliary devices,	kWh/(m^2a)
A	net heated area,	m^2

Electricity required for circulation pump in domestic hot water system is calculated according to equation 6.6 from National Building Code D5 /2/:

$$W_{DHW\ pump} = P_{DHW\ pump} \cdot t_{DHW\ pump} \cdot \frac{365}{1000} \qquad (7)$$

$W_{DHW\ pump}$	electricity consumption of the DHW circulation,	kWh/a
$P_{DHW\ pump}$	input power of circulation pump,	W
$t_{DHW\ pump}$	running time of DHW circulation,	h/day

In ventilation system electrical energy is required for operation of fan and energy calculation is based on the SFP value of the fan. For calculations equation 7.1 from D5 is used /2/:

$$W_{ventilation} = \sum P_{es} \cdot q_v \cdot \Delta t \qquad (8)$$

$W_{ventilation}$	electricity consumption of ventilation system,	kWh/a
P_{es}	specific fan power of a fan,	kW/(m^3/s)
q_v	air flow of exhaust or supply fan,	m^3/s
xt	running time during a year,	h/a

Electricity for lighting and equipment in building is calculated for standard use of the building according to National Building Code of Finland D3. Energy management in buildings, equation 4 /1/:

$$W = k \cdot P \cdot \frac{\tau_d}{24} \cdot \frac{\tau_w}{7} \cdot \frac{8760}{1000} \qquad (9)$$

W	annual electricity consumption,	$kWh/(m^2a)$
k	degree of use,	-
P	thermal load,	W/m^2
τ_d	period of use per 24 hours,	h
τ_w	number of days of use of the building per week,	d

For small residential buildings according to table 3 from D3 lighting thermal load is 8 W/m^2 and for equipment is 3 W/m^2. Degree of use k for small houses is 0,6 for equipment and 0,1 for lighting. Building is used by occupants 24 hours 7 days per week.

3.2 Calculation of total energy consumption

National Building Code of Finland D3: Energy Efficiency of the Buildings provides the method of estimation the energy consumption of the building. To describe the annual purchased energy consumption which is related to the heated net area of the building, its purpose and the energy source the E-value is used. Energy performance indicator or E-value [kWh/m^2a] is calculated according to the equation /1/:

$$E = \frac{\sum Net\ Purchased\ Energy \cdot Energy\ Form\ Coeficient}{Heated\ Net\ Area} \quad (10)$$

TABLE 1. Energy Form Coefficients /1/

Energy Form	Energy Form Coefficient
Electricity	1,7
District Heating	0,7
District Cooling	0,4
Fossil Fuels	1,0
Renewable Energy	0,5

So the E-value is the annual net purchased energy with energy form coefficient per heated net are and year. It depends much on the heat source as we can see from the energy form coefficients. When the E-value is calculated and the self-sustaining renewable energy is used in the building (e.g. solar collector for domestic hot water) it reduces purchased energy and effects on the E-value.

National Building Code D3 gives the standard E-values for different types of the buildings (residential buildings, office building, commercial building, schools, hospitals, etc.). For example in office buildings according to D3 2012 E-value should not exceed 170 kWh/m^{2}a. /1/

In general E-value can be reduced with using renewable energy sources with lower energy form coefficients or with the reducing of needed energy for heating and cooling.

Reducing the energy needed for heating can be done with minimization of heat losses, the internal heat gains taken into account, selecting the best shape and orientation of the building, area of the windows.

Reducing energy needed for cooling also can be done with taken into account the internal heat gains and the orientation of the building and windows to avoid overheating in summer time and uncomfortably high room temperatures.

There are a lot of different factors which combinations have an effect on the energy consumption. All of them can be taken into account in building simulation in order to achieve desired properties of the building.

3.3 Building simulation

Computer simulation helps to estimate building performance during the life cycle and operational costs. Models of the buildings developed with the simulation tools are employed to making decisions related with the engineering, construction and other building solutions.

In this bachelors thesis simulation will be done with computer simulation tools IDA ICE 4 (IDA Indoor Climate and Energy). IDA is a dynamic multizone simulation program which calculates thermal indoor climate and the energy consumption of the building during the whole year or the certain time period. Program analyses location of the building, weather and climate, orientation, building components, glazing, furniture, lighting and equipment and presence of the occupants during the specified time period or schedule. /3/

4 LOW ENERGY CONSUMPTION CONCEPTS

A lot of solutions can be indroduced in order to achieve low energy consumption. It is better then they are applied together in a complex way, so different building trends was developed. According to the energy efficency buildings can be classifed next way /4./:

1. Standard building. Made to meet minimim requirements of energy efficiency and thermal comfort which are given by National Building Codes.

2. Low-Energy Buildings. Made in such a way that energy consumption is approximately a half of the heating energy needed in a standard building. Energy efficiency is reached with the improved thermal insulation of building envelope and better windows. Also the heat recovery in ventilation system is applied. Space heating energy demand of this kind of buildings is about 50-60 kWh/m^{2}a according to VTT concept or 26-50 kWh/m^{2}a according to RIL 249-2009. /4;6/

3. Passive House. Consumes about quarter of need energy for standard building. It is possible to have only air heating system with the heat recovery because of a very low heat losses and using the internal heat gains with the solar radiation. Energy efficiency is achieved by very low U-values of building constructions and extremely good air tightness. Annual energy consumption of a passive house depends on the climate zone, for the European countries it is about 15 kWh/m^{2}a and for the Northern countries it is about 20-30 kWh/m^{2}a according to VTT concept or 15-25 kWh/m^{2}a according to RIL 249-2009. /4;6/

4. Nearly-Zero and Plus-Energy Buildings. It is a buildings with very high energy performance. This nearly zero amount of energy should be provided with the renewable energy sources which are produced on-site or nearby. Nearly-Zero Energy buildings produce required energy on-site, so it provides as much energy as possible energy to itself. Plus energy buildings are very rare now but they can become a new trend in next ten years.

Nowadays passive houses become more and more popular in Europe and they proved their efficiency. Passive houses usually have bigger investments than the ordinary buildings, but they have much lower operational and maintenance costs during the life cycle, so it is much more reasonable to invest money in a passive house.

Buildings with low energy consumption have been studied in Europe since the energy crisises in 1970`s and they have become more and more popular. Last ten years are peak in passive house building. European Unuion made a directive which makes all new buildings nearly zero-energy buildings to the year 2020. /4./

Therm ”Passive house” refers a special standards of residential buildings which garanties comfort thermal conditions and indoor climate in winter and summertime whit the energy consumption lower than for the ordinary residential building. In Finland the properties of passive house were defined by VTT Technical Research Centre of Finland in the European research project ”Promotion of European Passive Houses” /4./ :

- heating energy demand 20-30 kWh/m^2a depending on the location
- cooling energy demand 20-30 kWh/m^2a depending on the location
- primary energy consumption 130-140 kWh/m^2a
- leakage air rate $n_{50} < 0,6\ h^{-1}$

Definition of VTT based on the real use of the building and gives the values of energy consumption per gross floor area, so the building envelope is taken into account.

We can see that the definition of passive house is based on extremely low energy demand. And the aim of the passive house is also in application renewable and high-efficient energy sources. /5/

RIL 249-2009 made by Finnish Association of Civil Engineers gives the classification for buildings according to the energy demand levels. This publication also classifies building as standard houses, low-energy buildings and passive houses, depending on the heating energy demands, domestic hot water energy consumption and energy used for lighting, etc. /6./

The classification is shown in the following table.

TABLE 2. Energy classification according to RIL 249-2009 /6/

	Classification		Energy consumption			
Energy efficiency class	Net energy for heating spaces with internal heat loads and solar gains taken into account	Energy for heating spaces with effectiveness of heat production and distribution taken into account	Domestic hot water energy demand without losses (net energy)	Energy needed for heating, ventilation and producing domestic hot water	Energy demand of lighting and equipment in building	Total energy consumption
	$kWh/(m^2a)$	$kWh/(m^2a)$	$kWh/(m^2a)$	$kWh/(m^2a)$	$kWh/(m^2a)$	$kWh/(m^2a)$
Standard House	100	110	30	135	25-40	160-175
Low-energy Building	26-50	26-50	20-25	48-80	30-35	78-115
Passive House	15-25	15-25	20-25	35-51	25-35	60-86

This energy demand levels used for Central Finland (Jyvaskyla) and if we need to convert the requirements to another locations, coefficients from the following table should be used /6/.

TABLE 3. Coefficients for different locations /6/

Energy class	Southern Finland	Central Finland	North Finland
Standard House	0,90	1,00	1,25
Low-energy Building	0,88	1,00	1,27
Passive House	0,85	1,00	1,33

For example requirements for passive house in Helsinki is that net energy for heating spaces should be lower than 25x0,85 $kWh/(m^2a)$ = 21,25 $kWh/(m^2a)$

RIL 249 2009 classification gives the values for energy calculations made for standard use of the building according National Building Code D3 and values of energy demand levels are given per gross floor area also. /6./

Ympäristöministeriön Asetus Rakennuksen Energiatodistuksesta (Energy Certificate) gives the classifications for building according to the energy performance indicator of the building E-value depending on the floor area. /7./

Table 4 shows the classification for single family houses with the net heated area between 120 m^2 and 150 m^2. /7/

TABLE 4. Classification of the buildings according to energy certificate /7/

Energy Class	E-value, kWh/(m^2a)
A	E-value ≤ 230 – 1,13*A_{netto}
B	230 – 1,13*A_{netto} ≤ E-value ≤ 320 – 1,47*A_{netto}
C	314 – 1,4*A_{netto} ≤ E-value ≤ 373 – 1,4*A_{netto}
D	374 – 1,4*A_{netto} ≤ E-value ≤ 453 – 1,4*A_{netto}
E	454 – 1,4*A_{netto} ≤ E-value ≤ 583 – 1,4*A_{neto}
F	584 – 1,4*A_{netto} ≤ E-value ≤ 653 – 1,4*A_{neto}
G	E-value ≥ 654 – 1,4*A_{netto}

In our case for single-family house with the floor area 150 m^2 classification is the following:

- Class A E-value < 60.5
- Class B 60.5 < E-value < 99.5
- Class C 104 < E-value < 163
- Class D: 164 < E-value <243

In the simulation part we will try to achieve best possible energy class according to Ympäristöministeriön Asetus Rakennuksen Energiatodistuksesta (Energy Certificate).

In the following chapter important design aspects of the passive house will be described. We will go through the important features of building envelope, windows, shape and orientation of the building and others. After that according to computer simulation the best solution for passive house will be described.

5 IMPORTANT DESIGN ASPECTS OF PASSIVE HOUSE

There are several ways of achieving low energy consumption in a building: minimize losses, maximize solar gains and substitute with sustainable energy. However in a Northern Europe, especially on higher latitude all these three ways should be optimized to reach low energy consumption level. /8./

In general five steps for very low energy design can be applied, this design rules of low energy building are common for all types of very low energy buildings and they should provide good thermal and visible comfort as well.

General design rules are the following /9/:

1. reducing heat losses (and need for cooling)
2. reducing electricity consumption
3. utilizing solar energy including daylight
4. controlling and displaying energy use
5. supplying rest of energy demand with renewable energy sources

The first step is reducing of the heat energy demand. Part of the needed heating energy demand can be compensated with the renewable energy sources. /9./

Heat losses of the building envelope can be minimized by reducing the surface area of the building. In this case we should think about the relation between the surface to volume ratio. it can be defined as the relation between the area of building envelope area divided by the total heated volume of the building. Of course heat losses is lower than the building has better thermal insulation. /9./

Air tightness of building envelope is also a very important factor which has an effect on the energy efficiency of the building. A lot of construction details should be taken into account to have an air tight building. /9./

Windows are also significant component of building envelope and the significant factor for energy efficiency. Windows provides lighting and some part energy needs as well. We should think about heat gains, thermal losses and the daylight factors selecting the type of windows. /9./

Due to minimize heat losses through the window its size and orientation should be optimized and we should have proper glazing and the frame type. It is possible to have the high performance windows with insulated frames, multiple glazing, insulated glass spacers and inert gas fills, so the heat losses of the windows can be significantly reduced if we compare them to the ordinary windows. /9./

Solar shading helps to avoid overheating in summer. in this case orientation of the windows is significant because windows oriented to the east or the west facades of the building can cause overheating in warm time period and it is difficult to shade without blocking out the sun because of solar radiation low angle. This overheating can occur even in winter time for the windows oriented to the east or west. /9./

Heat losses of the building and solar gains depend much on the local climate and in Northern Europe it means /8./:

- lower annual temperatures of the outdoor air, so we need lower U-values for the building envelope and windows due to avoid increasing heat losses
- Less solar gains in wintertime and the solar radiation also is not constant.
- Another problem is freezing soil. It is a result of sub-zero temperatures in the northern latitudes, so the special attention should be paid to the foundation of the building. Low heat losses combined with low external temperatures can cause the frost damaged buildings if the insulation is not designed properly.
- Freezing of the heat recovery unit. If the efficiency of the heat recovery is high, the exhaust air can be cooled so much that the moisture in this air starts freezing.

The following sections describe more detailed information about the building components and important design factors.

5.1 Shape of the building

In a passive house or low energy building design it is not enough to have only low U-values with more insulated walls. Other important design factor is the geometry and shape of the building. More compact buildings always have less heating energy demand and less thermal bridges. It is so because of the smaller area of building envelope and less heat transmissions because of that. /9./

Two important parameters can be calculated according to the shape of the building /9./:

- The relation between the building envelope area and heated floor area A_e/A_{heat}
- Ratio between the envelope area and building volume A_e/V

Figure 1 shows how the shape effects on this ratio. With the lower ratio heat losses of the building are lower, so the compact shape is the best. /9./

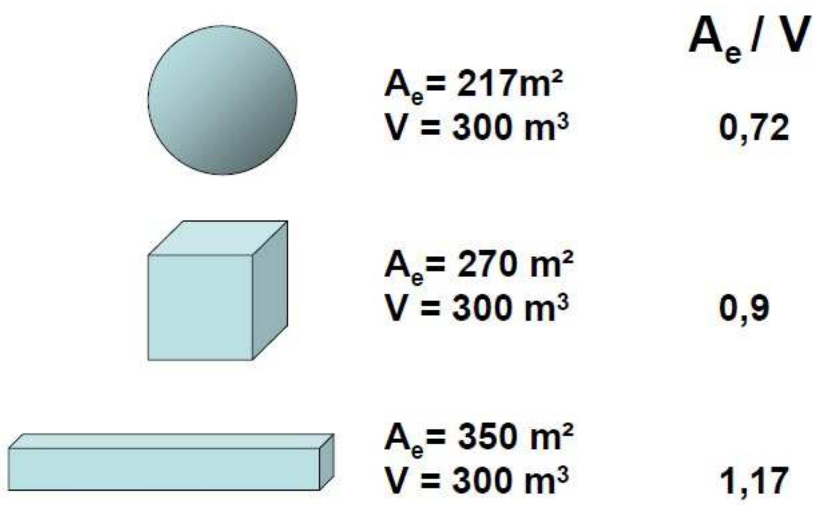


FIGURE 1. A_e/V ratio for different shapes /9/

Another factor is scale of the building. As we can see from *Figure 2,* cube which has the best A/V ratio compare to the other shape, changes its ratio in different scales. If the cube is bigger, the A/V ratio is smaller. /9./

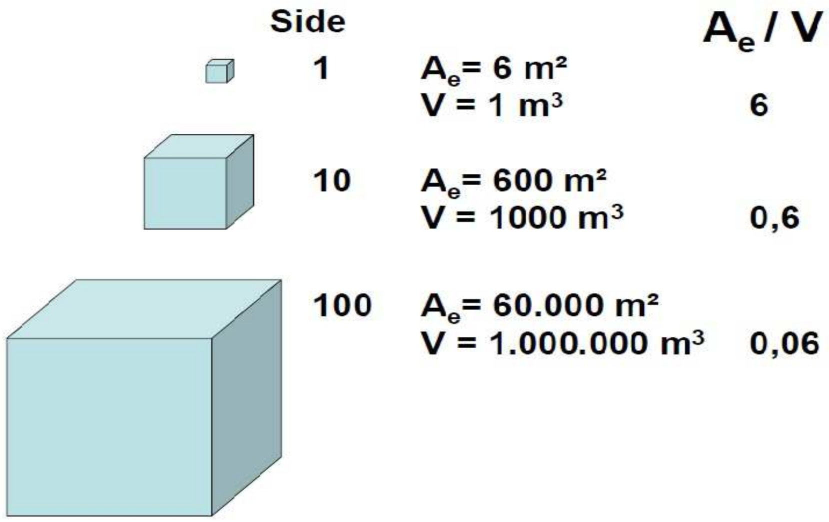


FIGURE 2. Scale effect on the A_e/V ratio /9/

Let’s compare two single-family houses with the simple rectangular shape and the floor area150 m^2, results are shown on the *figure 3***.**

In the first case the length of the building is 20 m and the with is 7,5 m, so the floor area is 150 m^2. Than the height of building is 2,5 m, so its volume is 300 m^3. We can calculate that the envelope area is 437,5 m^2 and the ratio $A_{envelope}/A_{floor}$ is 2,92 and the $A_{envelope}/V$ is 1,46.

In the second case we have half smaller building with two floors which still has the floor area 150 m^2. In this case the volume is increased to 375 m^3 while the envelope area is 325 m^2. The ratio $A_{envelope}/A_{floor}$ now is 2,17 and $A_{envelope}/V$ is 0,87

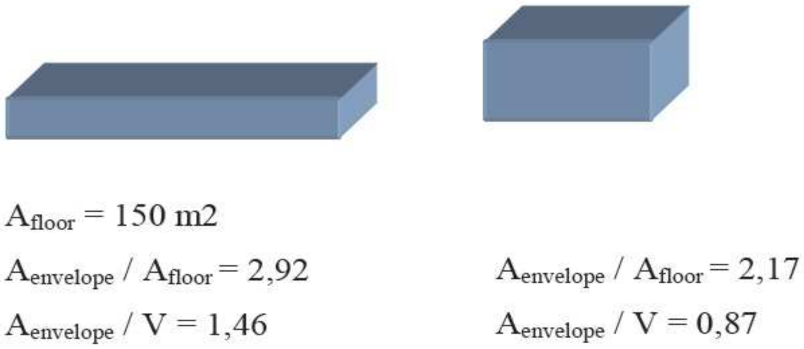


FIGURE 3. One-store building vs. two-store building /9/

We can see that two-stores building have preferable geometry with the same floor area but smaller A/V ratio and better energy efficiency. So it is better to have more compact shape to minimize heat losses and improve the energy efficiency. /9./

5.2 Orientation of the building

Very important thing is that in cold climates or in the Northern countries the peak of the power demand happens when it is dark outside or when the solar radiation is very small. In that the orientation of the windows does not make any effect on the peak heat load. However the annual purchased energy can be lower if the windows oriented in a proper way, because solar energy becomes more significant in spring or in the autumn, when the outdoor temperatures are still low, but there are much more solar gains. /9./

When the most of the windows are oriented to the south directions effective solar shading must be applied, otherwise the room temperatures in summer time can be uncomfortable increased. /9./

The best directions for the windows are between South East and North West, so from these directions maximum of solar radiation can be used for reducing the needed energy for heating. /9./

Heating energy demand also decreased when the building has more glass area oriented to the south depending on the glass quality. But in this case summer overheating and internal gains should be taken into account. Then the windows are oriented to the north it is not possible to have a good heat balance. The east and west orientation is better but windows should have the U-value more than 0,4 W/m^2K (with the thermal bridges and frame) in order to reach positive energy balance. /8./

5.3 Building envelope

The main design rules to minimize heat losses through the building envelope are /8./:

- low U-values of building envelope and windows
- thermal bridges should be avoided
- building envelope should be air-tight
- low ratio of thermal envelope to building volume (A/V)

Low U-values of building envelope means that thicker insulation or insulation material with lower thermal conductivity should be used. If we have lower U-values for the building envelope than lower heating energy demand is required. /8./

Conduction heat losses through the building envelope according to the equation 3.3 from D5 and consists of losses through the walls, doors, windows, floor, ceiling and losses from thermal bridges /2./:

$$Q_{conduct} = Q_{ext\ wall} + Q_{ceiling} + Q_{floor} + Q_{window} + Q_{door} + Q_{thermal\ bridges} \quad (11)$$

$Q_{conduct}$	conduction heat losses through the building envelope,	kWh
$Q_{ext\ wall}$	conduction heat losses through the exterior wall,	kWh
$Q_{ceiling}$	conduction heat losses through the ceiling,	kWh
Q_{floor}	conduction heat losses through the floor,	kWh
Q_{window}	conduction heat losses through the windows,	kWh
Q_{door}	conduction heat losses through the doors,	kWh
$Q_{thermal\ bridges}$	conduction heat losses through from thermal bridges,	kWh

In general heat losses through the building envelope are calculated according to the equation 3.4 from National Building code D5 /2./:

$$Q = \sum U_i \cdot A_i \cdot (T_{ind} - T_{out}) \cdot \Delta t / 1000 \quad (12)$$

Q	heat losses through the building component,	kWh

U_i	thermal transmittance factor (U-value) of a component,	$W/(m^2K)$
A_i	are of a building component,	m^2
T_{ind}	indoor air temperature,	˚C
T_{out}	outdoor air temperature,	˚C
Δt	time period length,	h

Building envelope components can be estimated according to the thermal conductivity λ [W/mK] which takes into account three ways of heat transmittance – convection, conduction and radiation. Then the thermal conductivity λ is lower building component has better insulation properties and less heat losses occurs. It is so that λ values of available building insulation materials are from 0,035 – 0,040 W/mK. If the thermal conductivity is higher, material should more thick due to keep as low heat transmittance as low as possible. Thermal conductivity of insulation materials for passive houses or low energy building should not exceed 0,05 W/mK
The heat flow through the building envelope according to the temperature difference between indoor and outdoor air is proportional to the U-value. U-value is thermal transmittance coefficient [W/m^2K]. With the lower U-value building component or construction has better insulating properties. /9./

Building envelope should be well insulated due to have lower heat losses and low energy consumption. The U-value of thermal insulation is typically around 0,1 W/m^2K which is equal to 400-500 mm thick of high quality insulation material. /9./

Building components should be made of materials with a low thermal conductivity and the insulation should have an adequate thickness. The most popular insulation materials for passive houses and low-energy buildings are mineral wool, polyurethane, glass wool and cellulose insulation. They always reach the requirement to have a thermal conductivity below 0,05 W/mK. /9./

Two common ways or making the building envelope construction can be applied: light multilayer construction or heavy construction. In the first case exterior roof and walls are made of several layers and each layer has its own function: rain protection, air-tightness, thermal insulation, load bearing, vapour barrier, etc. In this kind of constructions insulating layer usually made from 2-4 layers with studs placed horizontally and vertically due to minimize the effect of wall studs and thermal bridges. /9./

Another type of building envelope is heavy constructions which are popular in many North Europe countries. Masonry walls or walls made of concrete are the most common solutions. If we want to have low energy consumption some traditional materials like brick are not good because they have very poor thermal insulation, so more porous materials for example light weight concrete and expanded clay have better insulating properties. In order to provide low energy consumption with the lower heat losses masonry walls of light-weight concrete walls should have an insulation material or sandwich solution with two load-bearing layers and thermal insulation in the middle. In this kind of constructions mineral wool or polystyrene or polyurethane are the most suitable insulating materials. /9./

Even if each construction (wall, floor, roof, etc) is well insulated, so-called thermal bridges increasing the heat transfer. It is a part of building envelope which conducts more heat than the surrounding details. Thermal bridges can be classified as point shaped or linear. Point-shaped thermal bridge appears when for example the when beam sticks out through the building envelope. Linear thermal bridge can appear when the slab is connected to the wall and the external floor, in this case the length of thermal bridge is equal to the circumference of the floor. /9./

In order to achieve proper U-values of the building envelope thermal bridges should be avoided in all parts of the envelope to reach very low energy consumption. Usually thermal bridges can be found in the places where different parts of building envelope meet each other, for example in the corners or in the wooden frames bracing. Constructions which help to avoid thermal bridges are I-beams from concrete and wood or multilayer constructions. /9./

Another reason why thermal bridges should be avoided is the low local temperatures in the internal surfaces. These low temperatures can be reason for the mould growth or the condensation of moisture and worsening of the indoor air quality. /9./

Heat transfer from thermal bridges is calculated according to the equation 3.5 from National Building Code D5 /2./:

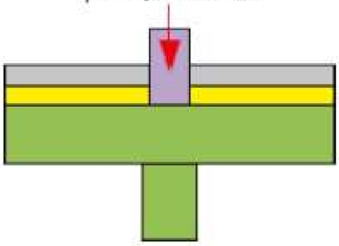
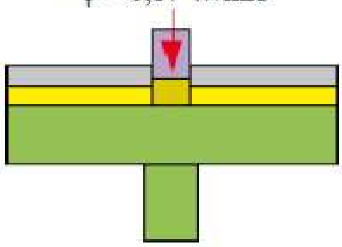
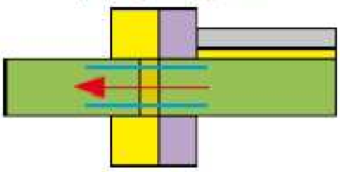
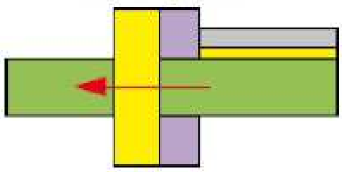
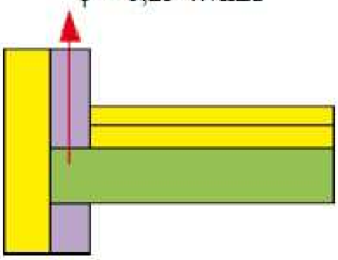
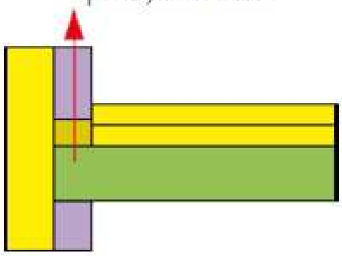
$$Q_{thermal\ bridges} = \left(\sum_k l_k \cdot \psi_k + \sum_j \chi_j\right) \cdot (T_{ind} - T_{out}) \cdot \Delta t / 1000 \quad (13)$$

l_k	length of a linear thermal bridge caused by joints of components,	m
ψ_k	additional thermal bridge conductance (linear),	W/(mK)
χ_j	additional thermal bridge conductance (point-shaped),	W/K

Thermal bridges can are measured with the heat loss coefficients ψ [W/mK] for linear thermal bridges and χ [W/K] for point-shaped thermal bridges. For the passive house`s construction target values for this coefficients are $\psi < 0{,}01$ W/mK and $\chi < 0{,}01$ W/K.

Table 5 shows the example of thermal bridges in poor and optimized constructions.

TABLE 5. Thermal bridges in poor and optimized details /9/

Type	poor/normal detail	optimised detail
Interior wall made of lime sand brick	$\psi = 0{,}55$ W/mK  without thermal separation	$\psi = 0{,}17$ W/mK  with thermal separation
Balcony	$\psi = 0{,}30$ W/mK  with thermal separation	$\psi = 0$ W/mK  balcony on it's own construction
Attic rail	$\psi = 0{,}25$ W/mK  without thermal separation	$\psi = 0{,}04$ W/mK  with thermal separation

In is important to take into account all thermal bridges into account in energy calculations to know exact heat transfer through the building envelope.

In order to achieve low energy demand with low heat losses, building should be airtight, so the uncontrollable air infiltration or exfiltration should be avoided. The airtightness can be achieved in different ways. For the buildings made with lightweight constructions airtightness can be provided with a vapour or air barrier inside the envelope made from plastic. All lead through-outs must be minimized and all seams should be tapped, all necessary penetrations must be fitted with the air-tight cuffs. One popular way to minimize the number of penetration is to make an air barrier about 50 mm into the wall and put where the wiring. /9./

Building envelope should provide air tightness in order to minimize heat losses with leakage air which proportional to the leakage air flow rate. Leakage air flow rate is calculated according to equation 3.8 from D5 /2./:

$$q_{v,air\ leakage} = \frac{q_{50}}{3600 \cdot x} \cdot A \qquad (14)$$

$q_{v,\ air\ leakage}$	leakage air flow,	m^3/s
q_{50}	air leakage number of envelope,	$m^3/(h\ m^2)$
A	surface area of building envelope,	m^2
x	factor which depends on the number of stores,	-

For one-stores building x is 35, for two-stores x is 24, for three and four stores x is 20 and for five stores buildings or higher, x is 15. /2./

Leakage air number of building envelope q_{50} on the volume of the building, its area and is calculated according to the equation 3.9 from National Building Code D5 /2./:

$$q_{50} = \frac{n_{50}}{A} \cdot V \qquad (15)$$

$q_{v,\ air\ leakage}$	leakage air flow,	m^3/s
n_{50}	leakage air coefficient with the pressure test 50 Pa,	1/h
V	volume of the building,	m^3
A	surface area of building envelope,	m^2

The main requirement of airtightness is the minimizing the airflow through the building envelope. The airtightness of the building is measured according to the pressure test with pressure difference 50 Pa between outside and inside. The airflow is usually related with building volume and expressed as the air change rate per hour. So the airtightness is explained like n_{50} and in Finland and many other countries n_{50} should not exceed 0,6 h^{-1}. /9/

Designing of passive house requires good knowledge in building envelope components and the accurate calculations with thermal bridges taken into account. The target values for U-values of envelope constructions are the following. /5./

- Wall: 0,07 – 0,1 W/m^2K
- Floor: 0,08 – 0,1 W/m^2K
- Roof: 0,06 – 0,09 W/m^2K
- Window: 0,07 – 0,09 W/m^2K
- Fixed window: 0,06 – 0,08 W/m^2K
- Door: 0,4 – 0,7 W/m^2K

5.4 Windows

Windows has a big effect on the heat losses of the areas and the heat demand of the buildings. In the building which built according to passive house or low energy concepts U-values of external walls, roof or external floor are usually around 0,08 – 0,1 in the Northern countries, but the U-values of the window in a best case is around 0,6 W/m^2K. /9./

So the heat transfer through the window is equal to the heat losses through 8 square meters of the exterior wall. In this point of view the area of the windows should be as low as possible in order to provide smaller heat losses. It is very important in the cold climate zones of the Northern countries when there is not so much daylight during the long and cold winters.
But nowadays modern low energy windows can use the solar gain to compensate most of the heat losses through the window, so the optimal area of the windows depends on the location of the building and climate zone, quality of the window and its orientation as well. /9./

For the passive house design as a rule used 15% of the window area in a relation to heated floor area. In that case window should be few but large to have more solar gains.

When the window is placed into the wall it is usually creates a thermal bridge and increases the heat transmittance through the construction, so the window should be placed into the wall in such a way that the increasing of the head demand should be as low as possible. Placing the window in the middle of the insulating layer gives the smallest thermal bridge and the placing close to the inner side or outer side of the insulating layer gives both high heat losses. Also placing the window not in the line with the insulating layer should be avoided. /9./

The U-value of the window summarize the heat losses due to convection and radiation losses in the glazed part of the window and conduction heat losses through the opaque parts of the window. The U-value is given as the average of the glass, slash and frame. /9./

Now the high-quality windows have a special sealed insulating glass unit – IGU. This unit is made of several layers of glass installed to a spacer creating a sealed glazing unit. The space between glasses is filled by the air or argon or krypton, so the convective losses are reduced. In modern low energy windows the aluminium or galvanized steel spacer is replaced by materials with lower heat transmittance. It is related with warm-edge technologies but does not save from thermal bridges along the perimeter of insulating glass unit, but this solution reduce the extra heat flow through the glass edge. /9./

Another common technology which is more and more popular in low-energy windows is the usage of low-emittance or low-e coatings. The surface of the glass is coated with a very thin layer of metal which makes the surface a low emittance so the long-wave radiation does not go between the panes. The coating should be placed on the surface between the glasses. There are two types of low-e coating – hard and soft one. Windows with the hard coatings are used in coupled windows and they are able to be cleaned and the soft coatings are sensitive to mechanical treatment and must be protected in a sealed insulating glass unit, but the soft coatings have a very low emittance 1- 3% when the hard coating has the emittance around 16%. /9./

The U-value of the windows also depends on the distance between glass panes and the type of –coating which is used. By optimizing these parameters the U-value of the window can be changed by several tenths of a unit. Also it is better to put window vertically because the horizontal or titled placement can effect on the convective patterns between the glass panes and increase the U-value. /9./

Frame and slash of the window can show its energetic quality. The material and thickness and construction details have an influence on the U-value, so different manufacturers have windows with different quality frames. During the window selection it is better to compare the windows from different manufacturers with the same U-value of glazing to choose the frame with better properties. /9./

Light transmittance – T_{vis} or LT is the amount of solar energy within the visible region (daylight) which passed through a window. For example about 90% of the solar energy light that goes to the surface normally case is transmitted through and about 8% of the energy is rejected and the last 2 % usually is absorbed. It depends also on the amount of the window panes and the selected coating. /9./

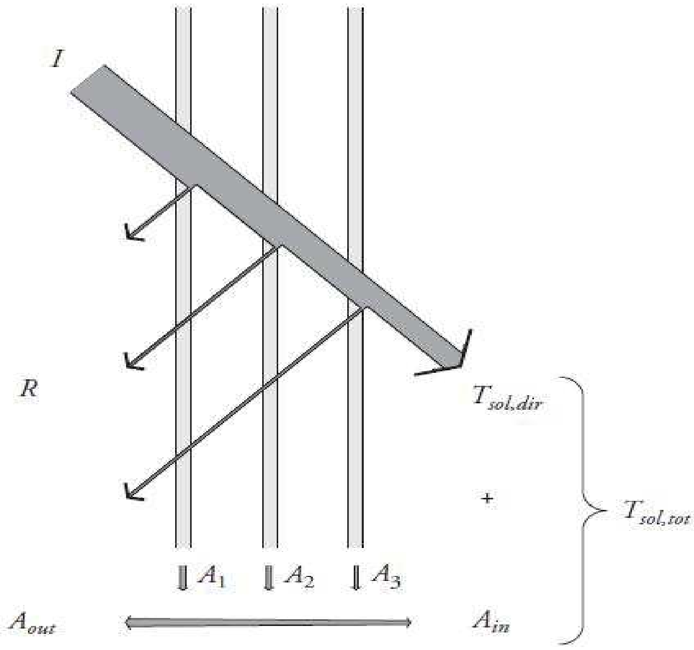


FIGURE 4. Solar transmittance through the window /9/

Solar transmittance is the transmission of solar radiation through the window. It should be noticed that the direct or primary solar transmittance $T_{sol,dir}$ is different from a heat gain from the secondary heat transfer process. The second part is related with the absorption of the energy from glazing and its transferring into the room A_{in}. So, the total solar transmittance T_{sol} is the sum of the directly transmitted part (primary) and the secondary solar transmittance part. It is expressed as a ratio – G-value or SHGC (solar heat gain coefficient). This value is usually lower than the corresponding light transmittance, for example for single clear float glass $T_{sol,dir}$ is about 83% and $T_{sol,tot}$ is 86%. /9./

In the design process it is important especially for the passive houses or low energy buildings to choose optimal glazing with the low thermal transmittance and high solar transmittance as well. /9./

5.5 Solar shading

The best way to use solar energy is to optimize the building for the wintertime and protect it from overheating in the summer time by mechanical shading because the indoor temperature can be too high during the warm days in summer.

In order to avoid uncomfortable high temperatures and high energy consumption for cooling in summer solar shading should be used. Solar shading protects the room spaces from the excess solar gains. It is possible to have fixed solar shading (overhangs or exterior venetian blinds) or a special glass type with solar control function can be used. Also it is possible to use interior solar shadings like pull-down blinds, curtains, screens or a solar control film. One of the most efficient ways of using blinds is to put them behind the glass panes in the windows.

Solar control glasses also can be used. It is made by adding a metal oxide (iron or cobalt or selenium) to the glass body so the glass becomes slightly green or grey. This kind of glazing should be placed as the outer pane in the window, so the most of heat will be rejected to outside by convection. After that came coated glasses with the active parts of stainless steel or titanium nitride. /9./

Another kind of solar control glazing has a solar control properties combined with the energy efficiency. This technology is based on the soft silver layer provides a low emittance. This type of glasses is usually installed as the outer pane with the coating facing to the inside. That glazing conducts a big part of daylight and do not let in the most of solar radiation in near-infrared region. /9./

There are a lot of different types of glazing with different g-values and levels of daylight transmittance, so the designers are free to choose the most suitable solution with the solar control performance. /9./

But the disadvantage of this type of products is that the g-value is static and we cannot adjust the solar radiation which is coming through the window in order to achieve required solar heat gains in cold seasons. That is why the exterior solar gains are quite popular solution for the low energy buildings. /9./

Exterior solar shading can be fixed and adjustable. Adjustable or operable solar shading devices are awnings, screens, Venetian blinds or movable louvers. Fixed solar shadings are overhangs, lamellas, fixed louvers or the balconies or terraces which are the shading devices for the downstairs apartments. /9./

Another important thing is the amount of solar energy is different according to the solar angle. The solar angle depends on the weather and a season, so in summer the overhang can block the undesired solar energy. *Figure 5* shows the solar exposure and the solar angles in different time of a year. /10./

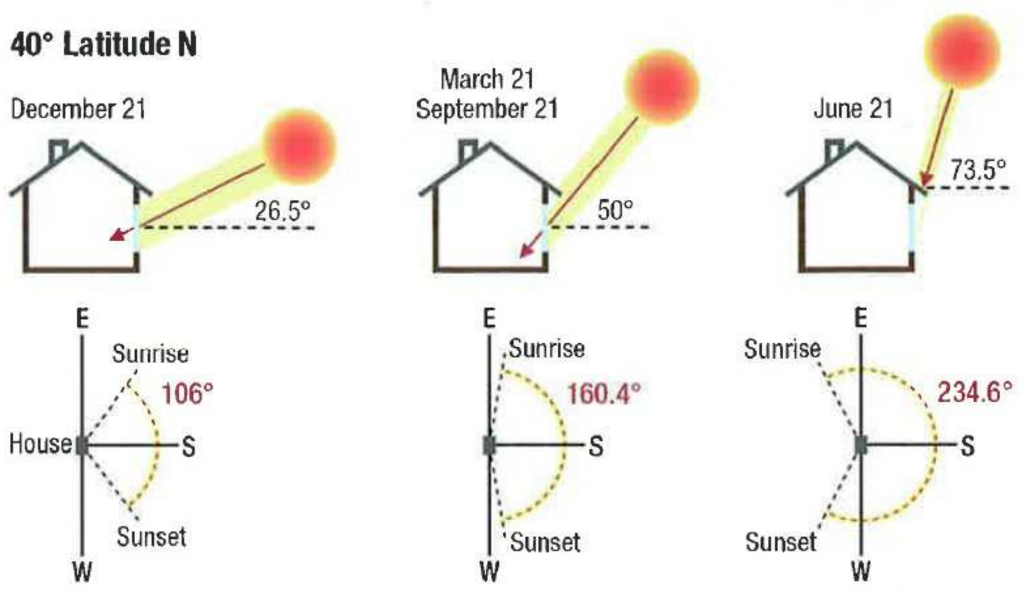


FIGURE 5. Solar exposure and solar angles in different seasons/10/

5.6 Heat source

It is important to choose a proper heat source in order to get cheaper and effective heat. Ecological aspects also should be taken into account and the best solution is renewable sources.

Energy needed from a heat source is calculated according to the following equation /2./:

$$Q_{heating} = \frac{Q_{heating\ spaces} + Q_{vent} + Q_{DHW} - Q_{solar\ HDW} - Q_{other\ production}}{\eta_{production}} \qquad (16)$$

$Q_{heating}$	energy needed from heat source,	kWh/a
$Q_{heating\ spaces}$	energy needed for heating spaces,	kWh/a
Q_{vent}	energy needed for ventilation system,	kWh/a
Q_{DHW}	energy needed for producing DHW,	kWh/a
$Q_{solar\ DHW}$	heating energy produced with solar collectors,	kWh/a
$Q_{other\ production}$	other energy (e.g. from a fire place)	kWh/a
$\eta_{production}$	annual efficiency of a heat source,	-

National Building Code of Finland D5 provides the values for annual efficiency of a heat source and they are shown in the following table.

TABLE 6. Annual efficiency of a heat source /2/

Heat source	$\eta_{production}$
Standard oil/gas boiler	0,81
Condensing oil boiler	0,87
Condensing gas boiler	0,92
Pellet boiler	0,75
Wood boiler with heat accumulator tank	0,73
Electricity boiler	0,88
District heating	0,94

District heating is the most effective heat source for passive house, but if district heating network is not available, air-to-air heat pump or air-to-water heat pump can be suitable solutions.

The main characteristic of a heat pump is its coefficient of performance. Coefficient of performance (COP) for the heat pumps – the relation between heating or cooling power to the work of compressor should be higher than 3. /9./

Air to water heat pump is a good solution for heating and producing domestic hot water. The heat of outside air is used for heating water. *Figure 6* shows the principle of air-to-water heat pump.

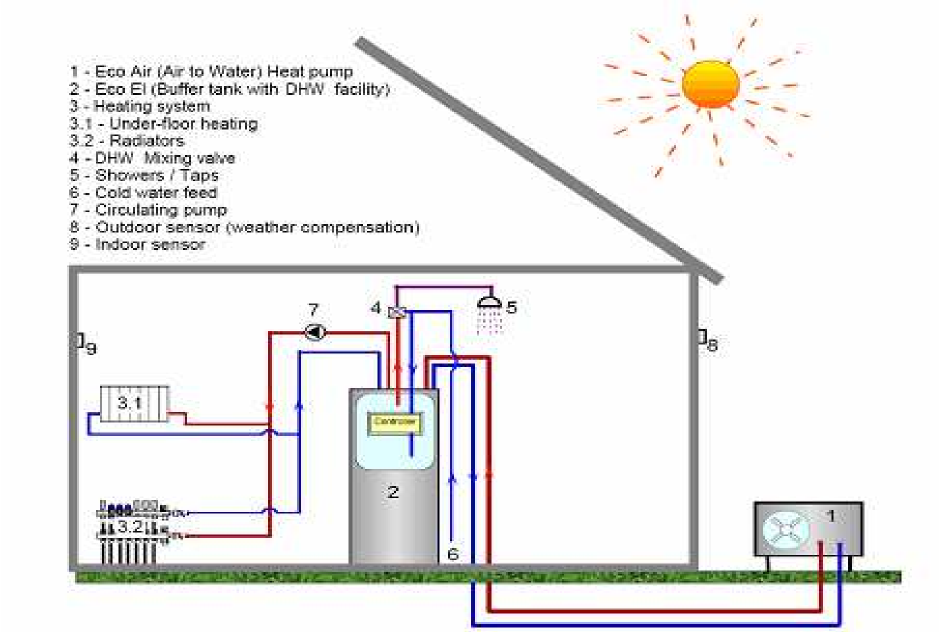


FIGURE 6. Air-to-water heat pump /11/

Exhaust air heat pump consists of an electric boiler and a heat pump which recovers heating energy from the air. The heat pump should be installed in a ventilation system with mechanical exhaust. /12./

When the exhaust air at room temperature passes through the evaporator, the refrigerant evaporates and the heat from the air is transferred to the refrigerant. After that refrigerant flows in compressor and its temperature is rising and the warm refrigerant is led to the condenser. /12./

In condenser it gives off its heat to the boiler water, so that the temperature of the refrigerant drops and its phases changes from gas to liquid. /12./

The principle of operation and the system diagram is shown in the *figure 7.*

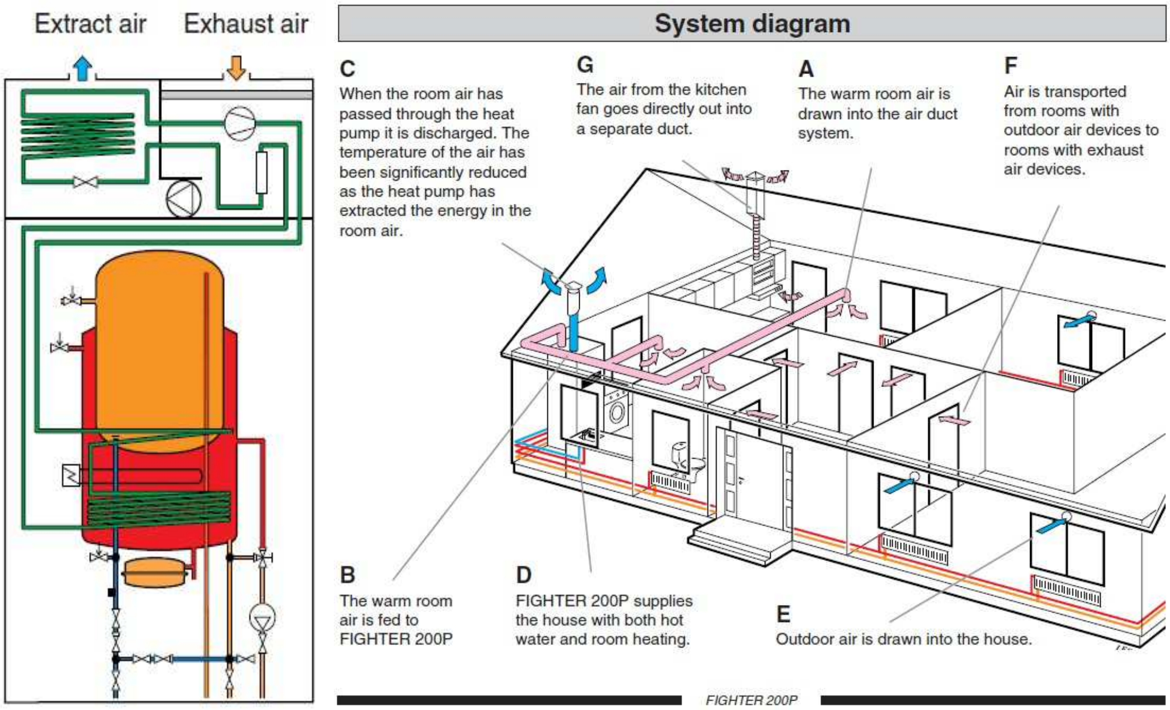


FIGURE 7. Operational principle and the system diagram of exhaust air heat pump/12/

These air source heat pumps are able to produce sufficient amount of heat even if the temperature of outside air is less than 30˚C. So the heat pump technology becomes more and more popular because the heat pumps produce very low cost space heating. /9./

Passive houses or low energy buildings are made for a low energy consumption of the heating system, so more attention should be paid for domestic hot water production. It is better if the part of required energy will be compensated with the solar collectors. /9./

5.7 Heating system

In general, heat demand for heating system is calculated according to the equation /2./:

$$Q_{heating\ spaces} = \frac{Q_{heating\ spaces,net}}{\eta_{heating\ spaces}} + Q_{distribution,out} + Q_{storage,out} \quad (17)$$

$Q_{distribution}$	out is the heat losses in the unheated spaces,	kWh/a
$Q_{storage\ out}$	is the heat losses in storage tanks integrated boilers, etc,	kWh/a
$\eta_{heating\ spaces}$	is the efficiency of heating system,	-

The efficiency of heating system takes into account heat losses in heat delivery and regulation layers. It depends on the type of heating system. National building Code D5 provides the information about the efficiencies of different kinds of hating systems, the values are shown in the *table 7*. /2./

TABLE 7. Efficiency of different heating system solutions /2/

Heating solution	$\eta_{heating\ spaces}$
Under floor heating 40/30 ˚C	
Against the ground	0,80
Against the crawling space	0,80
Against warm space	0,85
Water radiators 45/35 ˚C	
Insulated distribution pipes	0,90
Non-insulated distribution pipes	0,85
Water radiators 70/40 ˚C	
Insulated distribution pipes	0,90
Non-insulated distribution pipes	0,80
Water radiators with manifolds	
Radiators 45/35 ˚C	0,85
Radiators 70/40 ˚C	0,80
Ventilation heating	
Blown in from an interior wall	0,90

In order to achieve low energy demand level for the passive house efficiency of the heating system should be as high as possible it means that the hat losses in storage, transfer and distribution should be minimized.

If the heat losses in heating systems are minimized there are less heat gains and all the heat delivered as it was planned, so the next general rules should be applied /9./:

- pipes and valves should be well-insulated
- low temperatures in pipes should be used
- short distances should be used in for the distribution lines.

Because the energy needed for heating passive house is very low, ventilation heating or forced-air heating system can be applied. Air has a limited specific heat capacity but in case of passive houses it is usually enough to carry out required amount of heat to the room spaces. *Figure 8* shows the basic principle of ventilation heating system. /13/

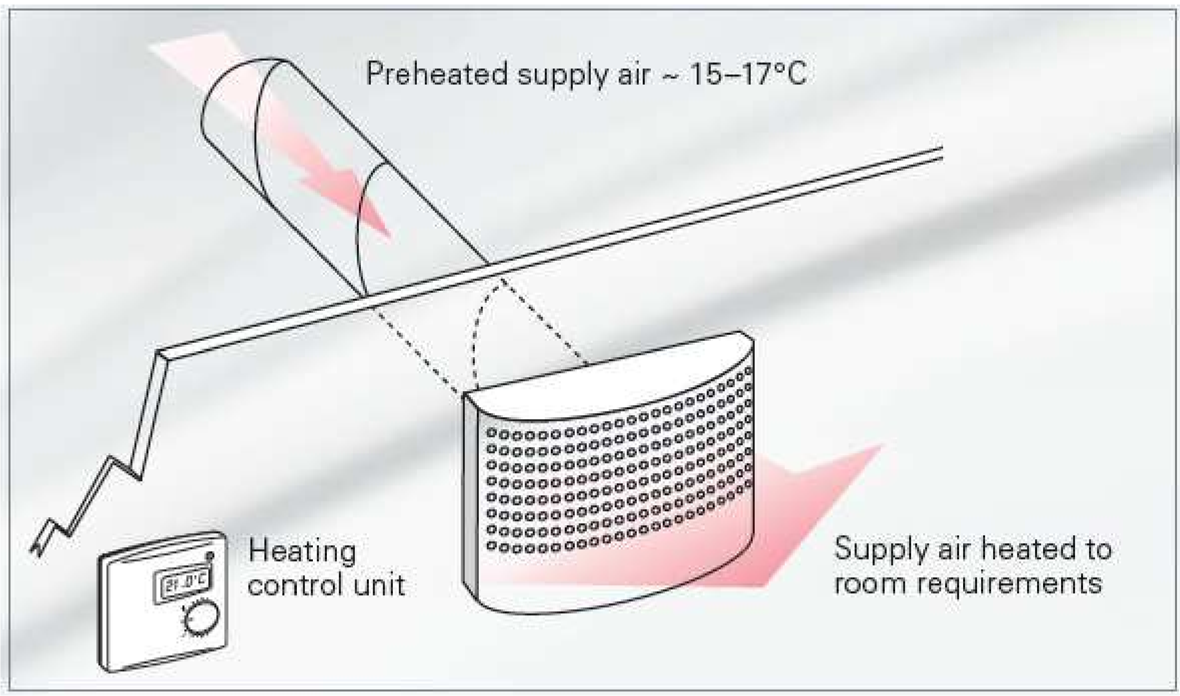


FIGURE 8. Ventilation heating system /13/

In case of forced-air heating rooms are heated individually, but air flows do not need to be changed as heating needs vary because the supply air temperature will be automatically regulated according to the heating needs of each room. Heating power is regulated by PI control and with higher deviation from the preset value, the higher the heating power will be given. When the room temperature is close to the preset value, the unit works at lower power. /13./

5.8 Ventilation system

Ventilation system has a great significance in building energy demand level. So if the minimizing of the ventilation`s energy consumption is the one of the key factors for the passive house technology.

Ventilation heat losses also have a big effect for the building. Because the building supposed to be air tight, the infiltration and exfiltration rates are very small, so the heat losses in ventilation system can be controlled. We cannot reduce the ventilation air flow rates, it is always given in the building regulations and national building codes, for example in D2 National Building Code of Finland Indoor Climate and Ventilation of Buildings it is said that the air change rate should be at least 0,5 h^{-1}. So the only way to reduce the ventilation heat losses is to use a heat recovery system. When building has the heat recovery in the ventilation system, than the heat losses are the heat which is not recovered by the air handling unit. So it is better to have more efficient heat recovery because in that case heat losses are the differences between 100% and the heat recovery efficiency. To avoid freezing it is better to have a system which prevents it, for example a ground-coupled heat exchanger (direct or indirect). /8./

Energy consumption of ventilation depends on the next parameters /9./:

- Air change rate
- Infiltration/exfiltration according to airtightness of the building
- Heat recovery efficiency
- Specific fan power –SFP

The ventilation air change rate is not the thing which should be minimized in general because it provides good and safe indoor air quality and it is also given by building codes and regulations. If the airtightness of the building is provided in a proper way all the heat losses of ventilation can be controlled and in that case, the losses of ventilation system is the heat which is not recovered in the air handling unit. /9./

The main design principle in the ventilation system for passive house or low energy building is that the ventilation system should be equipped with the heat recovery unit. Because of that the best solution is the mechanical exhaust-supply ventilation with the heat recovery. *Figure 9* shows the principle of mechanical exhaust-supply ventilation with the heat recovery. /9./

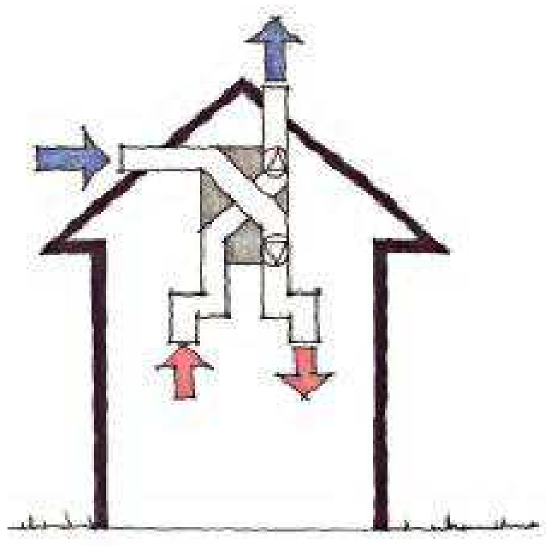


FIGURE 9. Mechanical exhaust-supply ventilation with the heat recovery /9/

There are several different methods of organizing the ventilation system in that way /9./:

- ventilation with the air-to-air heat recovery
- exhaust air heat pump
- combined air-to-air heat recovery with the heat pumps
- pre-conditioning of supply air using the heat of the ground

It is possible to apply demand controlled ventilation, which is popular in office building but it is also a good solution for the residential building. So the ventilation operation can be controlled for example according to the relative humidity by using control exhaust valve. /14./

Control exhaust valve consists of exhaust valve, control motor and controller card, which are installed in the valve cone. This exhaust has an integrated humidity sensor which controls the valve according to the humidity level in room or space. *Figure 10* shows control exhaust valve KSOM. /14./

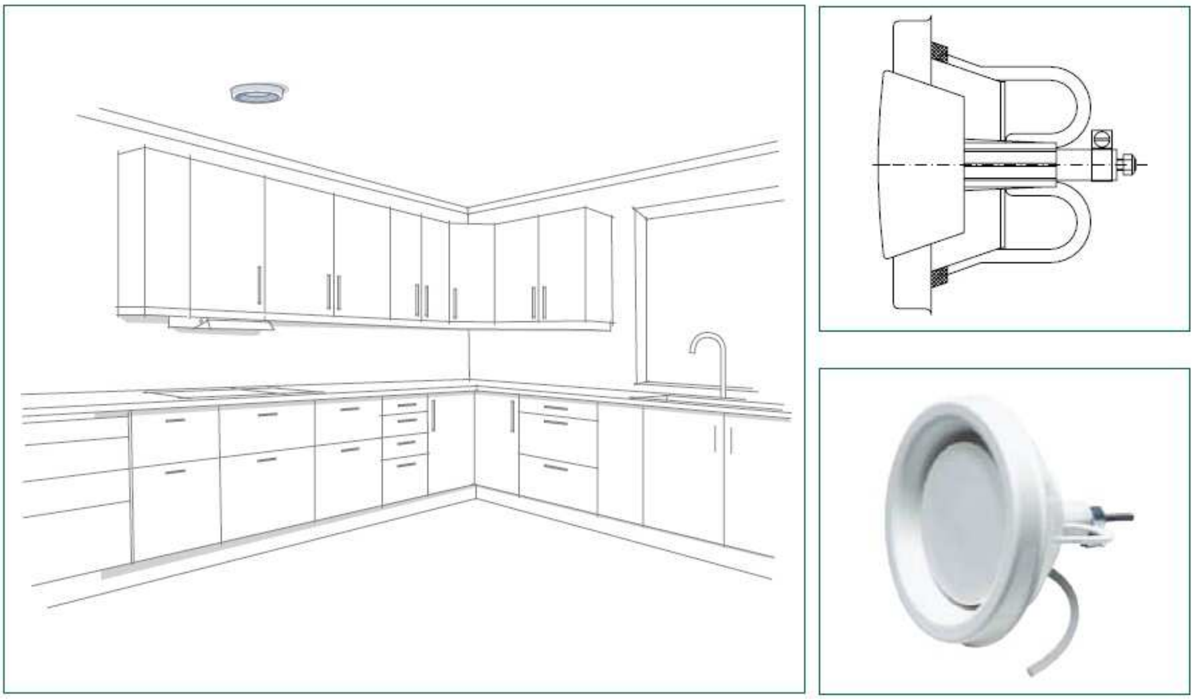


FIGURE 10. Control exhaust valve KSOM with humidity sensor/14/

Air-to-air heat recovery utilizes the heat from exhaust air for preheating supply air and reducing the heating power of the coil. Energy performance of air-to-air heat recovery system is expressed with the temperature ratio. /9./

According to National Building Code D5 temperature ratios should be calculated according to the following equations. Temperature ratio for supply air is /2./:

$$\eta_s = \frac{t_{sHR} - t_{out}}{t_{exh} - t_{out}} \qquad (18)$$

t_{sHR}	temperature of supply air after the heat recovery system,	˚C
t_{exh}	temperature of exhaust air from the room spaces,	˚C
t_{out}	outdoor air temperature,	˚C

Temperature ratio for exhaust air is /2./:

$$\eta_e = \frac{t_{exh} - t_{exit}}{t_{exh} - t_{out}} \qquad (19)$$

t_{exh}	temperature of exhaust air from the room spaces,	˚C
t_{exit}	temperature of exit air after the heat recovery,	˚C
t_{out}	outdoor air temperature,	˚C

The relation between temperature ratios for supply and exhaust air is /2./:

$$\eta_e = R \cdot \eta_s \qquad (20)$$

$$R = \frac{q_{sHR}}{q_{eHR}} \qquad (21)$$

q_{sHR}	volume flow of supply air through the heat recovery,	m^3/s
q_{eHR}	volume flow of exhaust air through the heat recovery,	m^3/s

Next we will go through different types of heat recovery systems which are the most common for single-family houses for ventilation systems. It is recuperative and regenerative heat exchangers.

Recuperative heat exchanger can be for example plate heat exchanger, can have temperature ratio from 0,6 to 0,8 and the recent developments increased it to 0,9. Also the yearly efficiency can be about 70%. /9./

It can be cross-flow or counter flow heat exchanger. Cross-flow recuperative heat exchanger is shown in the *figure 11*. /9./

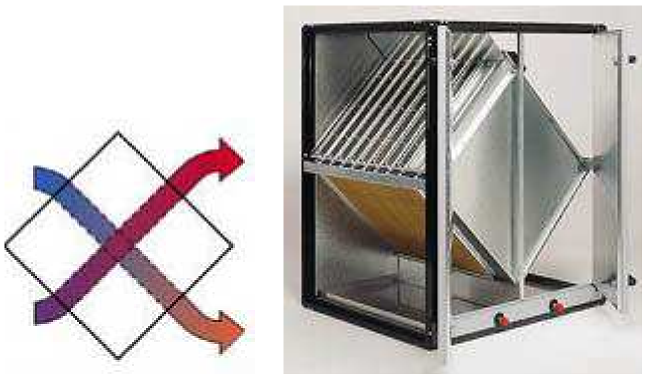


FIGURE 11. Cross-flow recuperative heat exchanger /9/

Cross-flow heat exchangers has a temperature ratio η_t = 0,55. Counter-flow recuperative heat exchangers has bigger temperature ratio η_t = 0,7. Counter flow heat exchanger is shown in the following figure. /9./

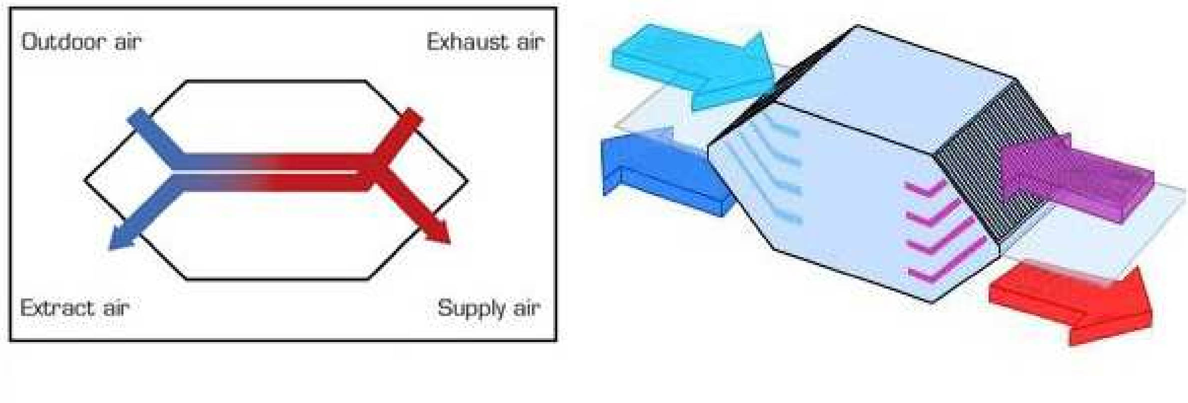


FIGURE 12. Counter-flow recuperative heat exchanger /9/

The advantages of recuperative heat exchanger /9./:

- the air flows are separate, so the risk of mixing the fresh air with the polluted one is avoided
- compact unit with a few moving parts

But it also has disadvantages such as /9./:

- should be defrosted, so heat recovery can be reduced
- has relatively higher pressure drop which increases the noise level and electricity demand for the fan

Other type of heat recovery unit is regenerative, for example rotating wheel which is shown in the *figure 13.* Usually it has higher temperature ratio than the recuperative heat recovery unit, so η_t is from 0,75 to 0,85. /9./

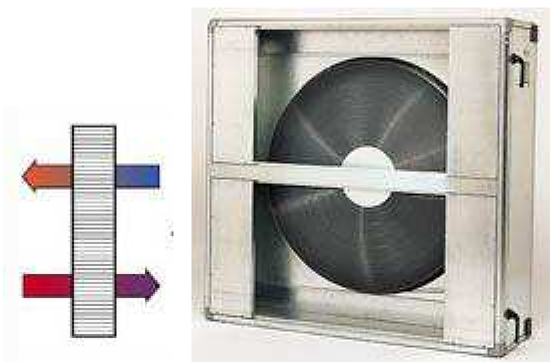


FIGURE 13. Regenerative heat exchanger /9/

Advantages of regenerative heat exchanger are /9./:

- the ability to regulate the temperature efficiency according to the rotating speed
- no need to defrosting

The disadvantages are /9./:

- heat exchanger needs the electricity
- has moving parts
- risk of transfer pollutants or humidity from exhaust air to supply

Annual efficiency of air to air heat recovery for the passive house should be higher than 80%. The best solution for passive house`s ventilation system is the counter flow regenerative plate heat exchanger or rotating wheel heat exchanger. /9./

With higher temperature ratio freezing of air handling unit is possible. To avoid freezing of the heat recovery unit, a ground-coupled heat exchanger for preheating the outdoor air can be used. One of these heat exchangers is shown in the *figure 14*. With this kind of heat exchanger energy for preheating can be minimized or avoided. /9./

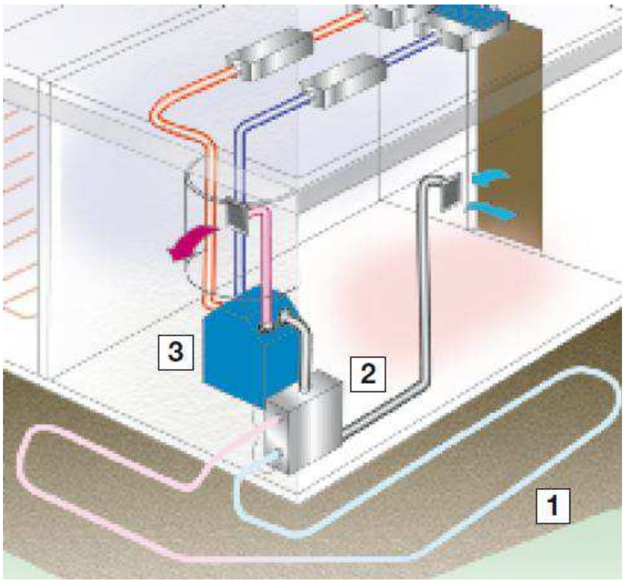


FIGURE 14. Preheating of the supply air /9/

When the ductworks are designed is better to have lower pressure in the ventilation system to reduce the electricity consumption of fan, so the short distribution distances are preferable. Also ducts should be well insulated to avoid the heat losses in distribution systems. /8./

Other important aspect of designing energy efficient ventilation system is SFP-value (specific fan power). As it was shown in the *equation 8* SFP is a key factor for ventilation system electricity consumption. According to the equation 7.2 from D5 SFP is /2./:

$$P_{es} = \frac{P_e}{q_v} \qquad (22)$$

P_{es}	specific fan power of a fan,	$kW/(m^3/s)$
P_e	electrical power of the fan,	kW
q_v	air flow through the fan,	m^3/s

In passive house design SFP for air handling unit with supply and exhaust fans should not exceed 2,0 $kW/(m^3/s)$ and for separate exhaust fans SFP should not exceed 1,0 $kW/(m^3/s)$. /9./

Basic principles of designing low energy ventilation system /9./:

- optimize the overall layout of the ventilation system, smaller distances for ductworks
- use high efficiency fans
- lower pressure drop in the duct system
- equipment for air flow controlling

Supply and exhaust fans should have specific fan power value (SFP) about 1,0 kW/(m3/s) for reducing excessive electricity consumption. Electricity consumption does not depend only on the fan, but it is also depends on the whole system. As it was said the pressure losses in the ducts should be minimized. /9./

5.9 Cooling system

In summer time cooling is needed to avoid uncomfortably high temperatures. The idea of passive house is that cooling demand is so small, so the energy consumption of cooling system is very low.

Ground source cooling system with a bore holes is a popular solution for passive house because of its high efficiency. In this kind of system water circulates through a buried loopand cooling down using the cooling power of the ground. Because the earth is cooler than the outdoor air in summer time, the geothermal system removes heat from the home and deposits it into the ground. The fluid is cooled by the ground temperatures and returned to the cooling coil in the AHU. Operational principle shown in the *figure 15*. It is so-called free cooling when the compressor off and cooling is based in the water circulation in the ground, so the cooled water flows to the AHU`s cooling coil and cooling devices in the rooms. /15./

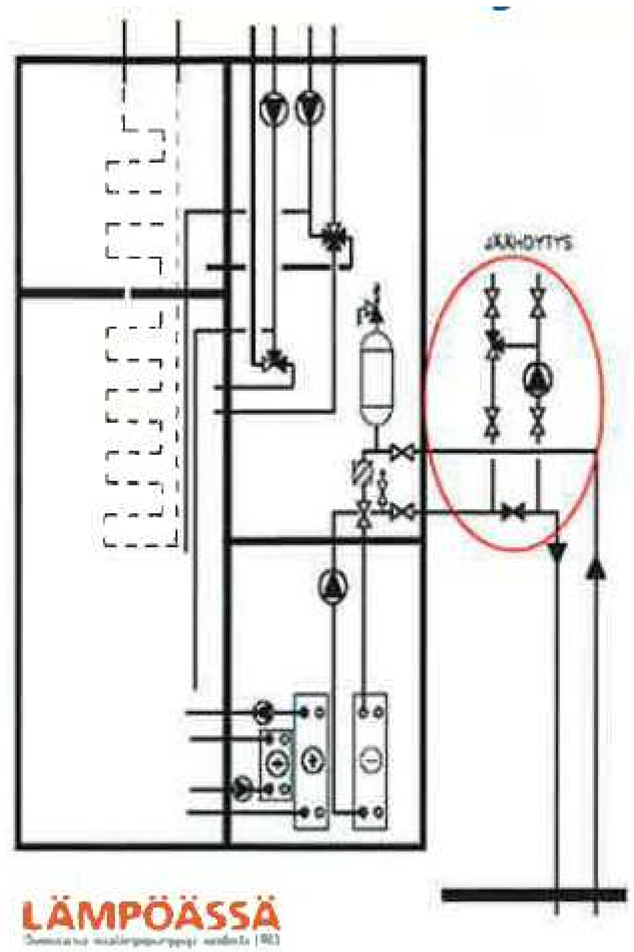


FIGURE 15. Ground source cooling system/16/

Free cooling is a good solution for passive house because the cooling load is very small and it is possible to provide comfortable indoor temperatures using this kind of system with low energy consumption.

5.10 Domestic hot water

When the E-value is calculated heating energy needed for domestic hot water should be calculated using the specific consumption value which shown in National Building Code D3 in table 4 and for the separated small houses it is 600 $dm^3/(m^2a)$ or the heating energy 35 $kWh/(m^2a)$. /1./

Energy for producing hot domestic water QHDW does not depend on the weather conditions. And HDW consumption cannot be changed so in a passive houses the we should focuses on minimizing the heat losses from distribution and production of hot domestic water. /2/

Because the building envelope of the passive house should be insulated very well, the heat losses from the distribution domestic hot water or heating pipes also should be minimized. The heat from the distribution pipes is not a big problem in cold time period but anyway this heat is not where it should be. /8./

Energy efficient faucets can be applied in water supply system, for example thermostatic shower with the eco-button which saves water and energy. Faucet provides water with constant temperature and regulates flow automatically. *Figure 16* shows basic principle of faucet with eco button. /17./

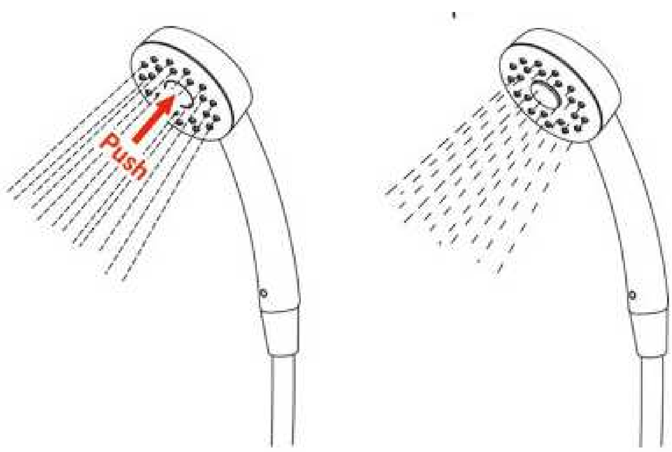


FIGURE 16. Shower with eco button/17/

Then we think about the internal heat loads, first the heat losses from the distribution lines of hot domestic water and the heating system pipes. To avoid this kind of internal gains in passive house the basic principles should be applied /8./:

- pipes and valves should be well-insulated
- low temperatures in pipes should be used
- short distances should be used in for the distribution lines

In the best case part of energy needed for domestic hot water can be compensated with the solar collectors. Even in the Nordic countries up to 50% of required energy can be supplied by mean of solar collectors. /9/

5.11 Electricity consumption

Because the energy consumption of the passive house is limited, the electricity use also should be reduced. Electricity from the network is used usually for lighting, household appliance and for engineering systems in pumps, fans, compressors and automation system.

Reducing the electricity consumption of lighting and different equipment can be done according to use latest energy efficient technologies.

Energy consumption of lighting equipment can be minimized if more daylight is used, but this solution has two sides. First, it is of cause reduces the operational time for lighting and because of that the electricity consumption, but from the other hand it reduces the internal heat gains which are not good in summer but can be utilized in winter time. Also the lager windows are can increase the heat losses through the building envelope. /9./

The daylight penetration in the room spaces depends on the several factors, how it was said before /9./:

- area and orientation of the windows
- glazing type
- light shelves

The daylight factor is important and should be taken into account in building simulations. It is not so much daylight in winter time, especially in Nordic countries, so the needed light should be provided with low energy lamps and demand controlled lighting. /9./

So the installed power and operative energy can be minimized. It means usage the appliance of class A or better. The energy performance certificate provides ratings 'A' to 'G' for the building components and equipment, so with 'A' it is being the most energy efficient. *Figure 17* shows the scale of energy performance certificate. /9./

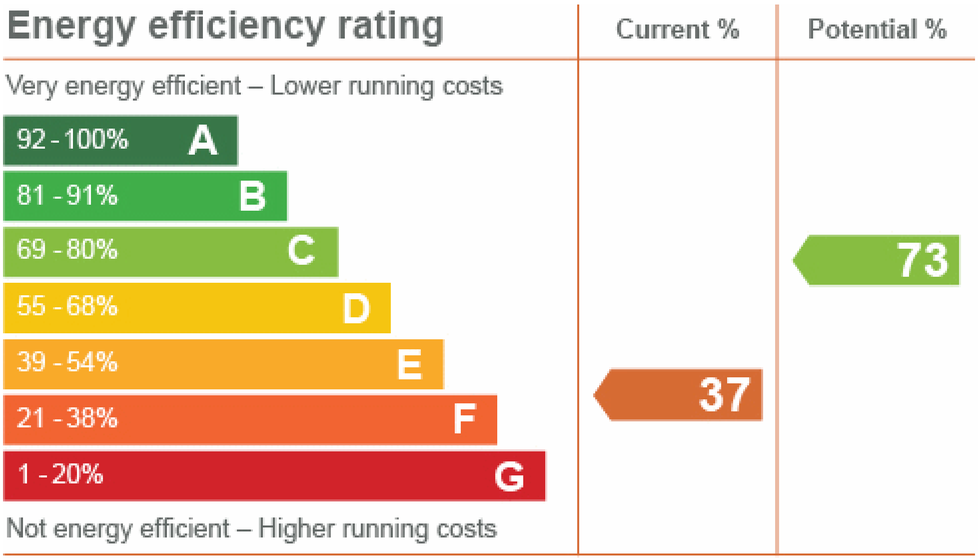


FIGURE 17. Energy performance certificate /18/

5.12 Automation and control system

Control system should be suitable for the low energy consumption and it should be able to control small amounts of required energy for space heating. It should guarantee the thermal comfort and no heat should be squandered. The user interface should display the indoor temperatures and the energy demands of heating system, ventilation, domestic hot water production and the usage of electricity in the building. It should be done to be sure that the building acts as it was planned and for the controlling thermal comfort as well. /9./

Well-designed automation system can improve the achievement of heat gains through the windows with blinds and awnings and protect the room spaces from overheating. Also the automation system using the sensors can control the operation of fans, conditioners and heating system; so that they are running only then desired temperature is needed to achieve. And the same for lighting – with the sensors it is possible to switch off the light automatically when the rooms are vacant. /19/

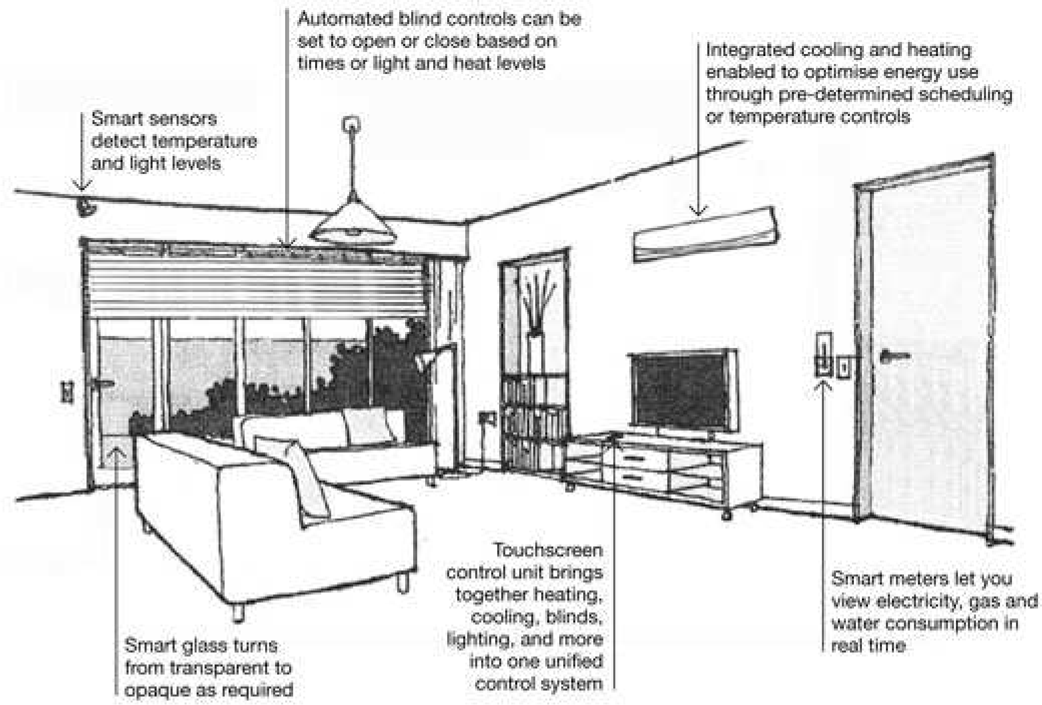


FIGURE 18. Automation and control system /19/

5.13 Summary. Building components

Low energy design considers the reducing of the heat losses, reducing of the electricity use, utilizing the solar heat, so the energy use is controlled and displayed. Passive houses require the application of modern construction, HVAC and automation technologies /20./.

To design and build this kind of houses a special components are needed, such as /20./:

- thermal insulation materials with the thermal conductivity less than 0,05 W/m^2K
- windows with the U-values less than 1,0 W/m^2K
- glazing with the solar transmittance g-value higher than 0,4 (40%) and daylight transmittance more than 0,5 (50%) depends on the glazing area related to the area of building facade or floor area
- solar shading
- doors with the U-values less than 1,0 W/m^2K
- construction components with minimum thermal bridges
- Specific fan power (SFP) of AHU should not exceed 1,5 -2,0 $kW/(m^3/s)$, so the pressure losses should be as low as possible
- air to air heat recovery units in ventilation systems with the efficiency higher than 80%
- heat pumps with the COP (coefficient of performance) higher than 3,0
- pumps with low electricity consumption
- domestic hot water heaters with low standby losses
- faucets with an eco-button (saving water and energy)
- domestic appliances class A effectiveness
- energy efficient water taps and faucets.

5.14 Design methods

Building energy requirements depends on the annual mean temperatures, especially in coldest months. The main question is how much energy should be compensated in a different cases (climate zone, indoor climate etc) and should it be full compensation of energy demand or partly. /8./

Two concepts of the passive house design were presented after some studies and energy calculations /8/:

Concept 1. “Compensation” Illustrated by heat demand calculated according to moderate climate passive house criteria and keep this characteristics in a Northern climate.

Concept 2. “No compensation” Calculation of the U-values for each climate zone.

Design characteristics for the concept Single family house (1 dwelling, 172 m^2 gross area) The main idea was the optimization of building envelope. The building has a compact shape; windows with the external blinds were oriented to the south. North facade has rather small area of windows and the balcony has an overhang to protect the building from overheating in summer. The size of the house and it`s shape were fixed. /8./

TABLE 8. Properties of building envelopes in two concepts /8/

	Concept 1 “Compensation”	Concept 2 “No compensation”
U-value opaque envelope	< 0,12 W/m^2K	0,04 - 0,12 W/m^2K
U-value window	< 0,7 W/m^2K	0,5 - 0,8 W/m^2K
Heat recovery efficiency	> 85%	> 90%
Air flow (country specific)	≈ 120 m3/h	≈ 120 m3/h
windows to south	30 - 50%	30 – 60%
windows to east/west	< 15%	10 – 20%
windows to north	< 5%	< 5%

Space heating demand and the resulting average U-values are shown in the *figure 19* for two concepts of passive house in a different climate zones. /8./

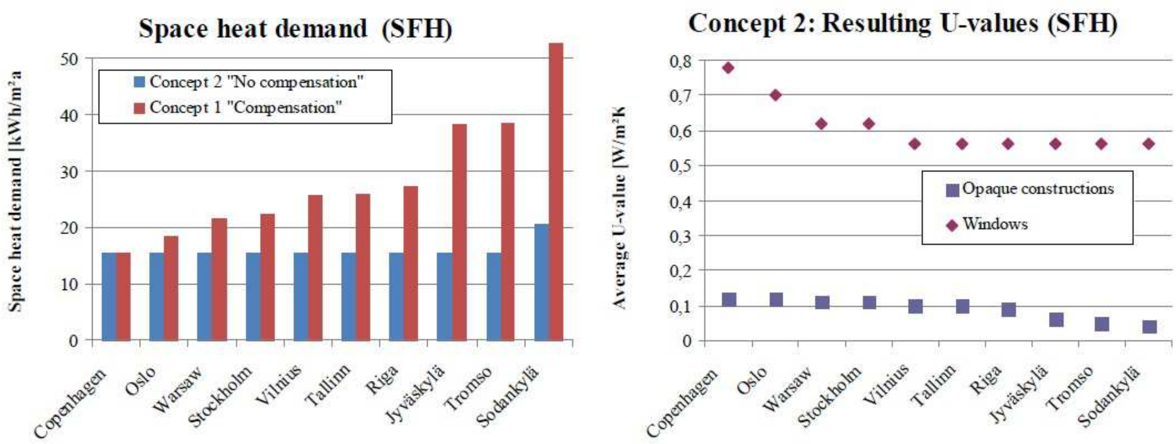


FIGURE 19. Space heating demand and the average U-values for different locations /8/

As we can see, Concept 1 application leads to increasing heating demand in all the Northern countries. And the Concept 2 shows that the U-values of the building envelope should be lower and lower throughout Northern climate zones. We can see that for the optimized concept house requires the U-values of building envelope under 0,04 W/(m^{2}K) and windows with U-values better than 0,56 W/(m^{2}K) due to achieve the passive house requirements in Sodankylä with the space heating demand about 20 kWh/ m^2/year. /8./

So the main idea is that U-values and properties of building envelope should be calculated for each location in order to meet passive house requirements and low energy consumption. /8./

6 BUILDING SIMULATION

In this chapter building simulation will be done in order to compare different design aspects of passive house. First according to simulation the lowest possible energy consumption and E-value will be found for single family house with net heated area 150 m^2 located in Helsinki with the weather data from year 2012. The following properties will be compared:

- shape of the building
- air tightness
- orientation of the building
- area and direction of the windows (area of the windows 12 – 20 % of floor area)
- glazing type
- solar shading (shadings around the site and in windows)
- heat source
- type of heating system

Simulation will be done without cooling and comfort conditions (lowest possible degree hours with temperature higher than + 27 ˚C) will be achieved with passive methiods using solar shading. If it the overheating in building will be too big, than free cooling using bore holes or horizontal pipework in the ground will be added.

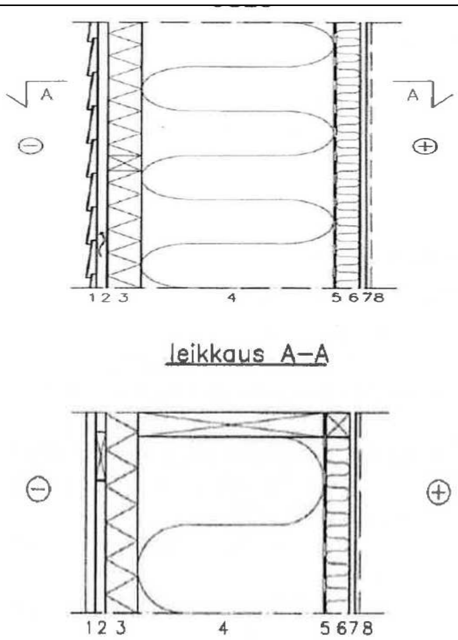
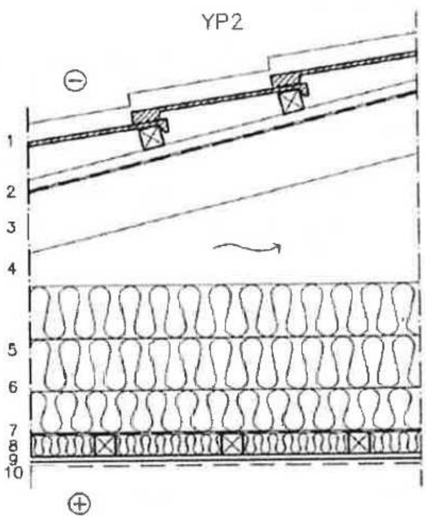
After that fireplace will be added, so the heat from fireplace will be taken into account for heating system. Also effect of solar collectors for domestic hot water on the E-value will be studied.

Finnaly the building witj the lowest E-value will be simulated in Sodankyla in order to find out will it meet the passive house requirements in colder climate.

Building will be simulated with the standard use, but for the best case simulation also will be done with real heat loads. In order to compare results with VTT Passive House definition energy consumption will be calculated also for the gross area with the real internal heat loads.

Initial data for simulations is shown in the following tables.

TABLE 9. Building envelope constructions /21./

External Wall			
Cross-section	Layers	Thickness, mm	U-value W/m^{2}K
	1. Timber cladding 2. Vertical air cap 3. Frames cc600 with mineral wool 4. Frames cc600 with mineral wool 5. Vapour barrier 6. Frames cc600 with mineral wool 7. Gypsum board 8. Surface material	20 22 70 400 0,2 50 13	0,09
Roof			
Cross-section	Layers	Thickness, mm	U-value W/m^{2}K
	1. Roof 2. Roof covering sheet 3. Supporting structure 4. Ventilated loft 5. Mineral wool 6. Frames cc900 with mineral wool 7. Vapour barrier 8. Frames cc600 with insulation	- - - - 250 100 0,2 50	0,1

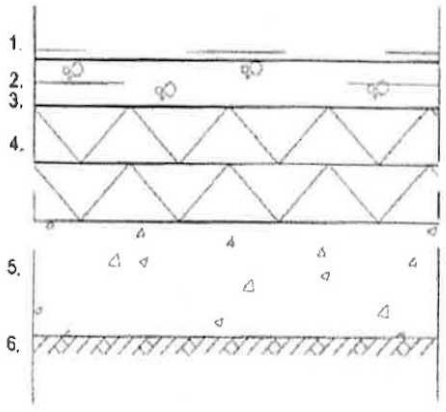
	9. Gypsum board	13	
External Floor			
Cross-section	Layers	Thickness, mm	U-value W/m^{2}K
	1. Linoleum 2. Concrete 3. Expanded poly-styrene 4. Expanded poly-styrene 5. Crushed stone	2,5 80 100 100 300	0,18

TABLE 10. Internal constructions

Internal wall		
Layers	Thickness, mm	U-value, W/m^{2}K
1. Gypsum board 2. Air gap 3. Mineral wool 4. Air gap 5. Gypsum board	26 30 30 30 26	0,6
Internal floor		
Layers	Thickness, mm	U-value, W/m^{2}K
1. Floor coating 2. Concrete	5 200	3,8

TABLE 11. Coefficients of performance

	Electric	District
Heating COP	3,1	0,94
Cooling COP	7	1
DHW COP	2,3	0,94

Values for thermal bridges in different constructions are shown in the following figure.

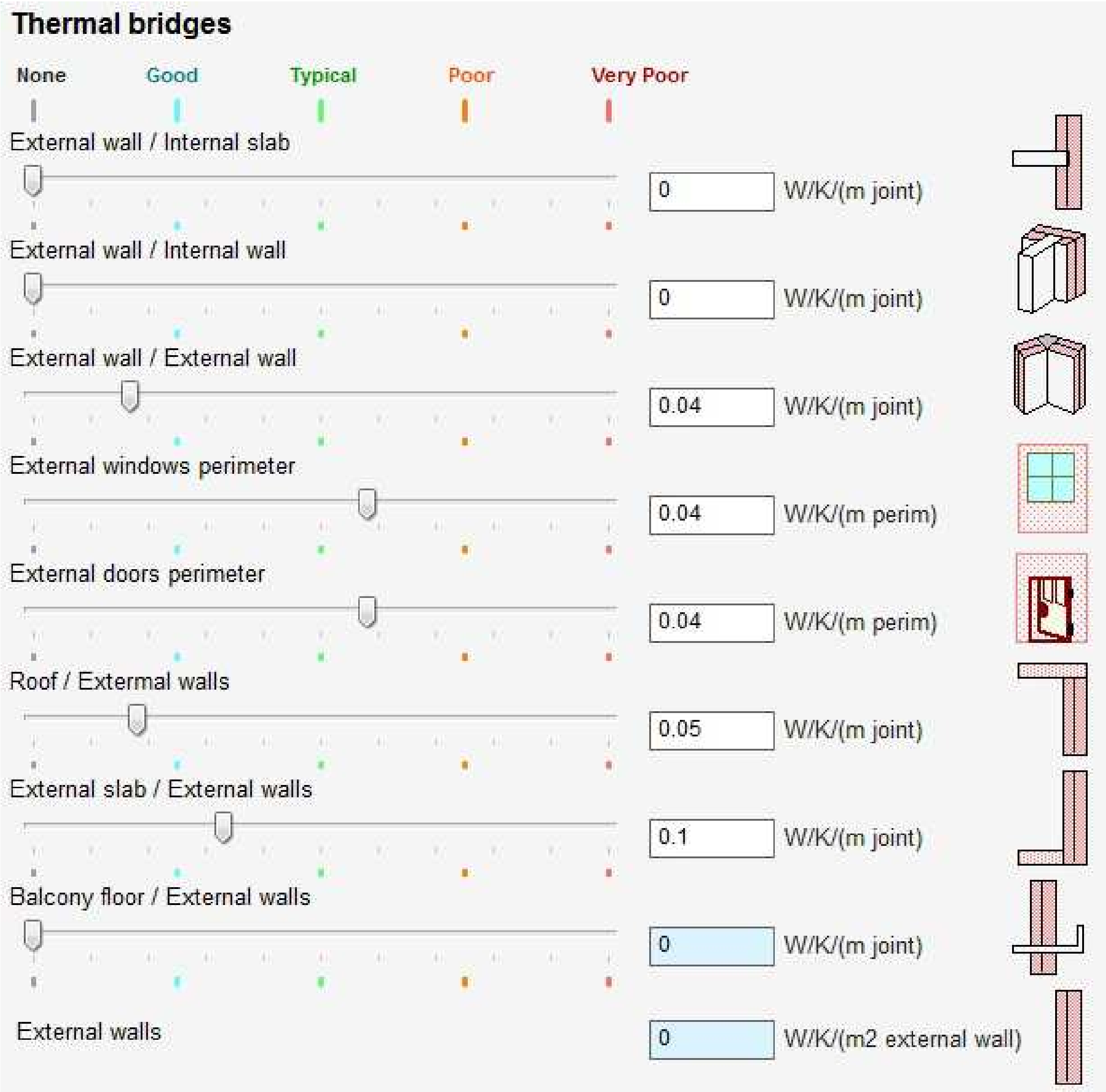


FIGURE 20. Thermal bridges

Extra energy and losses – domestic hot water consumption and losses from heat distribution are shown in the *figure 18.*

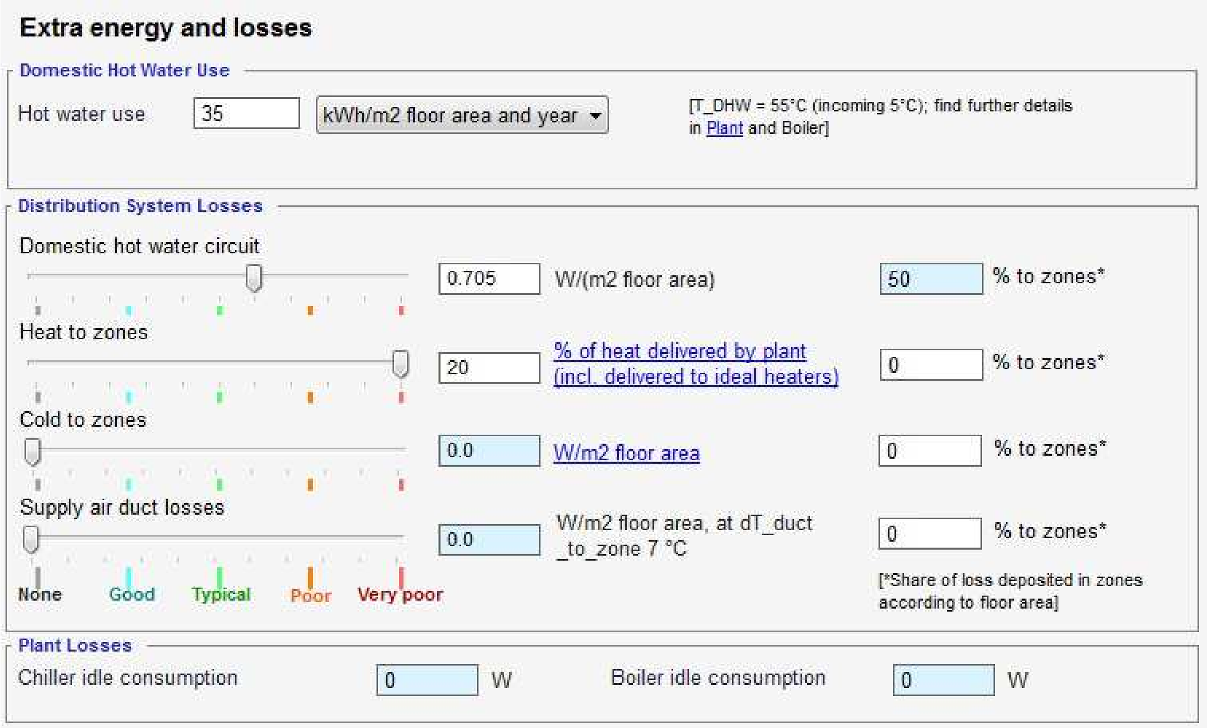


FIGURE 21. Extra energy and losses

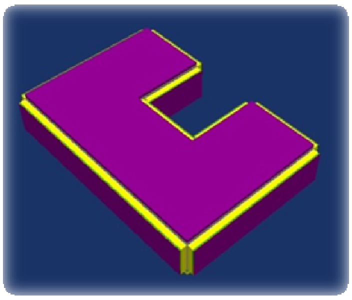
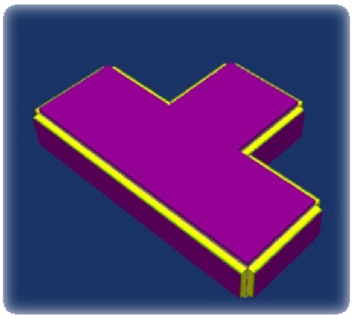
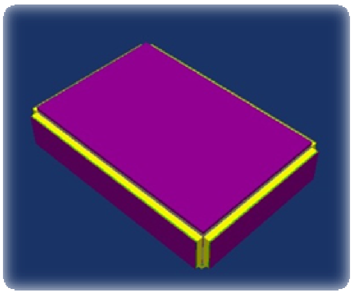
Properties of air handling unit are the following: SFP for supply and exhaust fan is 1 kW/(m^3/s), temperature ratio of heat recovery unit is 0,8.

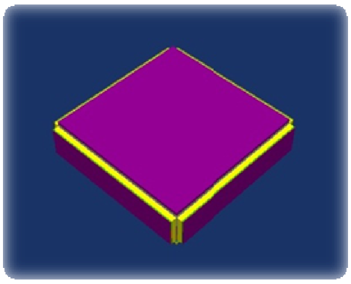
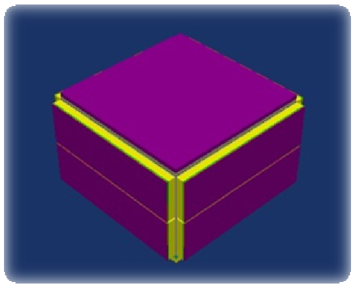
According to standard use lighting in the building gives 0,8 W/m^2 heat gains, equipment gives 3 W/m^2.

6.1 Shape of the building

Study cases for different shapes are shown in the *table 12*.

TABLE 12. Different shapes. Study cases

Case 1. U-Shape Floor area 150 m^2 (net heated area) Height of the building 2,6 m Volume of the building 375 m^3 Envelope area 464.3 m^2	
Case 2. T-Shape Floor area 150 m^2 (net heated area) Height of the building 2,6 m Volume of the building 375 m^3 Envelope area 453.1 m^2	
Case 3. Rectangular Shape Floor area 150 m^2 (net heated area) Height of the building 2,6 m Volume of the building 375 m^3 Envelope area 425.0 m^2	

Case 4. Square Shape with one floor Floor area 150 m^2 (net heated area) Height of the building 2,6 m Volume of the building 375 m^3 Envelope area 422.4 m^2	
Case 5. Square Shape with two floors Floor area 150 m^2 (net heated area) Height of the building 2,6 m Volume of the building 375 m^3 Envelope area 323.2 m^2	

Results of energy calculations are shown in the *table 13*. Values of delivered energy and heat losses will be compared.

TABLE 13. Energy calculations for different shapes

Case	$A_{enleope}/V$	$Q_{envelope}$	$Q_{thermal\ bridges}$	$Q_{leakageair}$	Delivered Energy
	m^2/m^3	kWh	kWh	kWh	kWh
U-shape	1.238	8154	1475	420	9556
T-shape	1.208	7942	1381	404	9464
Rectangular	1.133	7223	1094	367	9162
Square	1.127	7179	1062	362	9142
Square two-stores	0.8619	5276	843	492	8508

The following figures shows the dynamic of changing the heat losses and delivered energy with different shapes of the building.

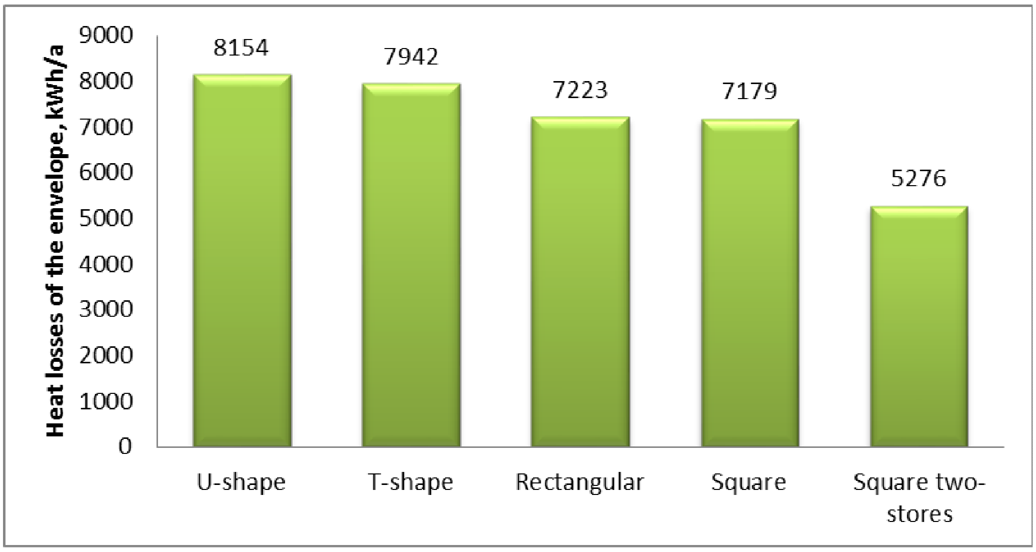


FIGURE 22. Heat losses of building envelope for different shapes

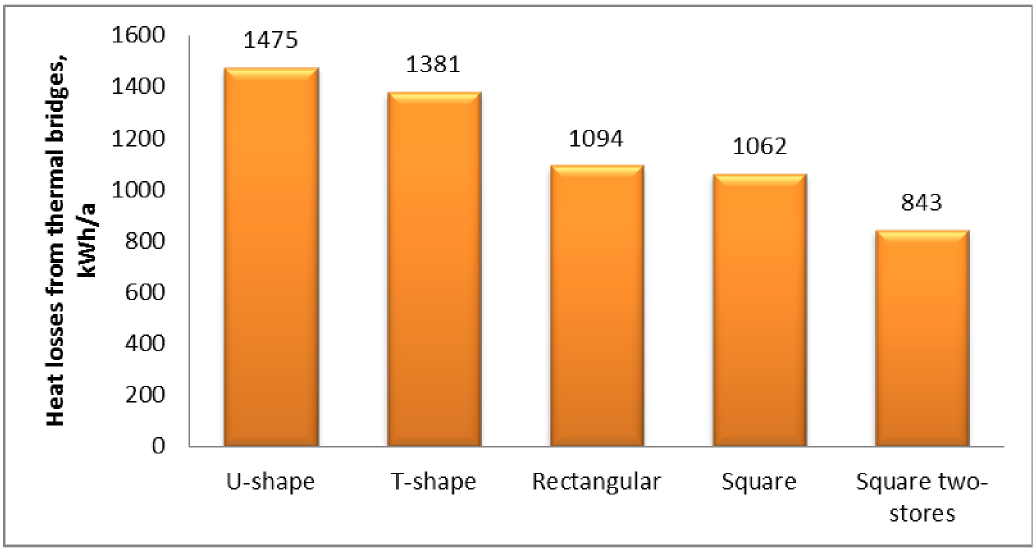


FIGURE 23. Heat losses from thermal bridges for different shapes

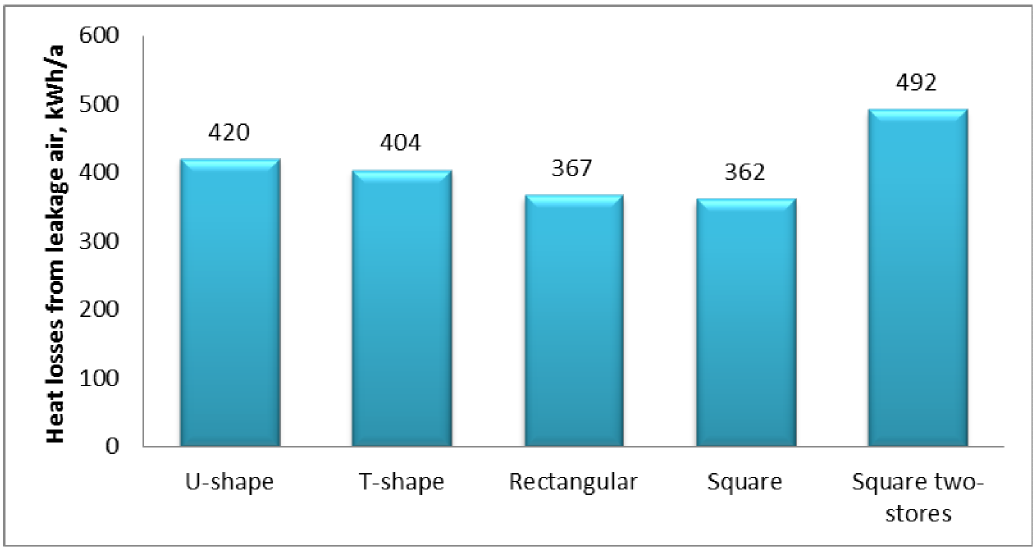


FIGURE 24. Heat losses from leakage air for different shapes

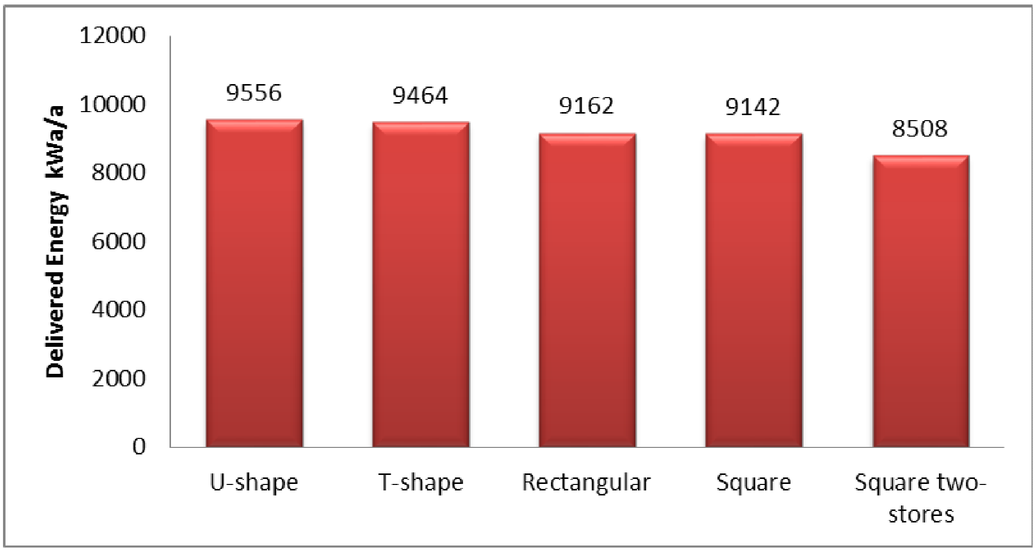


FIGURE 25. Delivered energy for different shapes

We can see that the best shape with the lowest energy consumption (delivered energy) is the square shape with two floors. It so because of smaller $A_{envelope}/V$ ratio and more compact envelope, so there are less losses from thermal bridges and heat losses with leakage air. Next we will take the square shape with two floors and will change other properties.

6.2 Air-tightness

The next important parameter is an airtightness of the building. It is measured with the coefficient of leakage air of building envelope q_{50}. We will take three typical values from the best case to the poor one:

- $q_{50} = 1\ m^3/h,m^2$
- $q_{50} = 2\ m^3/h,m^2$
- $q_{50} = 4\ m^3/h,m^2$

TABLE 14. Energy calculations with different coefficients of leakage air

q_{50}	Q_{leak}	Delivered Energy	Average leakage air airflows			
$m^3/h,m^2$	kWh	kWh	Inflow		Outflow	
			1st floor	2nd floor	1st floor	2nd floor
			l/s	l/s	l/s	l/s
1	492	8508	0,9	1,7	1,3	2,2
2	976	8683	1,9	3,5	2,4	4,2
4	1952	9047	3,8	7,1	4,4	7,9

The following figures shows how heat losses of leakage air and delivered energy changes with different q_{50} values.

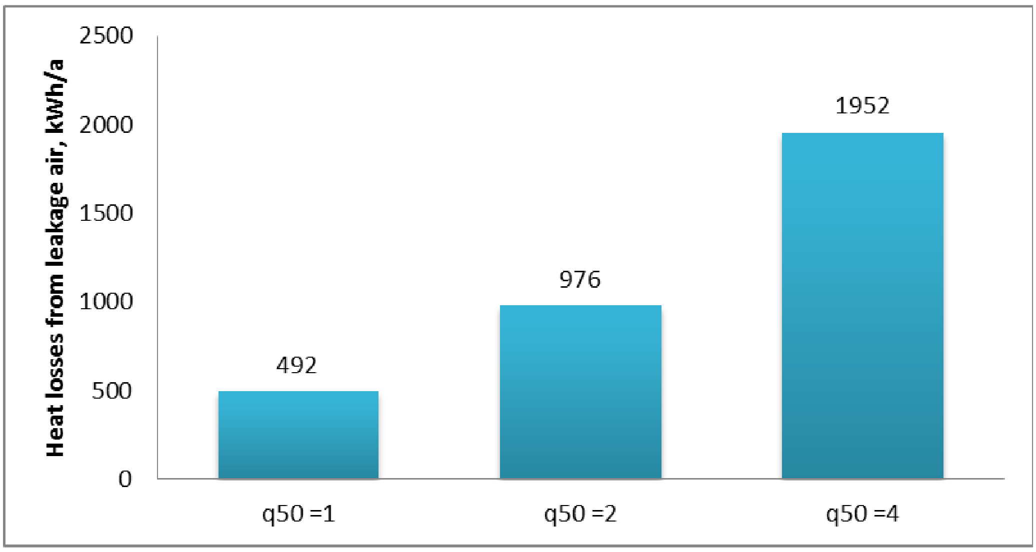


FIGURE 26. Heat losses from leakage air for different q_{50} values

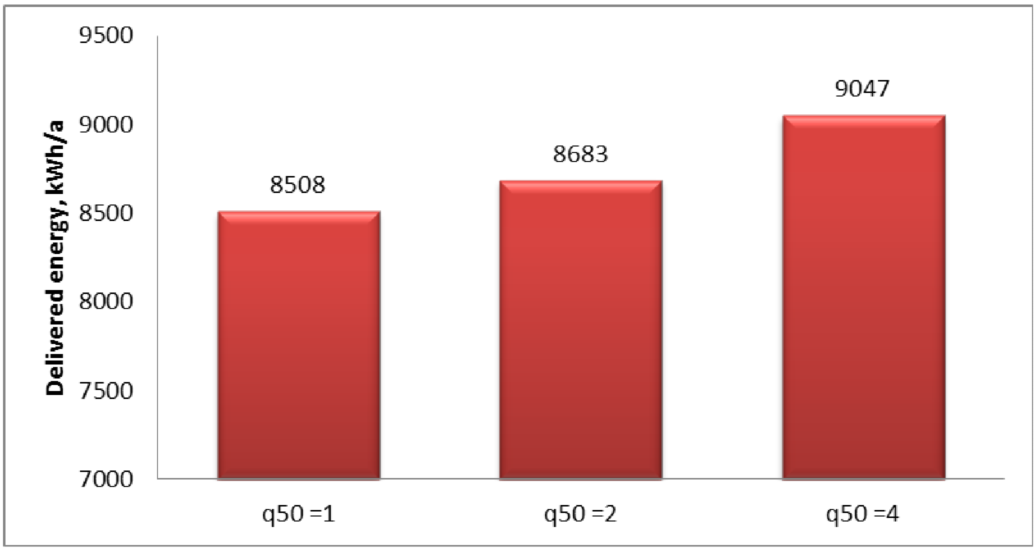


FIGURE 27. Delivered energy for different q_{50} values

Results shows that it is important to have better building envelope with lower q_{50} in order to achieve good airtightness. Because heat losses and then needed energy depends on the airtightness very much as it can be seen from the diagrams. Leakage air flow rates become bigger with poorer q_{50} number. Values of flow rater shows that it is an over pressure in building because outflow air flow rates are bigger than inflow.

6.3 Orientation of the windows

Orientation of the main window area is important because of the heat losses through the windows but another important factor is the solar gains. Heat gains from the sun are useful in winter time because they reduce the heating energy demand but in summer time they can cause overheating in the room spaces.

First we will compare the heating energy demand with different directions of the main window area. The area of the window is typically from 15 – 20 % from floor , so the total area of the windows is 27 m^2.

Area of a one window is 1,2x1,5 = 1,8 m^2, so it is about 15 windows.

In the simulation process first the situation when windows area is the same to all directions and then the main window area will be changed to different orientations. *Figure 28* shows the main windows area. There is the door oriented to the north, so there are 3 windows only oriented to the north except study case with 5 windows to north direction.

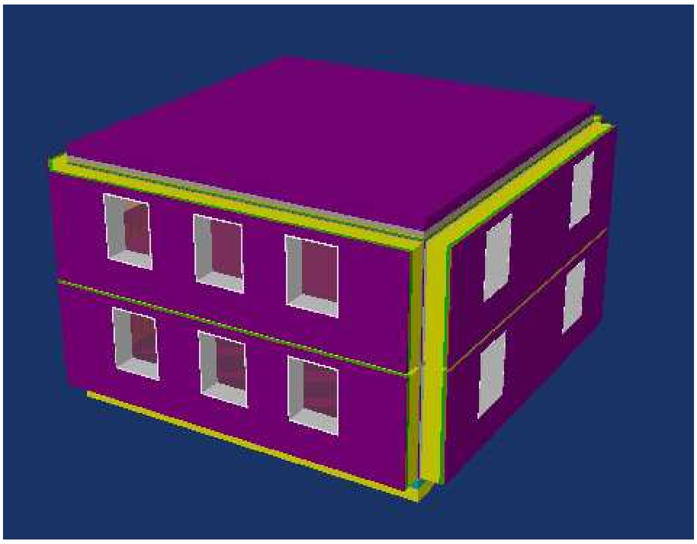


FIGURE 28. Main window area

The results of energy calculations with different orientations of the windows are shown in the *table 15* and *table 16*.

TABLE 15. Different orientations of the windows

Main orientation	Windows to north facade	Windows to east façade	Windows to south façade	Windows to west facade	Delivered energy, kWh
Same to all directions	3	4	4	4	9154
Main windows to east	3	6	4	4	9283
Main windows to south	3	4	6	4	9205
Main windows to west	3	4	4	6	9230
Main windows to north	5	4	4	4	9293

TABLE 16. Different orientations of the windows

Main orientation	Windows to north-east	Windows to south-east	Windows to south-west	Windows to north-west	Delivered energy, kWh
Main windows to north-east	6	4	4	3	9301
Main windows to south-east	4	6	4	3	9262
Main windows to south-west	4	4	6	3	9205
Main windows to north-west	3	4	4	6	9288

Figure 29 shows how delivered energy needs changes when the main windows area has different orientations.

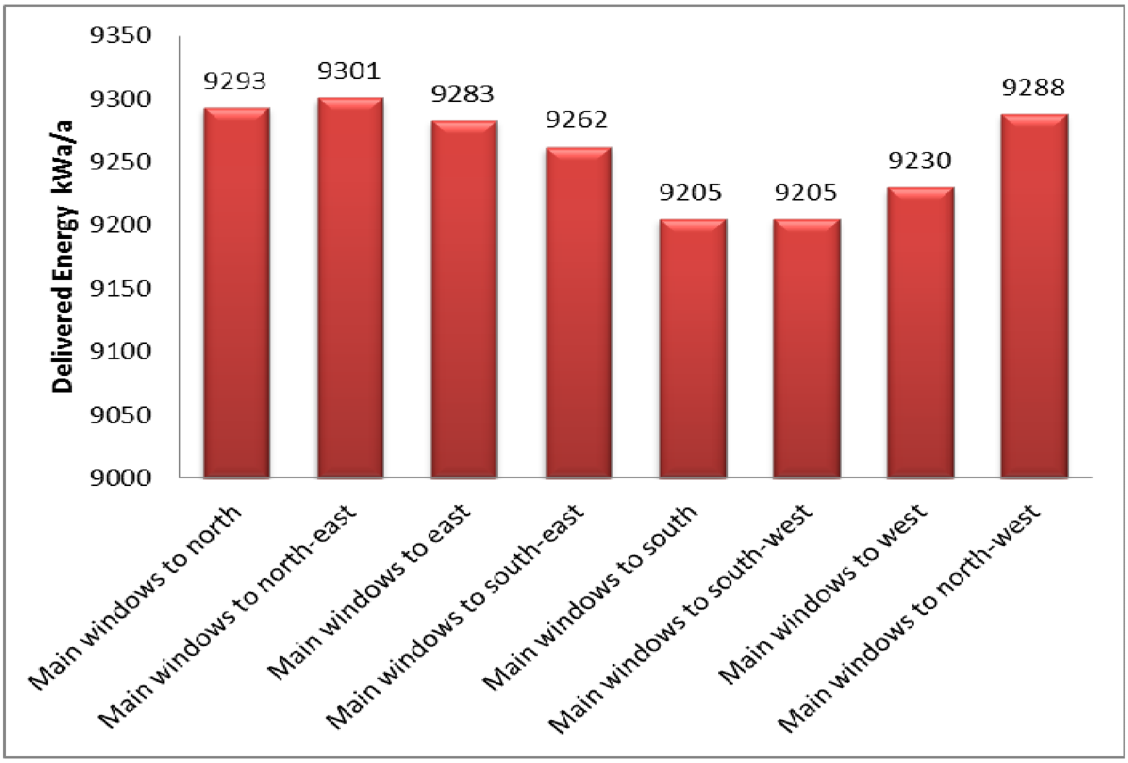


FIGURE 29. Delivered energy according to different orientations of main windows area

We can see that the lowest energy consumption achieved when more windows are oriented to the south. In other simulations we will use this direction for the main windows.

6.4 Glazing type

Type of glazing also has an effect on the energy demand of the building, so different types of window panes with different U-values and g-values will be compared next. The results are shown in the *table 17*:

TABLE 17. Comparison of different types of glazing

Glazing Type	U-value	G-value	Delivered Energy
	W/(m^{2}K)	-	kWh
Pilkington Optitherm S3 (4-15-Ar-4-12Ar-S(3)4)	1,0	0,55	9205
Pilkington SunCool 66/33 (6C(66)-15Ar-4-15Ar4S(3))	0,6	0,32	9088
Pilkington SunCool 70/40 (6C(74)-15Ar-4-15Ar-S(3)4)	0,6	0,38	9010
Pilkington Optitherm S3 (4S(3-15Ar-4-15Ar-S(3)4)	0,6	0,49	8890

Figure 30 shows how delivered energy changes with different g-values of window but with the same U-value.

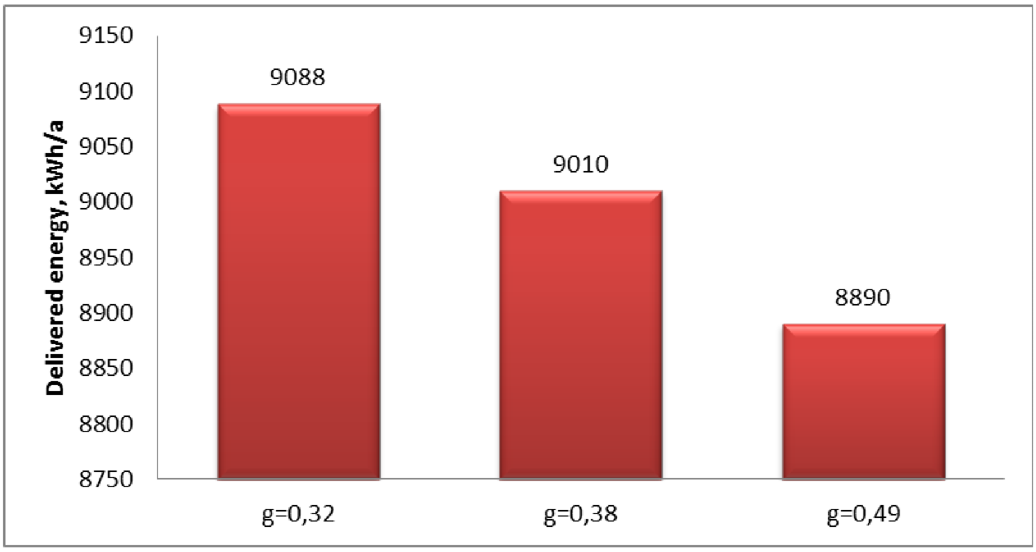


FIGURE 30. Delivered energy according to different g-values of windows

The best result is shown by the window Pilkington Optitherm S3 (4S(3-15Ar-4-15Ar-S(3)4). It is 3-glass window with outer glass Optitherm S3, cavity width 15 mm argon, middle glass Pilkington Optifloat Clear, cavity width 15 mm argon, inner glass Optitherm S3. This window has the best possible U-value, but not the best possible g-value.

6.5 Solar shading

G-value and solar shading of the window are important because it protects the room spaces from overheating and uncomfortably high temperatures in summer time. There is no limitation for the indoor temperature in summer for single family house, but we will try to achieve the lowest value of degree-hours when the room temperature is higher than 27 C.

First we will try the solar shading devices on the windows (*table 18*), then in the *table 19* shown results for horizontal solar shading which is presented on the *figure 31*, and after that other solutions like vertical solar shading 2 meters high (*figure 32*) shown in *table 20*.

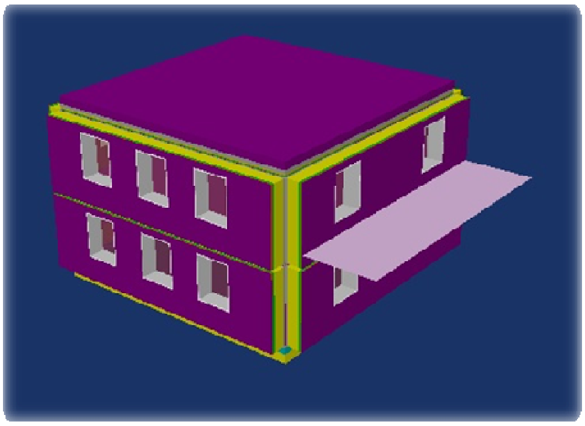


FIGURE 31. Horizontal solar shading

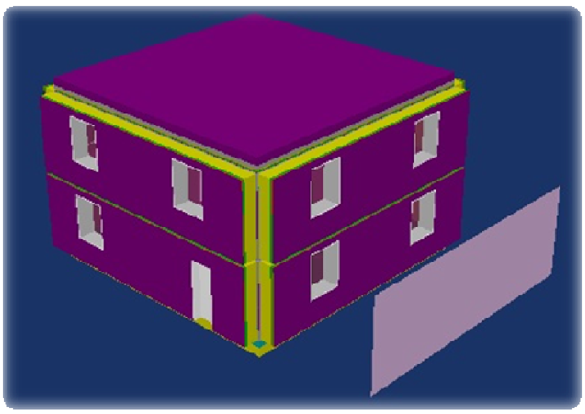


FIGURE 32. Vertical solar shading

TABLE 18. Simulation for solar shading on the windows

Type of Solar Shading	Degree Hours when t_{int}>27 ˚C	
	1st floor	2nd floor
No solar shading	15544	15758
Internal Blinds	12070	12581
External blinds	6151	6611
Blinds Between Panes	9081	9551
Blinds Between External Panes	8376	8836

Figure 33 shows degree hours when temperature is higher than 27˚C in summertime with solar shading on the windows.

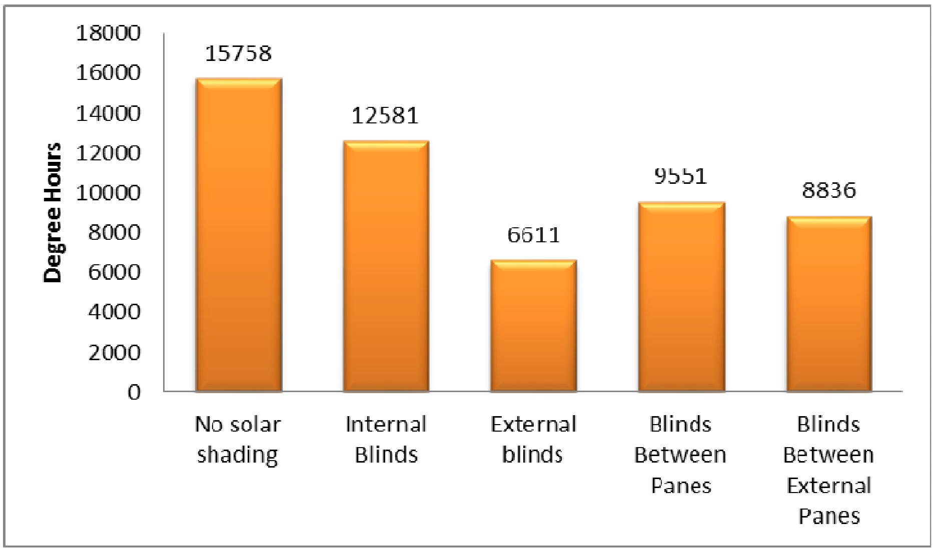


FIGURE 33. Degree hours when t_{ind} > 27˚C with solar shading on the windows

Table 13-1 shows the results of simulation for horizontal solar shadings combined with the internal blinds on outer glass panes in the windows.

TABLE 19. Simulation for horizontal solar shading in different directions

Horizontal shading orientation	Degree Hours when t_{int}>27 ˚C	
	1st floor	2nd floor
East	7940	8535
South	7584	8311
West	7964	8554
North	8231	8738
South+East	7062	7918

Figure 34 shows degree hours when temperature is higher than 27˚C in summertime with horizontal solar shadings in different directions.

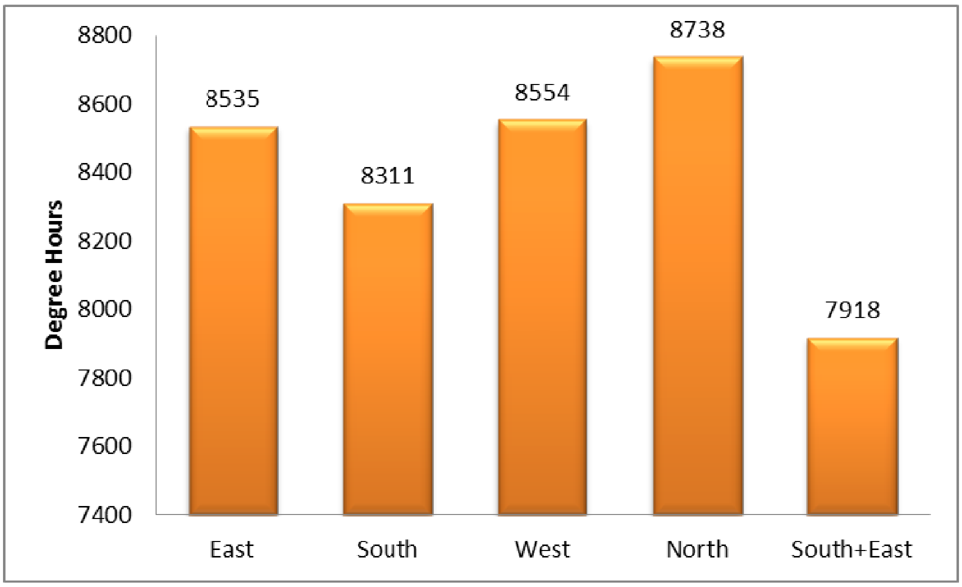


FIGURE 34. Degree hours when t_{ind} > 27˚C with horizontal solar shading

So the best solution for horizontal solar shading is to put it in two directions – south and east. In order to reduce the overheating vertical solar shadings can be applied in addition to horizontal solar shading. Results are shown in the following table.

TABLE 20. Simulation for vertical solar shading solutions

Other solutions	Degree Hours when t_{int}>27 ˚C	
	1st floor	2nd floor
Vertical shading 2 m west	6607	7580

Combination of vertical solar shadings with horizontal to the south and east and the internal blinds between outer window panes significantly reduces degree hours when temperature is higher than 27˚C in summertime, so the cooling power demand will be much lower.

Now we can apply ground source cooling system, so-called free cooling which is the best solution for passive house.

Figure 35 shows the room temperature during the summer with the cooling system.

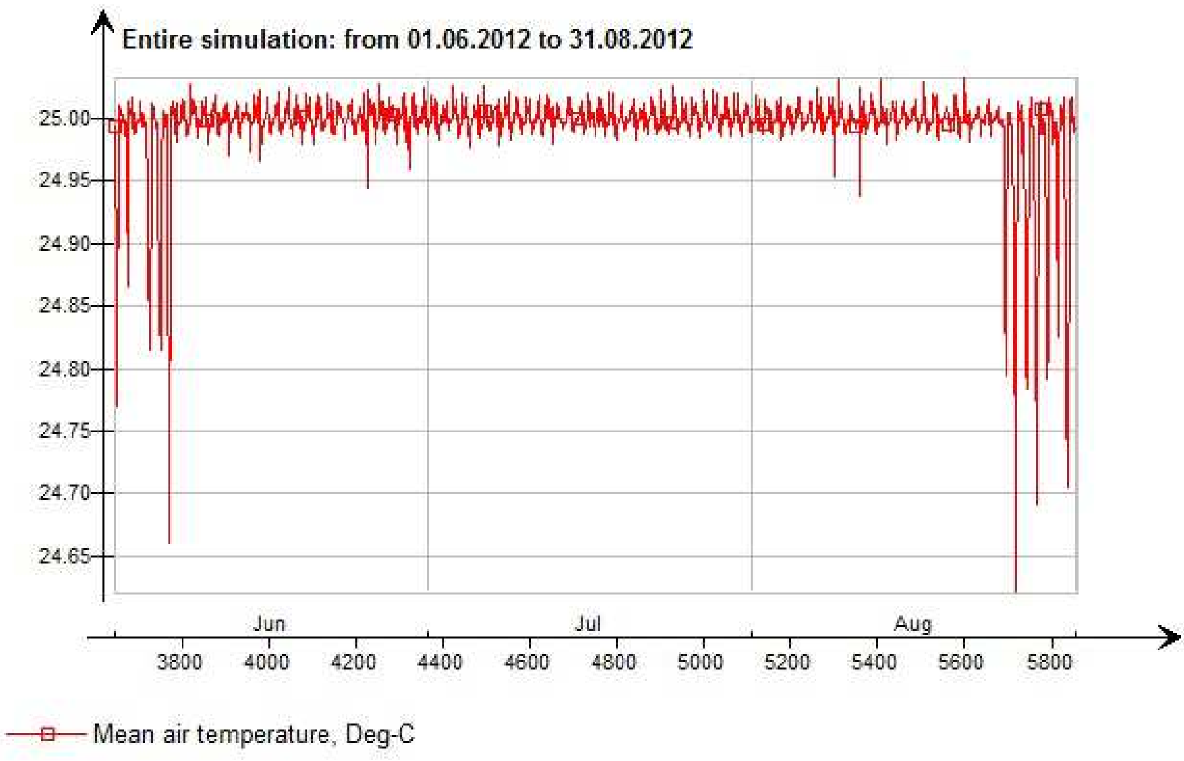


FIGURE 35. Mean air temperature during the summer with cooling system

We can see that now indoor air temperature does not exceed 27 ˚C at all which means the comfort conditions during the summer.

Energy consumption of this cooling system is 1.9 kWh/m^2 per year which fulfills the passive house concepts and requirements.

6.6 Heat sources

When the E-value is calculated, the heat source has a great significance because of the energy coefficients which are used for converting the delivered energy to primary energy.

We will compare three common solutions for the passive house:

- Ground Source Heat Pump
- District Heating
- Air Heating System with the electrical heaters in each room

6.6.1 Ground source heat pump

First ground source heat pump with the floor heating will be simulated. Cooling system is based on a ground source free cooling, domestic hot water use, ventilation air flow rates, lighting and equipment are given according to standard use from National Building Code D3.

Figure 36 shows generator efficiencies used in simulation for ground source heat pump.

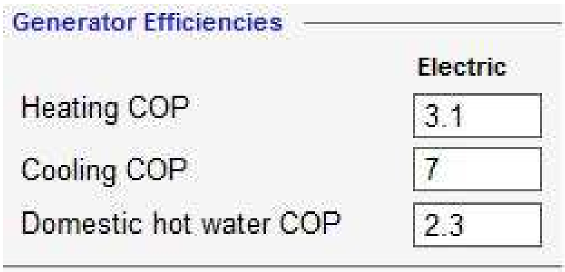


FIGURE 36. Generator efficiencies of ground source heat pump

Following table represents delivered energy overview, *figure 37* and *figure 38* shows delivered and primary energy per months.

TABLE 21. GSHP. Delivered Energy Overview

		Delivered energy		Primary energy	
		kWh	kWh/m²	kWh	kWh/m²
	Lighting, facility	1054	7.0	1792	12.0
	Equipment, facility	2372	15.8	4032	26.9
	Cooling	154	1.0	261	1.7
	HVAC aux	1036	6.9	1761	11.7
	Heating	1964	13.1	3339	22.3
	Domestic hot water	2693	17.9	4578	30.5
	Total, Facility electric	9273	61.8	15763	105.1
	Total	9273	61.8	15763	105.1

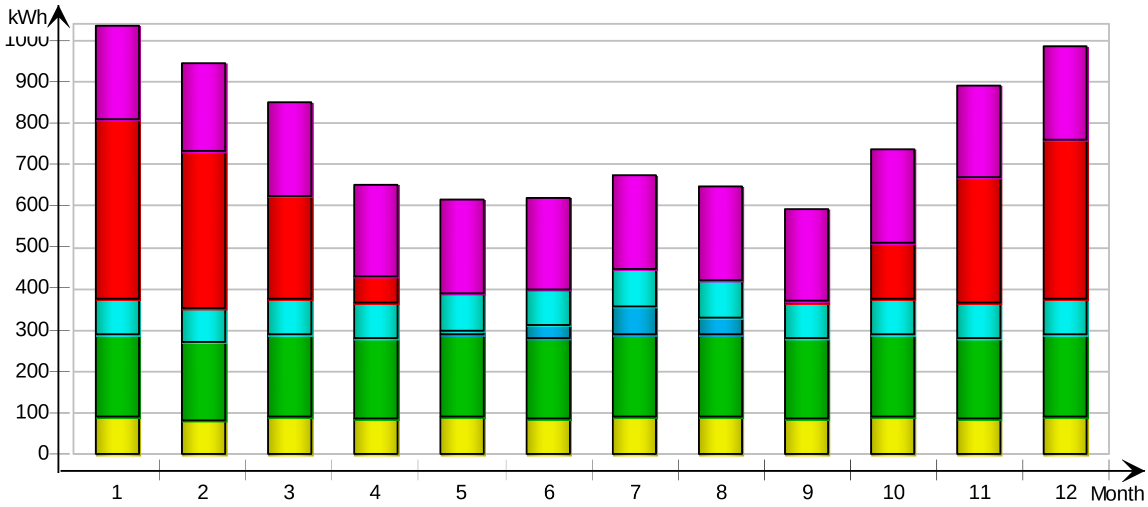
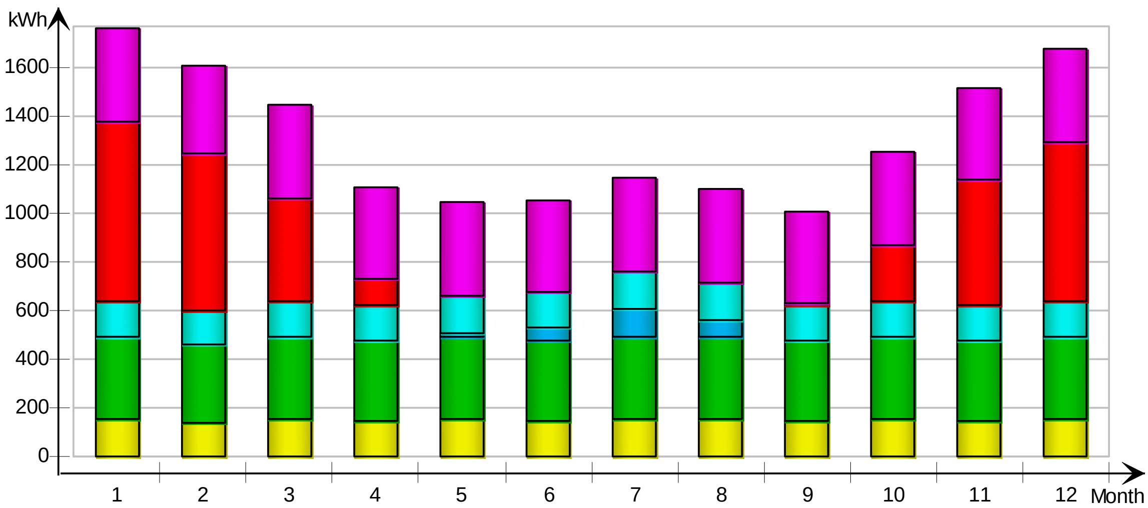


FIGURE 37. GSHP. Monthly Delivered Energy



FUGURE 38. GSHP. Monthly Primary Energy

6.6.2 District heating

In this case simulated house will be connected to district heating network, heating system will be based on a floor heating and cooling system will use district cooling, domestic hot water use, ventilation air flow rates, lighting and equipment are given according to standard use from National Building Code D3.

Figure 39 shows generator efficiencies used in simulation for district heating and district cooling.

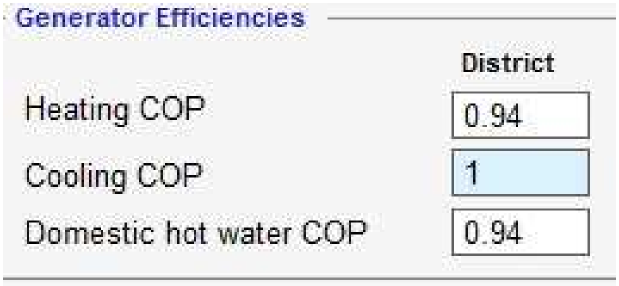


FIGURE 39. Generator efficiencies of district heating and cooling

Following *table 22* represents delivered energy overview, *figure 40* and *figure 41* shows delivered and primary energy per months.

TABLE 22. District heating and cooling. Delivered Energy Overview

		Delivered energy		Primary energy	
		kWh	kWh/m^2	kWh	kWh/m^2
	Lighting, facility	1054	7.0	1792	12.0
	Equipment, facility	2372	15.8	4032	26.9
	HVAC aux	1036	6.9	1761	11.7
	Total, Facility electric	4462	29.8	7585	50.6
	Cooling	1076	7.2	430	2.9
	Heating	6477	43.2	4534	30.2
	Domestic hot water	6589	43.9	4612	30.8
	Total, Facility district	14142	94.3	9576	63.8
	Total	18604	124.0	17161	114.4

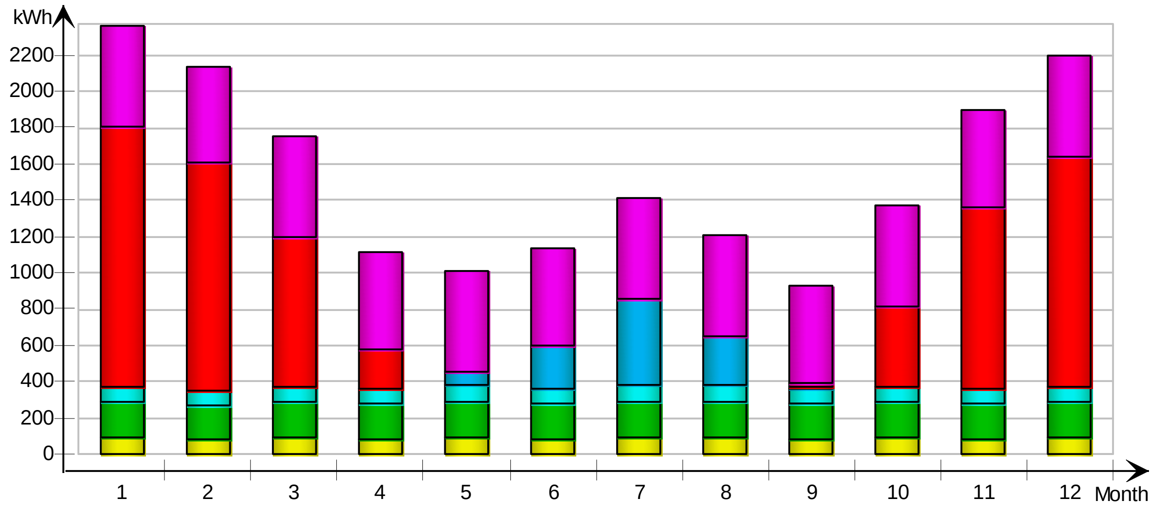


FIGURE 40. District heating and cooling. Monthly Delivered Energy

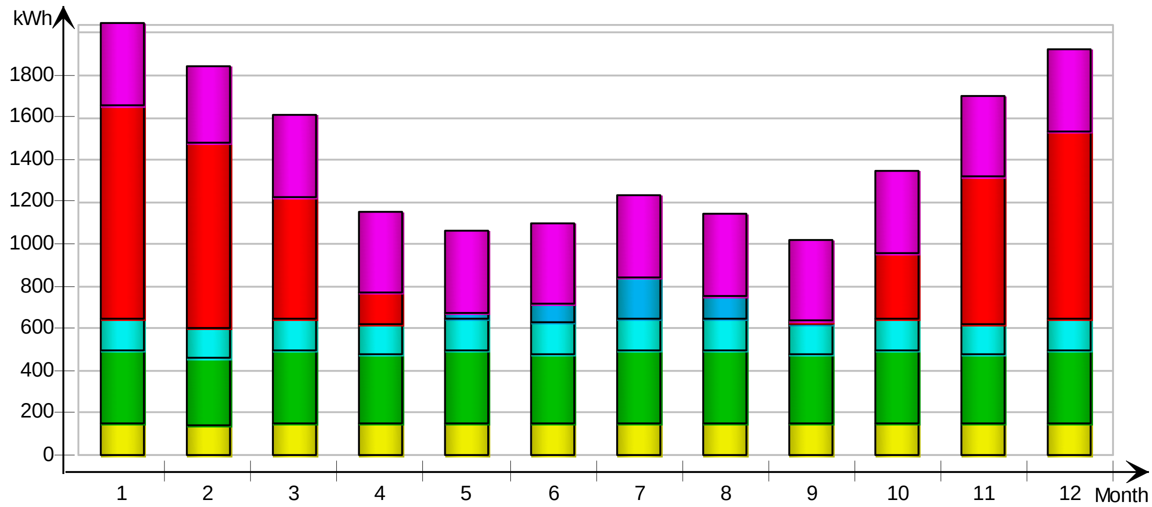


FIGURE 41. District heating and cooling. Monthly Primary Energy

We can see that heating energy demand is significantly increased compared to the case with ground source heat pump. It is so because GSHP has bigger COP and different primary energy form coefficient (0,7 for district heating instead of 1.7 (electrical) for ground source heat pump).

Delivered energy for cooling is bigger for the district cooling system compared to free cooling system with bore holes, because the COP used in a simulation for district cooling system is 1 instead of 7 for the previous one. But the primary energy for cooling is not much bigger because of energy form coefficient for district cooling system 0,4.

6.6.3 Electrical air heating

In this case in the simulated house electrical air heating system will be used and cooling will be based on ground source free cooling, domestic hot water use, ventilation air flow rates, lighting and equipment are given according to standard use from National Building Code D3.

Figure 42 shows generator efficiencies used in simulation for electrical air heating system.

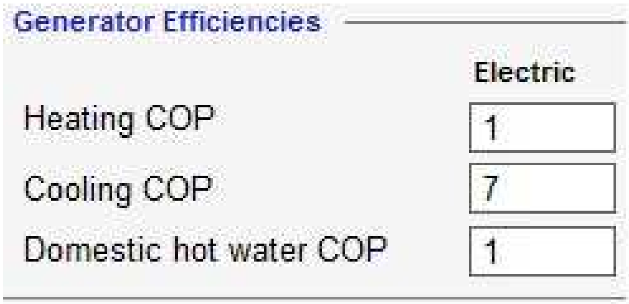


FIGURE 42. Generator efficiencies of electrical air heating

Following table represents delivered energy overview, *figure 43* and *figure 44* shows delivered and primary energy per months.

TABLE 23. Electrical air heating. Delivered Energy Overview

		Delivered energy		Primary energy	
		kWh	kWh/m²	kWh	kWh/m²
	Lighting, facility	1054	7.0	1792	12.0
	Equipment, facility	2372	15.8	4032	26.9
	Cooling	172	1.1	293	2.0
	HVAC aux	1034	6.9	1758	11.7
	Heating	4934	32.9	8389	55.9
	Domestic hot water	6194	41.3	10529	70.2
	Total, Facility electric	15760	105.1	26793	178.6
	Total	15760	105.1	26793	178.6

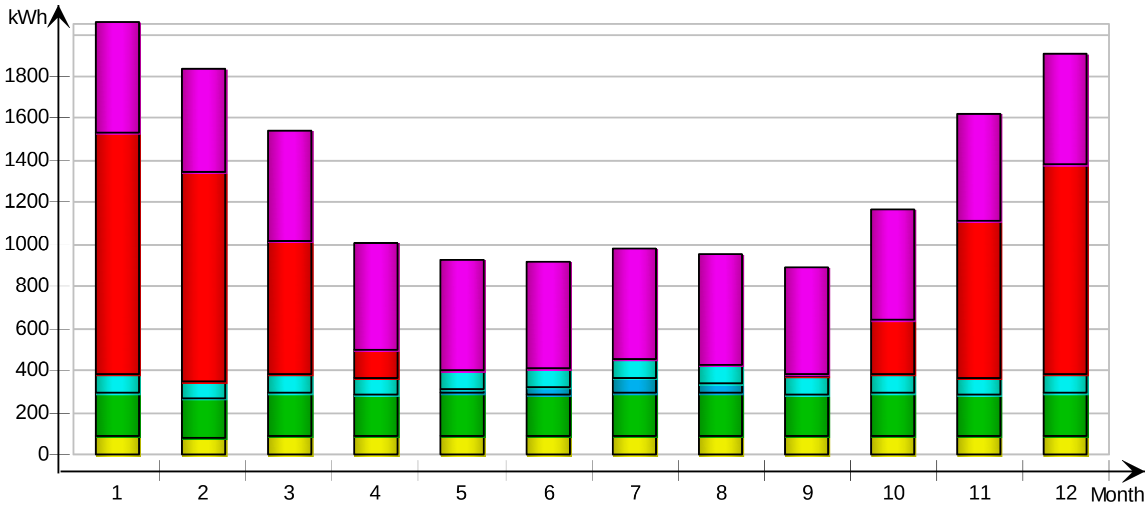


FIGURE 43. Electrical air heating. Monthly Delivered Energy

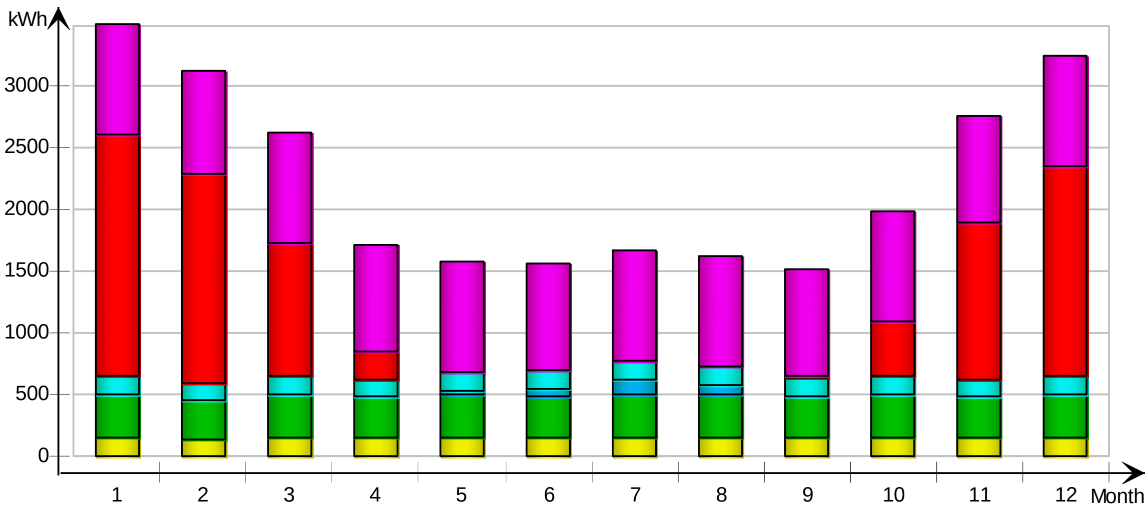


FIGURE 44. Electrical air heating. Monthly Primary Energy

Heating system delivered energy demand is bigger than for the ground source heat pump because of lower COP for heating used in the simulations and the cooling energy demand stays almost at the same level. Cooling energy demand for electrical heating is slightly bigger (1.1 instead of 1.0 kWha) compare to GSHP because of different distribution system and heat losses in DHW.

Electrical air heating system shows the biggest primary energy consumption and biggest E-value. The efficiency of this heating system COP = 1 with the primary energy coefficient makes primary energy consumption and E-value bigger than, for example for district heating.

Now those three types of heating solutions can be compared together. *Table 24* shows energy demands for ground source heat pump, district heating and electrical air heating.

TABLE 24. Comparison of different heat sources

Heat Source	Primary Energy	E-value
	kWh	kWh/m^2
Ground Source Heat Pump	15763	105.1
District Heating	17161	114.4
Air Heating	26793	178.6

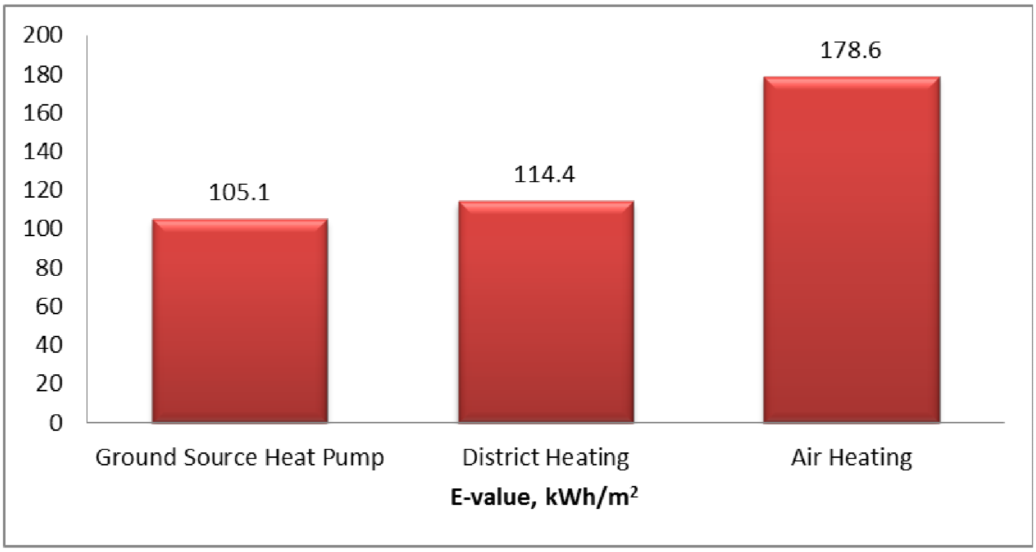


FIGURE 45. Comparison of different heat sources

Energy simulation shows that ground source heat pump is the most effective heat source for the passive house with lowest primary energy demand.

District heating is also good solution but the E-value is higher because of bigger delivered energy in the building with lower used COP for district heating.

Electrical air heating system require the biggest amount of delivered energy and also has bigger demand level of primary energy.

6.7 Domestic Hot Water with Solar Collectors

Space heating demand for passive house is very low, so the biggest heat demand has domestic hot water. It is possible to reduce the amount of required primary energy for domestic hot water by using solar collectors. They can compensate 40% of energy, so in our calculation we can use only 60% of the heat demand of domestic hot water per heated area.

For each case – ground source heat pump, district heating and electrical air heating, E-values will be calculated with 60% domestic hot water use.

6.7.1 Ground source heat pump

Table 25 shows delivered energy overview for ground source heat pump with the solar collectors for domestic hot water.

TABLE 25. Delivered energy overview for GSHP and solar collectors

		Delivered energy		Primary energy	
		kWh	kWh/m^2	kWh	kWh/m^2
	Lighting, facility	1054	7.0	1792	12.0
	Equipment, facility	2372	15.8	4032	26.9
	Cooling	154	1.0	261	1.7
	HVAC aux	1036	6.9	1761	11.7
	Heating	1964	13.1	3339	22.3
	Domestic hot water	1778	11.9	3022	20.2
	Total, Facility electric	8358	55.7	14207	94.7
	Total	8358	55.7	14207	94.7

Figure 46 shows the changes between E-value for ground source heat pump with and without solar collectors.

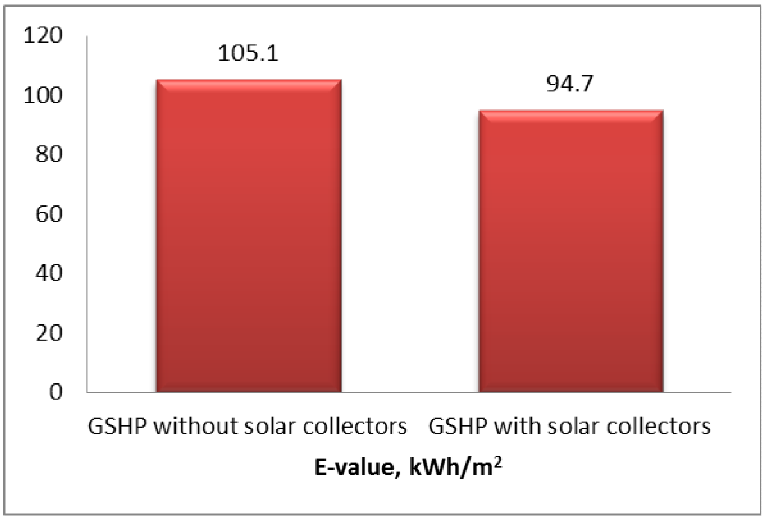


FIGURE 46. Effect of solar collectors on the E-value for GSHP

6.7.2 District heating

Table 26 shows delivered energy overview for the house connected to district heating network with the solar collectors for domestic hot water.

TABLE 26. Delivered energy overview for district heating with solar collectors

		Delivered energy		Primary energy	
		kWh	kWh/m^2	kWh	kWh/m^2
	Lighting, facility	1054	7.0	1792	12.0
	Equipment, facility	2372	15.8	4032	26.9
	HVAC aux	1036	6.9	1761	11.7
	Total, Facility electric	4462	29.8	7585	50.6
	Cooling	1076	7.2	430	2.9
	Heating	6477	43.2	4534	30.2
	Domestic hot water	4349	29.0	3045	20.3
	Total, Facility district	11902	79.4	8009	53.4
	Total	16364	109.1	15594	104.0

Figure 47 shows the changes between E-value for district heating with and without solar collectors.

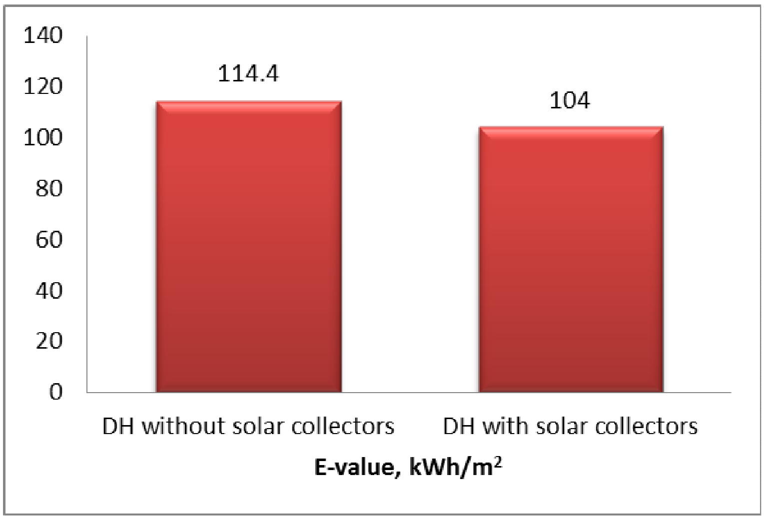


FIGURE 47. Effect of solar collectors on the E-value for district heating

6.7.2 District heating

Table 27 shows delivered energy overview for the house electrical air heating with the solar collectors for domestic hot water.

TABLE 27. Delivered energy overview for electrical air heating with solar collectors

	Delivered energy		Primary energy	
	kWh	kWh/m²	kWh	kWh/m²
Lighting, facility	1054	7.0	1792	12.0
Equipment, facility	2372	15.8	4032	26.9
Cooling	172	1.1	293	2.0
HVAC aux	1034	6.9	1758	11.7
Heating	4934	32.9	8389	55.9
Domestic hot water	4089	27.3	6950	46.3
Total, Facility electric	13655	91.0	23214	154.8
Total	13655	91.0	23214	154.8

Figure 48 shows the changes between E-value for electrical air heating with and without solar collectors.

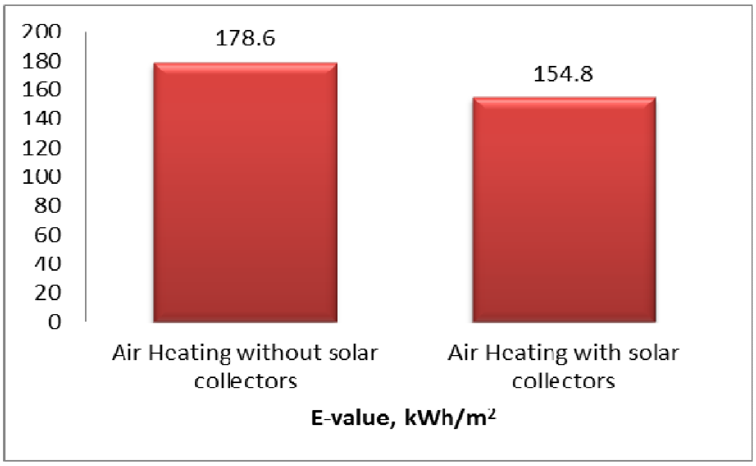


FIGURE 48. Effect of solar collectors on the E-value for electrical air heating

We can see that solar collectors for domestic hot water reduce the primary energy consumption and the most significantly it was reduced in case with electrical air heating. Following table shows primary energy consumption for different heat sources with solar collectors

TABLE 28. Compensation of primary energy demand with solar collectors for DHW

Heat Source	Primary Energy	E-value
	kWh	kWh/m^2
Ground Source Heat Pump	14207	94.7
District Heating	15594	104
Air Heating	23214	154.8

Figure 49 shows the energy consumption for different heat sources with solar collectors.

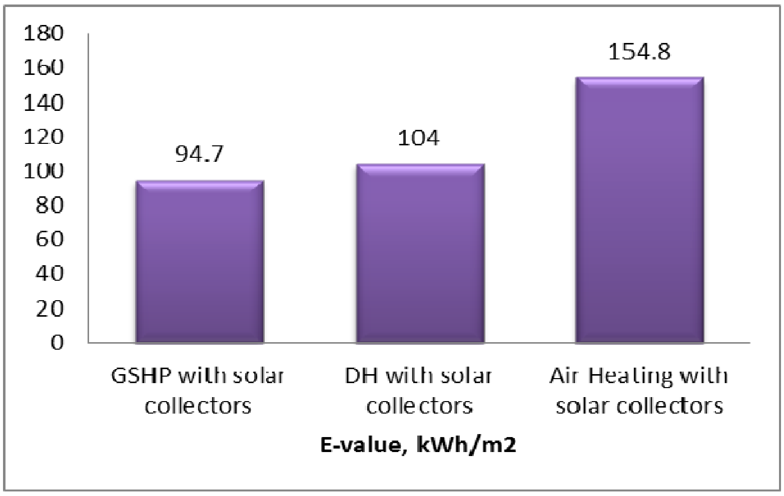


FIGURE 49. Comparison of different heat sources in combination with solar collectors

6.8 Using heat accumulated from a fireplace

Using heat accumulated from a fire place is a popular way in Finland and it can compensate part of heating energy demand for passive house.

Fireplace produce 2000 kWh/a heating energy with efficiency 0,6 and primary energy factor used in calculations for fireplace is 0,5.

Next heating energy demand will be calculated for cases when the fireplace is used with ground source heat pump, district heating and electrical air heating.

6.8.1 Using heat accumulated from a fireplace with ground source heat pump

Delivered energy from ground source heat pump according to *table 18* with heat energy from fire place taken into account is:

$$Q_{heating} = 1964\ kWh - 2000\ kWh = -36\ kWh \quad (23)$$

So energy needed from ground source heat pump is less than fire place able to produce. In this case if only fire place is used delivered energy is:

$$Q_{delivered} = \frac{2000kWh}{0{,}6} = 3333\ kWh \quad (24)$$

Primary energy from a fire place with energy form coefficient 0,5 is:

$$Q_{primary} = 3333\ kWh \cdot 0{,}5 = 1666{,}5\ kWh \quad (25)$$

For case when fireplace with ground source heat pump and the solar collectors for producing domestic hot water are used energy overview is shown in *table 22*.

TABLE 29. Energy overview for GSHP with fireplace and the solar collectors DHW

	Delivered energy		Primary energy	
	kWh	kWh/m²	kWh	kWh/m²
Lighting, facility	1054	7.0	1792	12.0
Equipment, facility	2372	15.8	4032	26.9
Cooling	154	1.0	261	1.7
HVAC aux	1036	6.9	1761	11.7
Heating	3333	22.2	1666.5	11.1
Domestic hot water	1778	11.9	3022	20.2
Total, Facility electric	9727	64.6	12534.5	83.6
Total	9727	64.8	12534.5	83.6

We can see that total delivered energy increased compared to the case when fireplace was not used. *Figure 50* shows delivered energy for two cases.

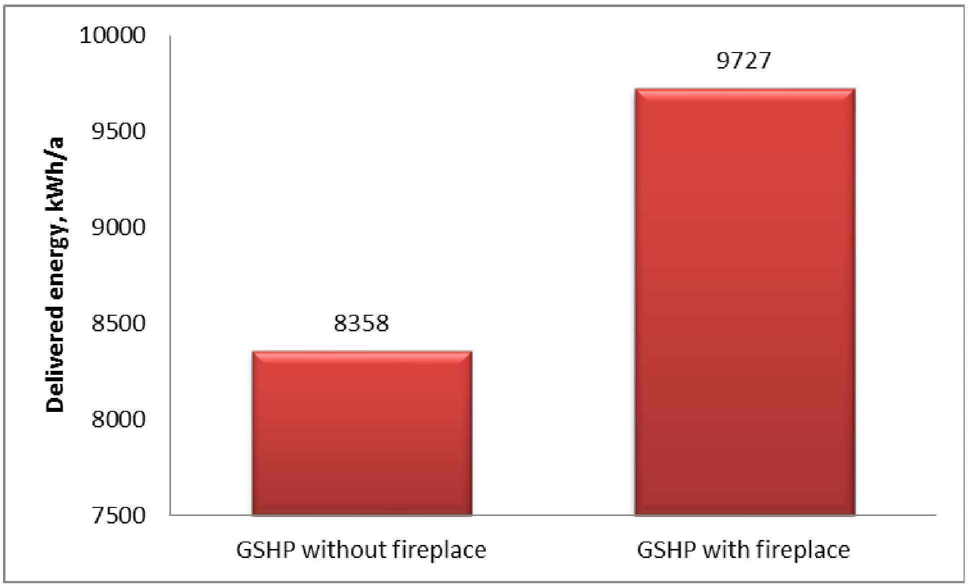


FIGURE 50. Delivered energy for cases with and without fireplace for GSHP

But because of different primary energy coefficients (1,7 for electricity with GSHP and 0,5 for fireplace with wood) primary energy becomes lower. *Figure 51* shows E-values for cases when fireplace was used for heating with GSHP and case without fireplace.

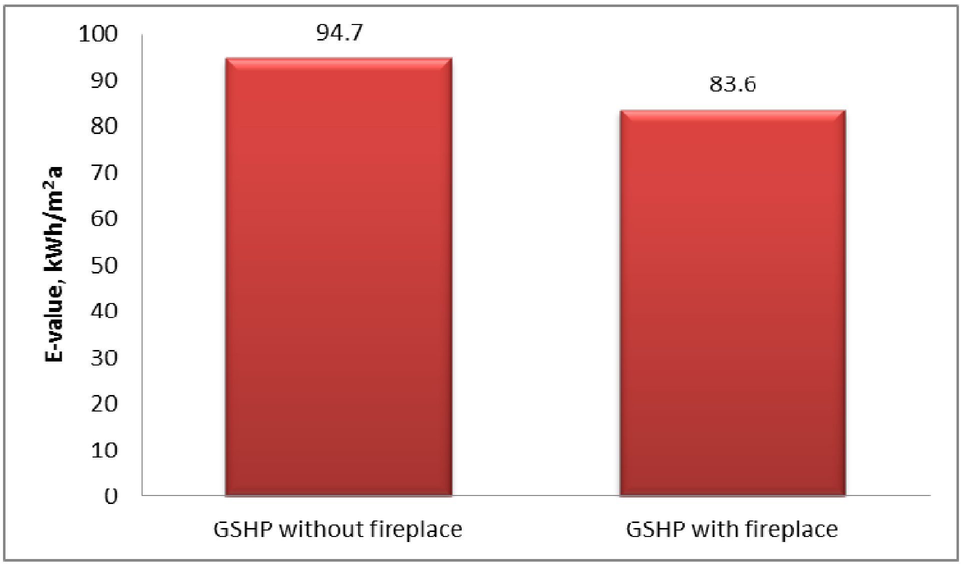


FIGURE 51. E-value for cases with and without fireplace for GSHP

Because the required delivered energy from ground source heat pump was lower than from a fireplace calculations was done in order to compare only the E-values for cases when we have GSHP in the building for heating and then only the fireplace is used for heating.

In general it is not reasonable to have fireplace for heating when the GSHP is installed because of more difficult operation and regulation of such heating system with only fireplace.

6.8.2 Using heat accumulated from a fireplace with district heating

Delivered energy from ground source heat pump according to *table 19* with heat energy from fire place taken into account is:

$$Q_{heating} = 6477\ kWh - 2000\ kWh = 4477\ kWh \qquad (26)$$

Than primary energy from district heating with energy form coefficient 0,7 is:

$$Q_{primary,DH} = 4477\ kWh \cdot 0{,}7 = 3134\ kWh \qquad (27)$$

Primary energy from a fire place with energy form coefficient 0,5 is:

$$Q_{primary,FP} = 3333\ kWh \cdot 0{,}5 = 1666{,}5\ kWh \tag{28}$$

Total primary energy now is:

$$Q_{primary,TOT} = 3134kWh + 1666{,}5\ kWh = 4800\ kWh \tag{29}$$

Table 30 shows total energy overview for case when district heating, solar collectors and the fire place are used.

TABLE 30. Delivered energy overview for DH, solar collectors and the fireplace

		Delivered energy		Primary energy	
		kWh	kWh/m²	kWh	kWh/m²
	Lighting, facility	1054	7.0	1792	12.0
	Equipment, facility	2372	15.8	4032	26.9
	HVAC aux	1036	6.9	1761	11.7
	Total, Facility electric	4462	29.8	7585	50.6
	Cooling	1076	7.2	430	2.9
	Heating	4477	29.84	4800	32
	Domestic hot water	4349	29.0	3045	20.3
	Total, Facility district	9902	66	8275	55.2
	Total	14364	95.8	15860	106.0

Results shows that delivered energy is reduced compare to the case without fireplace. But the primary energy and E-value stays at the same level. *Figure 52* and *figure 53* shows comparison of delivered energy and E-values for district heating when wire place was used and case when it was not used.

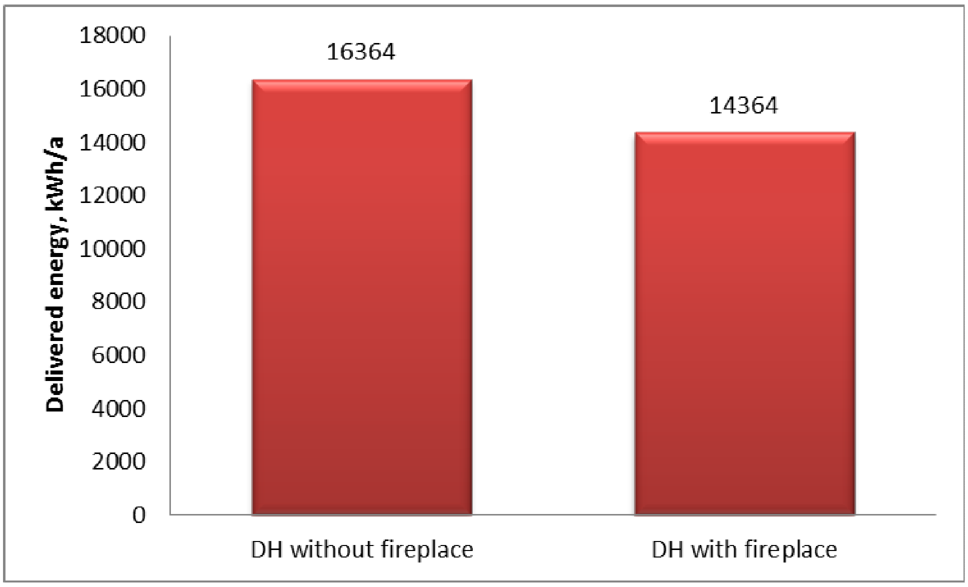


FIGURE 52. Delivered energy for cases with and without fireplace for DH

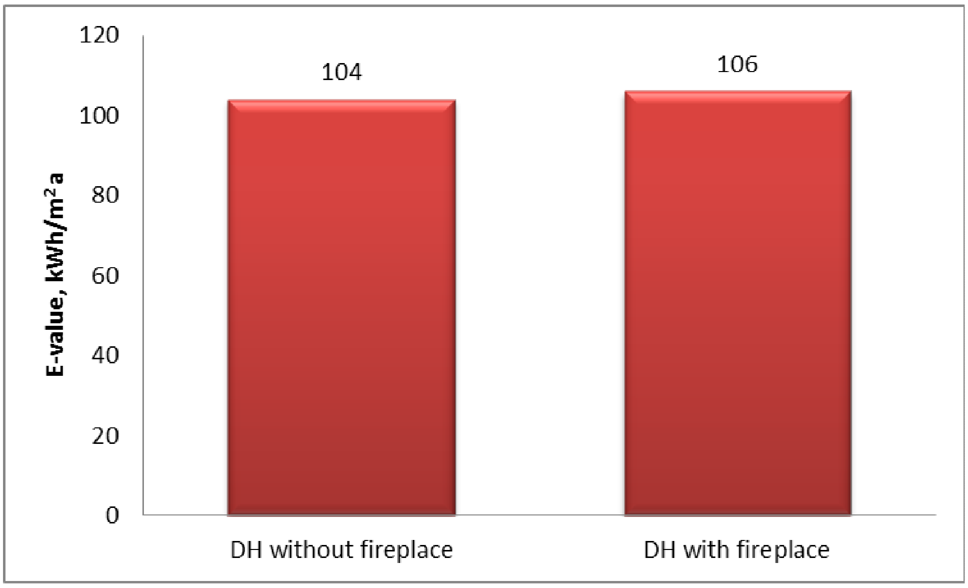


FIGURE 53. E-value for cases with and without fireplace for DH

6.8.3 Using heat accumulated from a fireplace with electrical air heating

Delivered energy from electrical air heating system according to *table 20* with heat energy from fire place taken into account is:

$$Q_{heating} = 4934\ kWh - 2000\ kWh = 2934\ kWh \quad (30)$$

Than primary energy from electrical air heating with energy form coefficient 1,7 is:

$$Q_{primary,EAH} = 2934\ kWh \cdot 1{,}7 = 4987{,}8\ kWh \tag{31}$$

Primary energy from a fire place with energy form coefficient 0,5 is:

$$Q_{primary,FP} = 3333\ kWh \cdot 0{,}5 = 1666{,}5\ kWh \tag{32}$$

Total primary energy now is:

$$Q_{primary,TOT} = 4987 kWh + 1666{,}5\ kWh = 6653{,}5\ kWh \tag{33}$$

Table 31 shows total energy overview for case when electrical air heating (EAH), solar collectors and the fire place are used.

TABLE 31. Delivered energy overview for EAH, solar collectors and the fireplace

	Delivered energy		Primary energy	
	kWh	kWh/m²	kWh	kWh/m²
Lighting, facility	1054	7.0	1792	12.0
Equipment, facility	2372	15.8	4032	26.9
Cooling	172	1.1	293	2.0
HVAC aux	1034	6.9	1758	11.7
Heating	2934	19.6	6653	44.35
Domestic hot water	4089	27.3	6950	46.3
Total, Facility electric	11655	77.7	21478	143.25
Total	11655	77.7	21478	143.25

Results show that in case when electrical air heating is applied, fire place is useful for compensation heating energy demand because it significantly reduces delivered energy and primary energy as well. *Figure 54* and *figure 55* shows comparison of delivered energy and E-values for electrical air heating when wire place was used and case when it was not used.

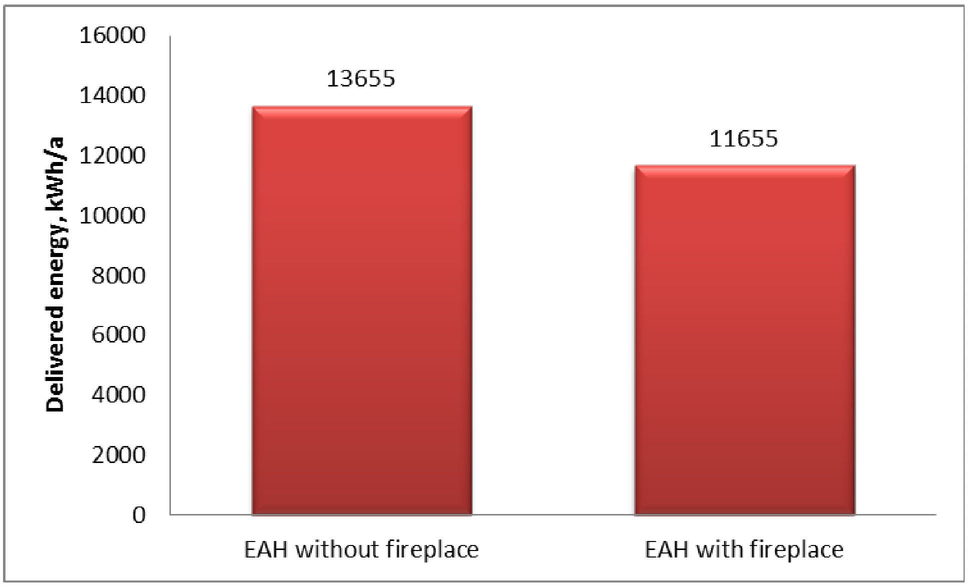


FIGURE 54. Delivered energy for cases with and without fireplace for EAH

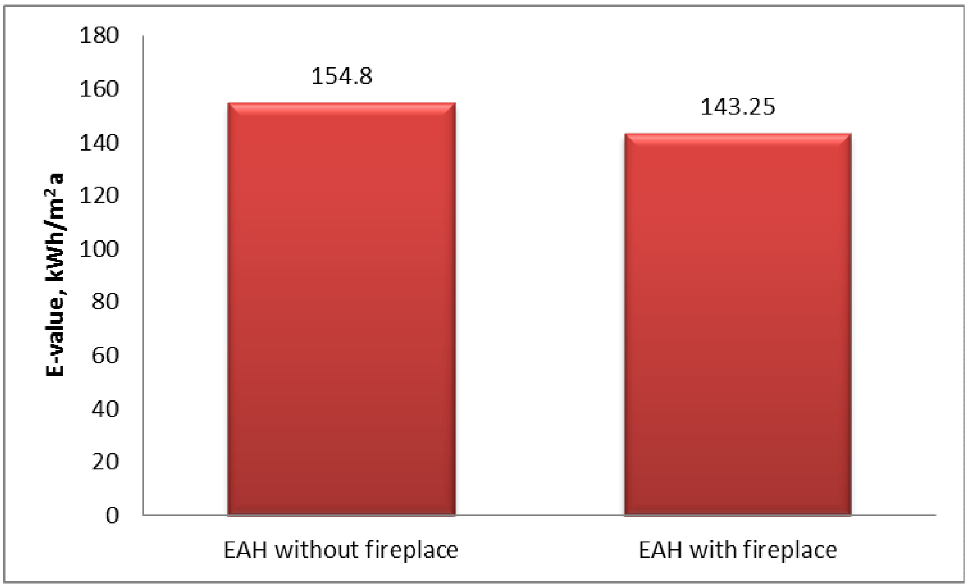


FIGURE 55. E-value for cases with and without fireplace for EAH

6.9 Passive house in colder climate

The best case with lowest energy consumption and E-value is passive house with ground source heat pump and the solar collectors. In Helsinki climate zone it fulfills the passive house requirements E-value 94,7 kWh/m^{2}a and primary heating energy demand 22.3 kWh/m^{2}a.

We can check the energy demand of this house in colder climate, for example in Sodankylä, and we can see how much energy should be compensated.

Results are shown in the following table. Also *figure 56* and *figure 57* shows monthly delivered and primary energy overview.

TABLE 32. Delivered Energy Overview for passive house in Sodankylä

	Delivered energy		Primary energy	
	kWh	kWh/m^2	kWh	kWh/m^2
Lighting, facility	1054	7.0	1792	12.0
Equipment, facility	2372	15.8	4032	26.9
Cooling	88	0.6	150	1.0
HVAC aux	1031	6.9	1752	11.7
Heating	3564	23.8	6059	40.4
Domestic hot water	1778	11.9	3022	20.2
Total, Facility electric	9887	65.9	16807	112.0
Total	9887	65.9	16807	112.0

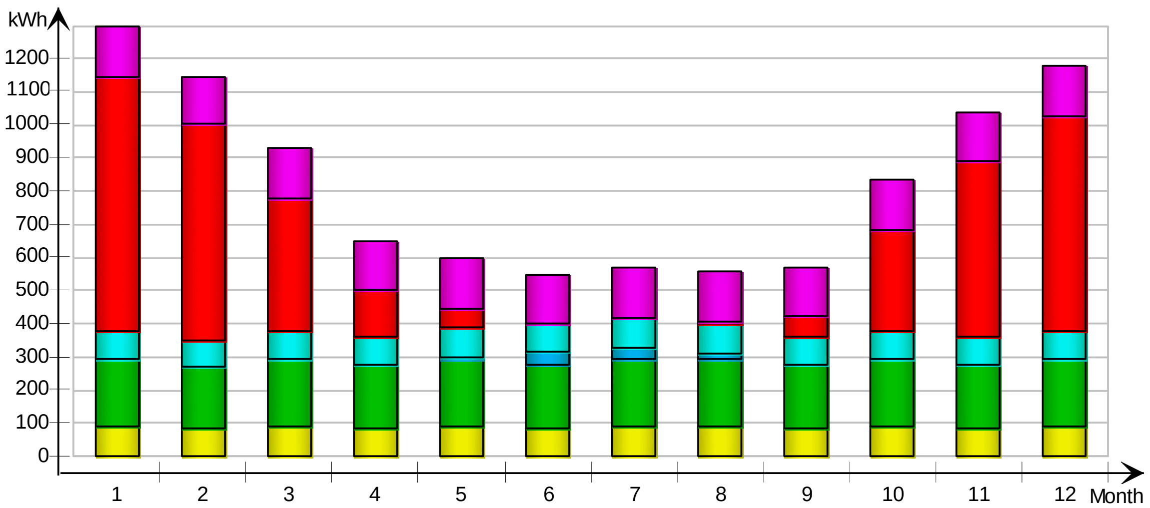


FIGURE 56. Monthly Delivered Energy for passive house in Sodankylä

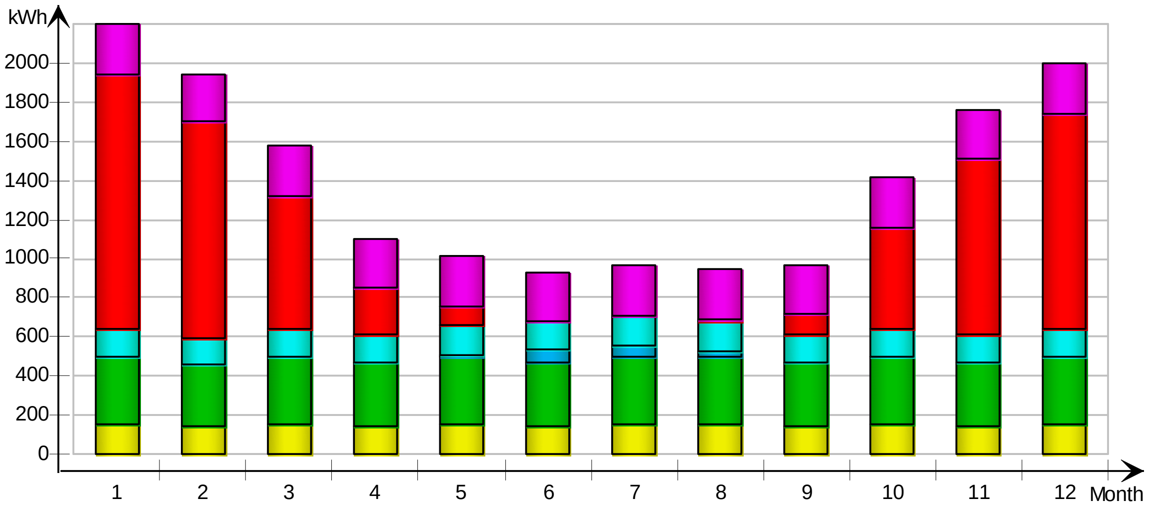


FIGURE 57. Monthly Primary Energy for passive house in Sodankylä

We can see that heating energy demand becomes two times bigger, so the heat losses should be reduced with better thermal insulation of building envelope.

6.10 Simulation with real use

In order to compare results of the best case simulation (ground source heat pump with solar collectors) with VTT definition of passive house and estimate real energy consumption of the building, simulation will be done with the real use.

Two store building made according to best cases from previous simulation has a ground source heat pump as heat source, solar collectors for producing domestic hot water with the solar shadings, located in Helsinki. *Figure 58* shows the first floor plane, *figure 59* shows the second floor plan and *figure 60* shows the building itself.

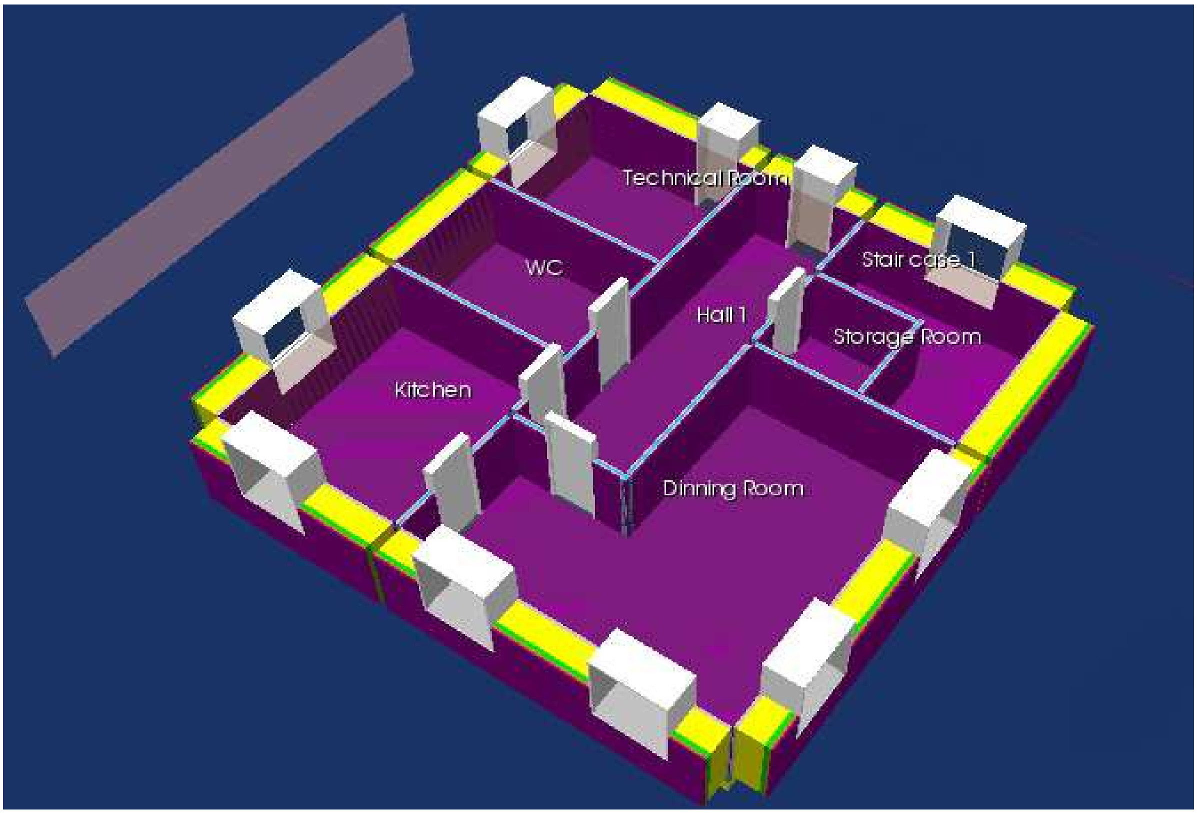


FIGURE 58. First floor of the building

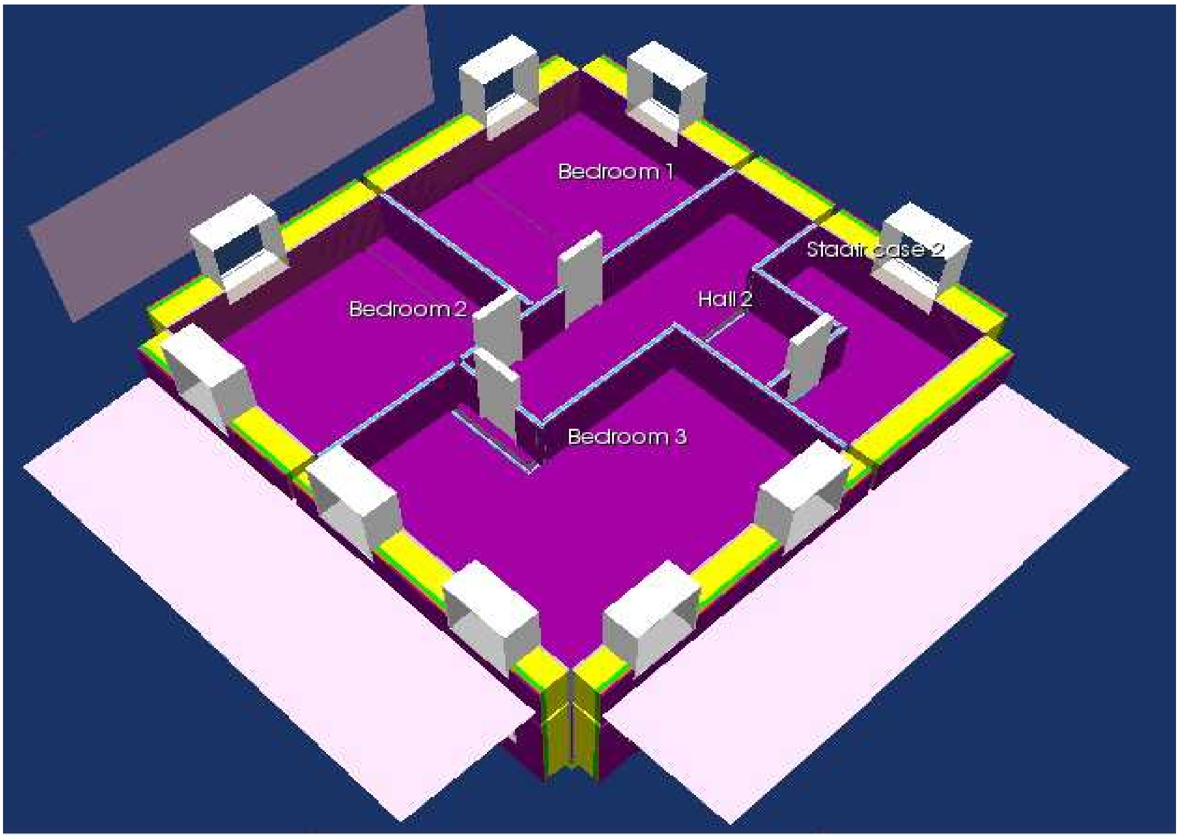


FIGURE 59. Second floor of the building

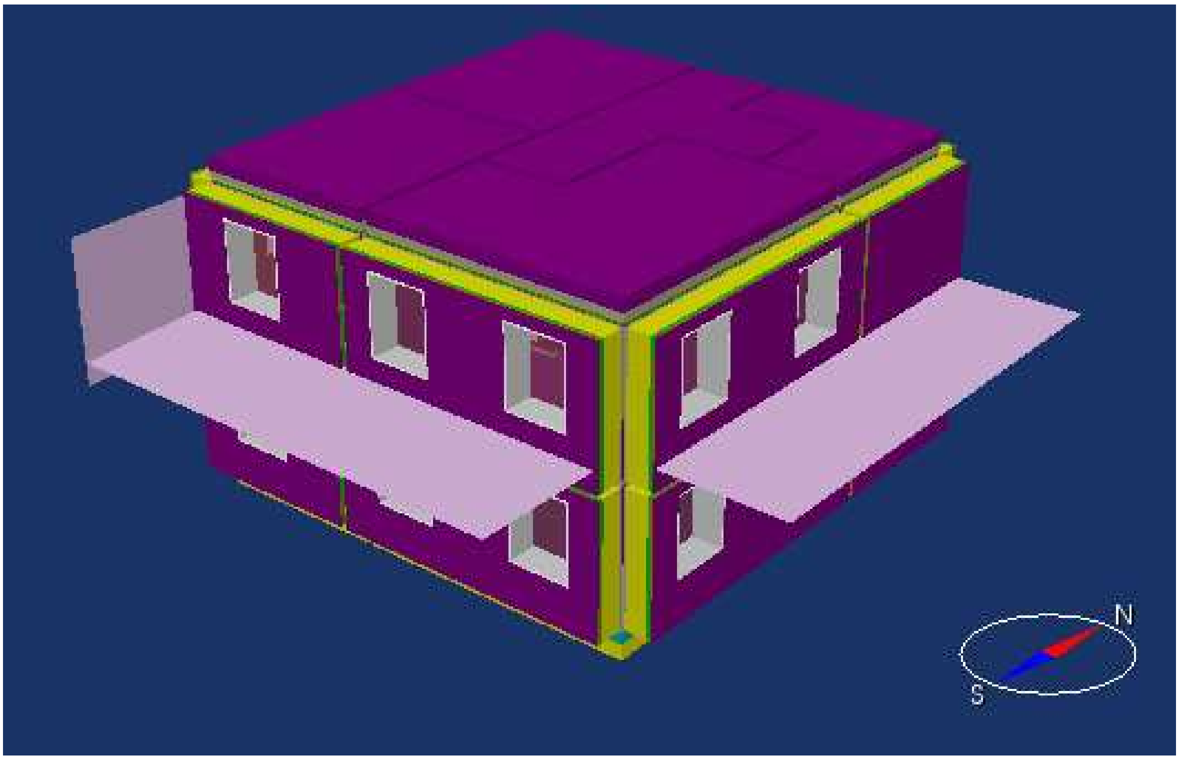


FIGURE 60. Facade of the building

There are five people living in the building, bedrooms, kitchen and dining room are equipped with cooling units. Building has a floor heating system and demand controlled ventilation according to the CO_2 level in bedrooms and dining room. Minimum ventilation air flow rates are taken according to National Building Code D2: Indoor Climate and Ventilation of Buildings, table 1. /22/

Simulation results are shown in *table 33* and *figures 61 and 62* shows delivered energy overviews.

TABLE 33. Delivered energy overview for real case simulation

	Delivered energy		Primary energy	
	kWh	kWh/m²	kWh	kWh/m²
Lighting, facility	151	1.1	257	1.8
Equipment, facility	2728	19.2	4638	32.6
Cooling	127	0.9	217	1.5
HVAC aux	770	5.4	1308	9.2
Heating	3536	24.9	6011	42.3
Domestic hot water	1685	11.9	2864	20.2
Total, Facility electric	8997	63.3	15295	107.6
Total	8997	63.3	15295	107.6

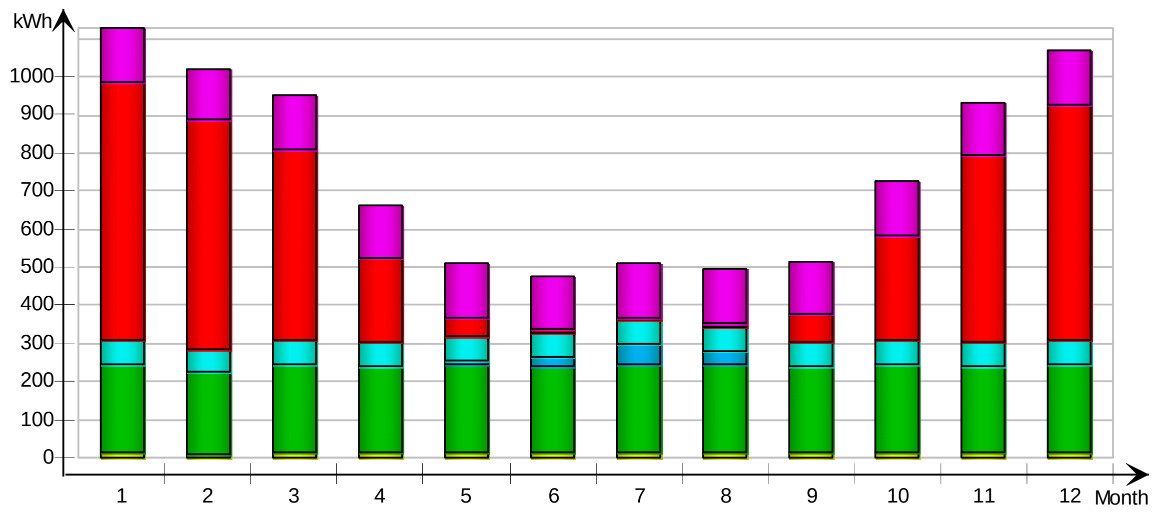


FIGURE 61. Monthly delivered energy for real case simulation

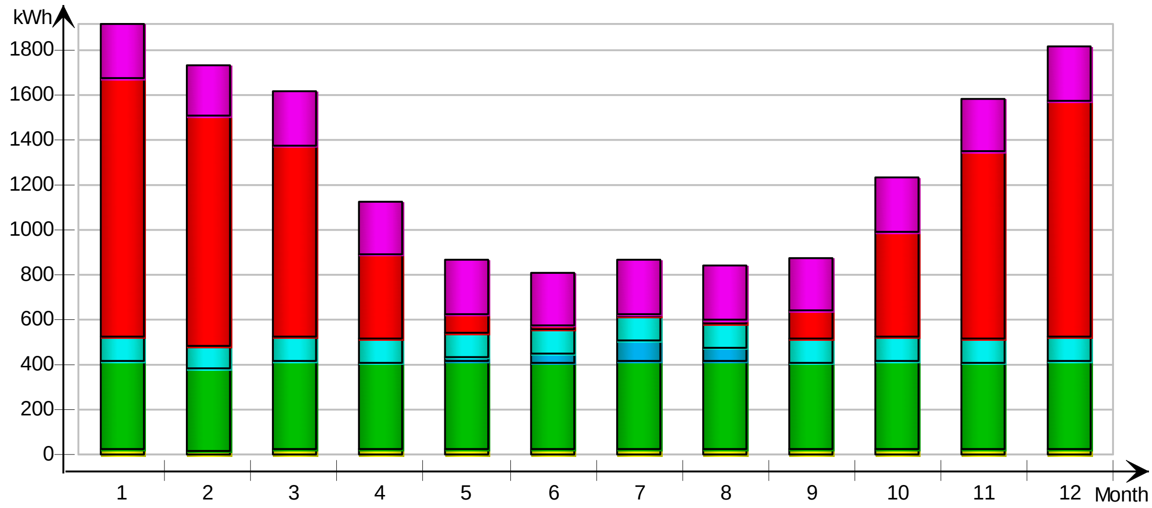


FIGURE 62. Monthly primary energy for real case simulation

We have different values compared to the simulation with the standard use, for example now heating energy demand is bigger, because now there are less internal heat gains from lighting people and equipment (people are not in the house during the day time, lighting is used only in the evening not in each room). But now there are less energy needed for lighting and equipment in building with a real use.

7. COMPARISON OF RESULTS WITH PASSIVE HOUSE CONCEPTS

In this chapter we will compare the simulation results with different passive house concepts: VTT definition, RIL 249-2009 and Ympäristöministeriön Asetus Rakennuksen Energiatodistuksesta (Energy Certificate). They are based on different approaches for energy consumption (different ways of calculation floor area – net area or gross are, and different ways of calculation energy – delivered energy and primary energy).

7.1 Comparison with VTT Passive House Concept

VTT Technical Research Centre of Finland gives the following criteras for passive houses /4./:

- heating energy demand 20-30 kWh/m^{2}a depending on the location
- cooling energy demand 20-30 kWh/m^{2}a depending on the location
- primary energy consumption 130-140 kWh/m^{2}a

This definition is based on the real use of the building and gives the values per gross area, so the building envelope is taken into account and also delivered energy is used without energy form coefficients taken into account.

For the real case simulation gross area is 194 m^2 (thickness of building envelope is 0,6 m)
It means that:

- heating energy demand is 18 kWh/m^2a
- cooling energy demand 0.65 kWh/m^2a
- total energy consumption 46 kWh/m^2a

We can see that simulation case fulfills the requirement for passive house made by VTT.

7.2 Comparison with RIL 249-2009

According to RIL 249-2009 passive house should have the following values for energy consumption in Helsinki climate zone (Southern Finland) /6./:

- heating energy demand is 12 - 21 kWh/m^2a
- total energy consumption 51 - 73 kWh/m^2a

This definition is based on the standard use of the building according to D3 and gives the values per gross area, so the building envelope is taken into account and also delivered energy is used without energy form coefficients taken into account.

For the best case with ground source heat pump and solar collectors for domestic hot water values of energy consumption per gross area are the following:

- Heating energy demand 10 kWh/m^2a
- Total energy consumption 43 kWh/m^2a

So the best case fulfills the requirements of RIL 249-2009 for passive house.

7.2 Comparison with Energy certificate

Ympäristöministeriön Asetus Rakennuksen Energiatodistuksesta (Energy Certificate) gives the classification for single family houses according to E-value, depending on the net heated floor area. It divides buildings for classes with different E-values. E-value is calculated for the standard use and net floor area according to National building code D3. /1;7/

For the single family house with net heated area 150 m^2 the requirements are following /7/:

- Class A E-value < 60.5
- Class B 60.5 < E-value < 99.5
- Class C 104 < E-value < 163
- Class D: 164 < E-value <243

For the best case with ground source heat pump and solar collectors for domestic hot water energy performance indicator E-value is 94.7 kWh/m^2a. So it is a Class B according to Ympäristöministeriön Asetus Rakennuksen Energiatodistuksesta. /7/

The best class A is difficult to achieve, it gives the values of energy consumption of nearly zero energy buildings, and for our case with the small heating and cooling energy demand there are big values of electricity consumption of lighting and appliance and electricity should be produced in a house with the self-sustaining energy sources.

8. DISCUSSION

The aim this bachelor`s thesis was achieving lowest possible energy consumption for single family house with net heated area 150 m^2 with the computer simulation by changing different factors such as:

- shape of the building
- air tightness
- orientation of the building
- solar shading (shadings around the site and in windows)
- glazing type
- heat source

With the simulation tool we get different values of energy consumption for the single-family house with the same floor area but different properties. By changing different parameters of the model it was defined that:

- Energy calculations shown that the best shape for achieving low energy consumption is the compact two-store square shape because of the $A_{envelope}/V$ ratio.

- Building envelope of passive house should have good air tightness in order to avoid big heat losses with the leakage air.

- Orientation of the main windows area to the south it is a best way to reduce the heating demand

- Windows should have best possible U-value and such a g-value to achieve less overheating with small heat losses. In our calculations it was found that window with u-value 0,6 W/m2K and g-value 0,49 shows the best energy performance

- Solar shading is important in avoiding high temperatures in summer and reduce the cooling demand. Cooling energy demand is lower when windows are equipped with blinds between panes and also horizontal shading helps to reduce the heat gains from the sun in summertime. That is the way to reduce cooling energy demand significantly.

- It was found that the best heat source for passive house is a ground source heat pump. District heating is also a good solution but with the higher E-value

- It is possible to reduce the heating demand and the E-value using the solar collectors for hot domestic water which produces 40% of required domestic hot water.

- Fire place is useful in reducing heating energy demand especially when electrical air heating is applied.

- If the building is situated in colder climate heating energy demand is increasing, so the constructions should have lower U-value in order to achieve less heating energy demand with less heat losses.

Simulation results were compared with different passive house concepts: VTT definition, RIL 249-2009 and Ympäristöministeriön Asetus Rakennuksen Energiatodistuksesta (Energy Certificate). Passive house level for best study case was achieved according to all of the definitions. /4;6;7/

9. CONCLUSION

Passive houses become more and more popular because of low energy demands and low operational costs compared to the ordinary buildings. Careful design can help to reduce the energy demand even for a passive house.

Computer simulation programs are very useful and it was shown in this bachelor's thesis. Different models of single family house with the same floor area but different properties were made and then the energy performance of each model was compared to each over.

Best shape of the building, orientation of the windows, type of glazing; solar shading solution and the heat source were found by simulation.

This method should be used in a real designing because it shows what solution will be more energy and cost-effective. It is difficult to calculate energy efficiency of the whole building and its systems and estimate the energy consumption. But with the simulation we can change it as it is needed.

During next 10 years low-energy buildings will become more and more common and according to the European Union directive after the year 2020 all the buildings will be mad according to nearly-zero building concepts. And high level of energy performance will require the precise calculations, so that a lot of factors should be taken into account and it is much better with the simulation programs.

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