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Passive House Concept:

Standard and Case Study

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The main purpose of this bachelor's thesis was to prove that the passive house standard could be fulfilled even in cold weather conditions like Finland. The technology and materials used in the development of the passive house were clearly described in this thesis.

For the case study of this thesis, several interviews with the owner of the Kerava passive house and site visit were conducted. Information available on web pages, as well as an article related to passive houses, were used to complete this thesis.

Recently developed technology was studied to see if it would fulfill the requirements of the passive house. The laws and requirements for the passive house were studied, hence to prove that the requirements can be fulfilled in Finland. This thesis can be further used as a tool regarding the passive house concepts.

Keywords	passive houses, solar collectors, ventilation system, heating system, insulation

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Contents

1 Introduction

The main purpose of this thesis is to provide information about the technology and systems used in a passive house. They are described in detail. A passive house is a long-term solution of a regular building with high-energy demand. Using the available resources and renewable sources of energy, the passive house concept is even considered the best way to reduce the energy use in the building. When compared to a building of common energy efficiency, the passive house additionally reduces life-cycle cost significantly and it is a most beneficial solution for this growing world. [1.] Data used in ventilation and heating system are further described. The thesis also discusses ground loop heating.

People became more conscious about the living environment and they try to consume a less energy in buildings so energy buildings was developed. [2.] All new buildings must be nearly Zero energy buildings after 2020 according to the European Union. [3.] In a nearly zero energy building, significant part of the energy needed in the daily use of buildings must be covered by a renewable energy source. [4.] It increases the living comfort and other factors like air quality. Different models of passive houses can be considered while designing depending on the geographical locations. Weather condition also determines the design of a passive house in all over the world. The energy supplied must be safe and it must not be harmful to the surrounding environment and it must be available at affordable cost. [3.]

Passive houses construction would not be possible without major development in energy saving technologies that includes heating system technology and ventilation system technology. Building passive houses means the consumption of purchased energy is minimum. An alternative source of a renewable energy like solar or biogas energy can be used for daily building operations. [2.]

According to the Passive House Institute, “A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to fulfill sufficient indoor air quality conditions (DIN 1946) - without a need for recirculated air." [1.]

This definition is a functional definition and it does not contain any numerical values. Thus, it is valid for all climatic regions. All airtight buildings need an efficient ventilation system which in case of the passive house can also be used for other purposes like heating. An efficient heat recovery system can be installed at a very economic price. In passive house construction, any kind of ventilation system with heat recovery system can be used. An exhaust system can be included in the ventilation system as it helps the building to fulfill the requirements of low energy house. [1.]

2 History

The passive house concept is a part of sustainable construction. The passive house revolution began in the end of 20^{th} century. There were a number of houses in China, Germany, and Iceland which were recognized as passive houses in the 1990’s. [5.]

A passive house is not a brand name, but it is a construction principle. A passive house helps to lower the energy consumption up to 90 % compared to the existing regular buildings. The passive house in Finland typically needs slightly more heating load compared to a regular passive house due to the climatic conditions. The first passive house in Finland was completed in Tikkurila in Vantaa in May 2009. [6.]

The construction traditions of both regular as well as passive houses in different countries are, naturally, different. Particularly in European countries, outer wall plastering is common in Germany whereas in Nordic countries the broad experience in wooden buildings is practiced. [2.]

The concept of a passive house was evolved in Finland after the successful completion of passive house in Germany in early 1990’s. Heating energy demand is the main focal point in the passive house as it has some alternatives to reduce the heating energy. [2.] In Europe, three categories of passive houses were developed according to the climatic and geographical conditions. They are the Nordic passive house, Central European passive house, and the Mediterranean passive houses. [2.]

3 Energy Balance Requirement of Passive House

A passive house must be well insulated with a minimum amount of space heating demand. Heat can be delivered to all rooms by heating the air supplied through the ventilation system. The heating and cooling load must not exceed 10 W/m^2, and the maximum space heating energy is 15 kWh/m^2a. Primary energy use must not exceed 120 kWh/m^2a in a regular passive house but due to the development of renewable energy sources, it is better to keep the primary energy demand below 60 kWh/m^2a. Airtightness is the most important factor as it directly affects the use of energy in the building. [7.]

Table 1. Passive house Specification [8.]

	Germany	Finland		
		South	Central	North
Heating demand, kWh/m^2	≤ 15	≤ 20	≤ 25	≤ 30
Heat demand, W/m^2	10	-		
Primary energy demand, kWh/m^2	≤ 120	≤ 130	≤ 135	≤140
Over heating hours/year Temperature > 25°C, %	10	-		
Air tightness, n_{50} 1/h	0,6	≤ 0,6		
Functional unit, area m^2	Treated floor area	Gross floor area		
Energy calculation method	PHPP	Optional		

Table 1 above illustrates the specification of a passive house. Due to climatic differences, factors like primary energy demand can be slightly higher in Finland compared to Germany. Heating demand of a passive house in Finland can be higher than up to 10 kWh/m2 compared to the passive house in Germany. PHPP calculation for the passive house in Germany is compulsory whereas its optional in Finland. [8.]

The construction of a passive house is very demanding in terms of performance of the building materials used in construction. There are specific rules for the materials to be used but they differ slightly according to the climatic condition. For the central European of mild climate, the basic principles are:

- All external building elements must have a U-value below 0.15 W/(m²K).
- The external building envelope must be designed and constructed without thermal bridges.
- Air tightness of the building envelope must be according to DIN EN 13829 standard.
- All glazing used in the building must follow the European standard EN 673, which states the U-value of glazing must be below 0.8 W/m²K.
- The windows must have U-value less than 0.8 W/m²K according to DIN EN 10077.
- The ventilation system must be designed so that it uses less energy to operate and has an energy recovery efficiency below 75%.
- Hot water generation and distribution systems must follow the European code for the passive house, must have minimal heat losses.
- Electric appliances used in the building must be highly energy efficient. [8.]

4 Standard for the Passive House

The passive house is the world leading standard in energy-efficient construction. The passive house requires as little as 10 percent of the energy used by a typical central European building that means energy savings of up to 90 percent. Owners of passive houses are barely concerned with increasing energy prices. [8.]

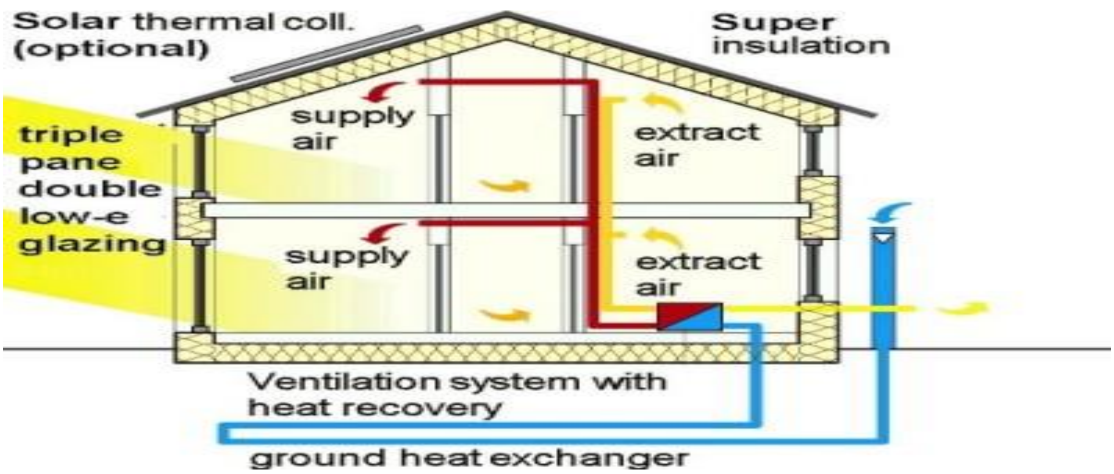

Figure 1. Standard of passive house [7.]

Figure 1 above illustrates the standard of a typical passive house which includes solar thermal collectors, super insulation, glazing, ventilation system with heat recovery and ground heat exchanger. The process of air flow for supply air and extract air is clearly shown in the figure. [7.]

4.1 Structural Features

Buildings are responsible for 30-40 % of total energy used in every country. To improve this, buildings must be designed using perfectly insulated components, resulting in an airtight and moisture free building. [7.]

Airflow through the building envelope is caused by air density, pressure differentials, and ventilation effects. As always warm air rises and cold air sinks, also in a building, as warm air has a lower density than cold air. Borders between materials may cause lack of complete airtightness. Risky structures can be found between masonry and carpentry or electrical equipment, between junction of walls and the roof, and around pipes and hatches. [8.]

Preventing all risks for air leakage, the best solution is to build an airtight building, which in turn helps reducing energy bills and maintaining building integrity. Airtight solutions decrease the cooling and heating demand of a building as well as play a significant role in extending a building’s life. [8.]

The building envelope includes foundation, roof, walls, windows, doors, and floor. The proper use of materials during. Indoor comfort is directly related to the design and performance of the building envelope. The walls of a regular building are usually 30 cm thick, whereas the walls of a passive house must be approximately 40-50 cm thick. The U-values of walls, roofs, and floors must be less than 0.1 W/m^{2}K. The thermal transmittance Ψ in any passive house should not exceed 0.01 W/mK. [3.]

Table 2 below gives the thermal conductivity of materials used in a regular building and a passive house construction. When the heat flow is parallel with the direction of the fibers, then the thermal conductivity of wood and wood products is multiplied by a factor of 2.2. [9.]

Table 2. Building Components with thermal conductivity [9.]

Materials	Thermal conductivity λ (W/mK)
Concrete (reinforced)	2.1
Lightweight Concrete	0.15-0.3
Rubber	0.17
Carpet	0.06
Linoleum	0.17
Float Glass	1
Aluminum	160
Mild Steel	50
Stainless Steel	17
Solid Plastic (Typical)	0.17-0.3
Gypsum Plaster	0.18-0.56
Gypsum Plasterboard	0.25
Cement Screed	1.4
Natural Stone	1.5-3.5
Sand-Lime Masonry	1
Softwood	0.13
Hardwood	0.18
Chipboard	0.1-0.18
Oriented Strand Board (OSD)	0.13
Wood Fiberboard, Medium Density	0.07-0.18
Expanded Rigid Polystyrene Foam	0.035-0.04
Extruded Rigid Polystyrene Foam	0.030-0.04
Mineral Wool	0.035-0.045
Solid Clay Brick Masonry	0.8-1.2
Vertically Perforated Lightweight Block	0.3-0.45
Wood Wool Lightweight Building Board	0.065-0.09
Rigid Polystyrene Foam	0.025-0.04
Fiber Insulating Material	0.035-0.05
Cellular Glass	0.045-0.06
Wooden Softboard	0.04-0.07

The U-values are calculated using the thermal resistance of the materials. The exterior facing components used adjacent to the air-space are not considered in the U-valve calculation. The thermal resistance is calculated by multiplying the thickness of materials with thermal conductivity.

$$R - value = \frac{l}{\lambda} \tag{1}$$

R-value is the resistance of materials

l is the thickness

λ is the thermal conductivity. [9.]

For the U-value calculation the following formula is used.

$$U - value = \frac{1}{Rsi + R1 + R2 + R3 + \cdots + Rn + Rse} \quad (2)$$

Rsi is the thermal resistance at interior surface

Rse is the thermal resistance of the exterior surface

R1…. Rn is the thermal resistance of individual building materials [9.]

Table 3. Thermal Resistance [9.]

Direction of Heat Flow			
Thermal Resistance	Upward	Horizontal	Downward
Rsi [m^2(K/W] Thermal Resistance of the Interior Surface	0.10	0.13	0.17
Rse [m^2(K/W] Thermal resistance of the Exterior Surface	0.04		
Rse [m^2(K/W] Thermal resistance of the Below Ground Exterior Surface	0.0		

Table 3 above illustrates the surface thermal resistances (R), corresponding with EN ISO 6946. The value Rse = 0 must be used for construction materials used on the ground.

Windows are a significant part of the building envelope and they should be selected in according the standard. Windows are responsible for maximum heat losses in some buildings. Therefore, high standard windows which have a lower U-value than 0.9 W/m^2K must be used for the passive house. Usually the windows used in passive houses are triple glazed with a noble gas in the spaces between the glass layers. Some windows have a vacuumed air inside the spaces between the glasses. Both types of windows reduce heat losses from building significantly. Basically, windows in a typical house do not have high resistance to cold draughts. Cold draughts in the windows can result in a decrease in thermal comfort, which can be prevented by using triple glazed windows as they have a higher insulating capacity and additionally, they make the indoor environment better and comfortable. [3.]

Table 4. U-values standard for Finnish climate [3.]

Elements	U-value (W/(m²K).
Roof	0,06 - 0,09
Walls	0,07 - 0,1
Floor	0,08 - 0,1
Window	0,7 - 0,9
Fixed Window	0,6 – 0,8
Door	0,4 – 0,7

As the U-value depends on the materials and insulation in a building, high quality insulated materials with lower thermal conductivity are preferred so that they meet the requirements of U-values. Table 4 above illustrates the U-values of building components according to the passive house standard in Finland. [3.]

4.2 Ventilation

Ventilation is the key part used in all buildings and passive houses. To avoid problems of thermal discomfort and bad indoor environment, special attention should be paid to in the ventilation system. There are different types of the ventilation system, which can be chosen according to the building need to maintain the indoor air quality these days. Depending on the building structures and climatic conditions, three types of ventilation system are frequently used: natural ventilation, mechanical ventilation and controlled balanced ventilation with heat recovery. [9;10]

In natural ventilation, air flow is maintained through open doors or windows, through the cracks around windows and through any penetration through the walls. Natural ventilation is caused by wind or pressure and temperature differences between the indoor and outdoor environment. It can be used as an alternative to air conditioners to save 10%-30% of total energy consumption. Since buildings nowadays are increasingly airtight, ventilation through cracks and joints is not enough for comfort and healthy living conditions. Even ventilation through windows in some weather conditions is waste of energy. This type of ventilation also reduces the life expectancy of a building. [10.]

In mechanical ventilation, outside air is transferred inside with a fan or with any other artificial technology that draws air from the outside and forces it through ducts to the place where occupants are located. Mechanical ventilation can exacerbate the cracks in the buildings. In Finland, mechanical ventilation is mostly used. A highly efficient ventilation system requires extra investment at first, but it will save energy costs in the end. [10.]

Ventilation system installed in a building determines the quality and comfort of a building. Controlled balanced ventilation with heat recovery is the key feature of passive house buildings as well as the key to excellent hygienic conditions. A high-efficiency ventilation unit should remain as close as possible to the building envelope, as heat losses from or to the ducts result in serious effects for the efficiency of heat recovery. Ducts should be well insulated, and they must be as short as possible as it is required to minimize the heat loss. Mechanical ventilation system reduces the operating costs of buildings. In a passive house, the extract air is circulated to the ventilation system which filters the air and it can be further recirculated as supply air in the building. Therefore, a minimum amount of fresh air can be supplied to the buildings in winter which results in the reduction of energy bills. [11.]

The infiltration air change rate is caused by leakages in buildings and is measured by a simple formula according to EN ISO 13790. Specific focus should be given to limit the air leakage rate to 0.6/h in the passive house as it is the standard according to passive house institute. [1.]

In balanced ventilation systems with heat recovery, infiltration air change rate is calculated as:

$$N = \frac{\mathrm{n50} * \mathrm{e} * \mathrm{V50}}{\mathrm{V}} \tag{3}$$

N is the infiltration air change rate

n50 is the fan pressurization test result

e is the wind screening coefficient according to EN 832

V50 is the net air volume for the fan pressurization test

V is the air exchange volume [9.]

There are several ventilation units approved and certified by the Passive House Institute on the market. Heat recovery efficiency and other parameters are automatically adopted in the selected ventilation units. For the humidity balance in the building, it is required to check humidity level in the ventilation unit. [9.]

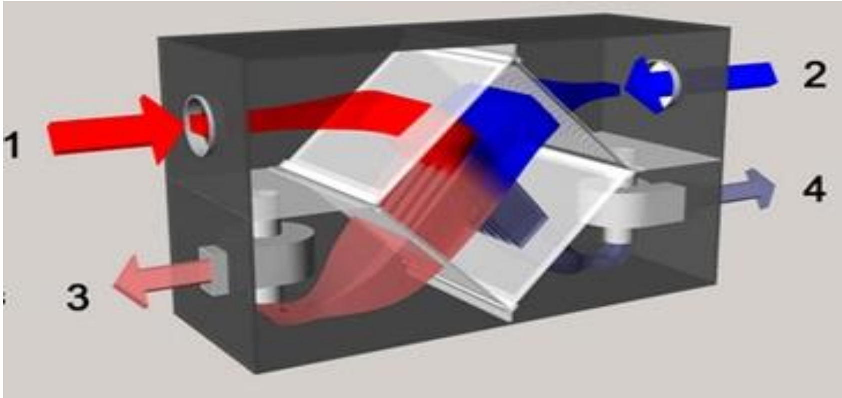

Figure 2. Heat recovery unit (HRC Unit) [12.]

Figure 2 above describes the process of heat recovery system in a diagrammatic way. The number one indicates the extracted air, that comes from the inside of the building. The air then passes through the heat recovery unit that takes the heat from the air. Number two indicates the fresh air supplied to the building. Number three is air supplied to bedrooms and living areas after the temperature is raised in the heat recovery system with the heat of the extract air coming from the inside of the building. Finally, number four is extracted cool air that is exhausted out of the building.

There are different heat recovery systems regarding the use of the heat from the extract air. Some systems just take the heat from the exhaust air and transfer it to the supply air. Other systems use fresh air from outside in minimum amount and it further uses heat and air from extract air which is filtered and reused in heat recovery unit and is supplied to the building again. Just small amount of cool air is extracted outside the building. [12.]

4.3 Heating System

A regular building may waste heat because of poorly designed heating systems, poorly selected insulation materials and a poorly maintained heating system. Therefore, an ordinary heating system cannot be used in a passive house as it would increase the heating loads in the house. As the temperature in Finland drops below zero in the winter, it is best to use alternate source to heat the house. Some methods can be used for heating, cooling, and domestic hot water production. [13.]

The heating and cooling systems of a building are installed according to weather conditions. The passive house in Finland basically focuses on heating, as it is impossible to maintain a comfortable indoor surrounding without mechanical heating. The Heating of the passive house is currently mainly done with ventilation air heating system, underfloor heating system and solar energy system. It is very important to find an efficient heating system with an adequate control system for a building. [14.]

Table 5 below lists the energy sources of buildings. For a passive house, the regenerative energy source is compulsory. Heating and cooling need to be done with the minimal use of district heating or direct electricity. In a passive house, solar collectors or a photovoltaic system should be used to maintain the energy balance. Firewood, wood chip or pellet stove is used to maintain the heating system of the passive house during winter time.

Table 5. Energy Sources [15.]

Final energy source / system	Conversion / heat generator
Electricity	Compact heat pump unit Air/soil/water–based heat pump Direct electricity (Joule heating)
Fossil fuel	Gas: low temperature /condensing boiler technology (natural gas, liquefied gas) Oil: low temperature /condensing boiler technology, district/on-site heating
Combined heat and power generation	Small CHP Fuel cell District/local heating with/without cogeneration
Regenerative energy sources	Biomass heating/cogeneration Solar thermal system /photovoltaic firewood, wood chips, pellets Liquefied and gaseous biofuels

The stoves used to burn pellets and fire woods are highly considered highly ecological and they fit perfectly in a passive house. The heat from stoves is used to warm the indoor environment, and water which is stored in a tank which can be placed nearby the stove. When the tank is heated up to certain temperature, it transfers the water to a storage tank. Then the hot water is circulated for underfloor heating and used for domestic hot water purposes. The stove takes 20-25 kg of firewood or pellets at once in extreme weather conditions, ensuring that the system works for two days as the temperature of the water in storage tank does not decrease in huge amount. [13.]

Underfloor heating is nowadays often used in low energy buildings as it reduces the use of primary energy. Water used to heat the floors is circulated through copper pipes that are installed during the construction of the building. A small circulation pump is installed to circulate water constantly through the pipes to the floors. The water used in this system is heated with the energy from the firewood stoves and solar collectors. [8;16]

An earth heat exchanger can also be used to cool and heat the house. In the winter the earth heat exchanger heats the fresh air supplied to the building through the pipes which are positioned around the building. By using the ventilation system, ambient air is cooled in the summer and heated in the winter. [16.] The system reduces the heating demand of fresh air ventilation and prevents freezing of the heat exchanger in the heat recovery system. In some parts of Europe, this system works perfectly for building cooling where the temperature is moderately between 25-35°C. As the ground temperature is almost 10-15 °C colder in the summer and warmer in the winter, it reduces the maximum energy use for ventilation. [17.]

4.4 Renewable Source of Energy

Renewable energy is obligatory in the passive house as it makes it easier to maintain the energy use requirement. Wind energy can be produced if the community is developed consists of low energy houses and passive houses, then they would not need to buy electricity produced with nuclear power or fossil fuels. Various sources of renewable energy can be used in a passive house such as wind, solar and biomass. For the economical reason, it is not possible to use wind energy for a residential building, so the concept of solar energy seems more relevant. Therefore, it is the best idea to use solar energy. The cost of solar energy is almost nothing compared to alternative sources, as only installation costs must be paid at the time of installation. This is a key of energy source in a passive house as it can be used for many purposes like electricity, ventilation, and heating. [4.]

For solar energy purposes, photovoltaic(PV) cells are used. They convert solar energy from the sunlight into electricity. The photovoltaic solar energy is based on the semiconductor principle which has diodes and transistors. It is a free form of energy that can be stored in a battery for the evening and cloudy weather conditions. PV cells have different modules which have been created to offer different values of temperature coefficient, rated current and voltage. According to the EN 50461 standard, the temperature coefficient should be implemented as mA/K or mV/K. [9.]

Temperature coefficient can be of two types depending on the module types.

- Temperature coefficient of the short-circuit current **(α in %/K)**
- Temperature coefficient of the open-circuit voltage **(β in %/K)** [8.]

Table 6. Modules types with temperature Coefficient [9.]

Module type	Amorph-Si	Poly-Si	Mono-Si	CIGS
α in %/K	+0.1	+0.03...+0.07	+0.02…+0.07	+0.04
β in %/K	-0.27…-0.38	-0.29…-0.42	-0.21…-0.48	-0.2…-0.29

Some types of modules, used in passive houses, and their respective temperature coefficients are summarized in table 6 above. According to the table, the CIGS array has the best temperature coefficient compared to the other three alternatives.

However, for a residential building in the Nordic region, especially in Finland, it is almost impossible to use solar energy all through the year. Therefore, the solar collectors can be used to convert the solar energy to heat water and for space heating during summer and autumn season. Water passes through the solar collectors in insulated pipes and is then collected in a water tank. In the winter, the solar collectors do not operate frequently, so other means of heating is used for space heating and domestic hot water purposes. It is important to pay attention to the orientation and inclination of the collector surface when installing the solar collectors. Insulation is obligatory for the solar collectors as it minimizes the heat loss. The solar collectors installed in a passive house help in the heating system and for hot water purposes. The solar collectors work when the temperature of the panels reaches 50 °C, and cold water circulates through the collectors to heat the water which is then led to a storage tank. [8.]

5 Kerava Passive House

A passive house recently constructed in Kerava, Finland, was studied as a case study in this thesis. The construction process began in late 2015. This house fulfills the required criteria according to the Finnish rules for the passive houses. The house is a single-family house constructed with advanced components and technology. The demand of heating load and primary energy is managed using a renewable source of energy. The main parties in the building project were Potius Oy, ArkStudio Tuomas Neimi, Hämeen Rakennuskone Oy, Styroplast oy, and the electrician students at the vocational College Kauda. [17.]

Buildings are responsible for 30-40 % of the total energy used in every country. To improve this, the building must be designed using perfectly insulated components resulting airtight and moisture free building. Preventing all kind of moisture and indoor environment issues, the best solution is to build an airtight building, which in turn reduces energy bills and helps to maintain building integrity. Airtight solutions lower the cooling and heating demand of the building, as well as play a significant role in extending a building's life. [2.] The insulation used in the kerava passive house was the best possible option for a passive house.

5.1 Structural Features

When the Kerava passive house was built, work on the walls and groundfloor started after the piling and foundation were done. Since the walls must be airtight and highly insulated, the best possible insulation material with a good U-value was selected. Vapor barrier (Clima Intello Plus) was used in walls, roof, and floor to protect the building from moisture and humidity problems in a best possible way. The core idea of Intello is to prevent water vapor from entering the insulation. To meet the requirements for the U-value, 250mm of EPS insulation and 100mm of Platinum EPS floor insulation were used with 120mm of load-bearing concrete for the wall that gives the U-value of 0.10 W/m²K. Urethane was used for wall-to-wall adhesion. Bitumen concrete, EPS insulation and compressed crushed stone were used in the floor along with fabric filter, so that the U-value of the floor stays below 0.09 W/m²K. The roof structure in the Kerava passive house offers a possibility to tackle moisture problems and leakage. The roof includes flat tiles, wind deflector and ventilated wool with wood fiber, ensuring the U-value of 0.07 W/m²K. [17.]

Table 7. Properties of EPS insulation 250mm [18.]

Bending strength (kPa)	350
Vapor resistivity (MNs/gm)	238
Water vapor permeability (Pa.h.m)	0.007-0.018
Water vapor diffusion resistance factor	40-100
Thermal conductivity (W/mK, at 10ºC)	0.034
Thermal resistivity (mK/W)	29.41

Other technical properties of 250mm EPS insulation are:

- Nominal density: 35 kg/m3
- Working temperature: -150ºC to 80ºC
- Long life cycle

Tolerances in cut dimensions of the 250mm EPS insulation are:

- Length: ± 3mm or ± 0.6% whichever is greater (L1)
- Width: ± 3mm or ± 0.6% whichever is greater (W1)
- Thickness: ± 2mm (T1)
- Squareness: ± 5mm per 1000mm (S1) [18.]

Skaala windows were chosen as they have windows that suit for a passive and low energy houses. The U-value of the windows and doors of Skaala are less than 0.8 W/m²K. To meet the requirements, doors from ARS wood Oy was used. The doors offer good soundproofing and long durability is ensured. The main specifications of the windows are:

- High energy efficiency
- Excellent soundproofing and better thermal comfort
- Long life cycle and low maintenance
- Options for timber and timber aluminum [19.]

The windows are tested and verified to consume the lowest amount of energy compared to other windows option available in the market. As the Skaala are energy efficient, it reduces the heating load of the building, thereby saving the heating costs significantly. However, the windows were selected to make a standard living comfort as it has an efficient soundproofing too. During summer, the building needs to be protected against sunlight as it increases the temperature inside the building. So, to protect the building from direct sunlight, a venetian blind with roller blinds that works as a sunlight blocker, was installed in the windows facing south. The roller shutters can be adjusted according to the weather condition. Venetian blind blocks around 70% of sunlight from entering to the building. [17.]

Although the required air flow rate of the passive house is 0.6 /h, the main target of this test was to obtain an airflow rate to 0.3 /h. Special attention has been paid to sealing joints and other insulation to make the building airtight. [17.]

The thermal camera measurements were used to calculate the airflow in the building and the pressure was set at 50 pascals. Data below was calculated using software and the formula number 3 in sub heading 4.1. The building leakage was calculated to find the flow coefficient and correlation coefficient.

Airflow at 50 Pascals

V50: 143 m3/h
n50: 0.18 1/h
w50: 1.06 m3/ (height*m2 Floor Area)
q50: 0.24 m3/ (height*m2 Surface Area [17.]

Building Leakage

Flow coefficient (CL)= 5.5 (+/-27.1%)
Exponent (n)=0.834 (+/-0.066)
Correlation Coefficient= 0.987 [17.]

Thermal bridges must be avoided in a building therefore, the air leaks were checked using a thermal camera. While checking, the biggest leaks were found on the ground floor through an electric pipe, which had been left unattached. Once it was fixed, the air leaks were controlled. No actual leakage points were identified with the thermal cameras. [17.]

5.2 Ventilation

The ventilation system installed in the Kerava passive house is a mechanical system with heat recovery, which is the standard and hence required to fulfil the requirements of a passive house. The ventilation system used is the best ventilation system for a passive house in Finland as well as in Nordic regions. It is highly efficient i.e. 95% and minimum external power is needed to operate the heat recovery system. The owner of the Kerava passive house had a different possibility at first for the ventilation system. After some research, a ventilation system manufactured by PAUL was selected as it has so many options for saving energy. [17.]

The PAUL ventilation system is widely used in passive houses as it has high-energy efficiency as well as heat recovery to 96%. 21W power is used in all processes including air transfer from the outside to the inside. The use of this ventilation helps to reuse and refilter the extract air in the maximum amount. This system has remote control facility that monitors exhaust and supply fans in working mode. Airflow, air pressure, and a carbon dioxide sensor are all controlled by remote. The ventilation system is perfectly maintained using this system. [20.]

All the bedrooms in this building have inlet and outlet valves for the supply and extract air, so the required amount of air is 170 liters per second, which is up to 100 liters per second more than the airflow in a residential building. This machine is little oversized, this has better heat recovery efficiency and airflow can be set according to the requirements. So, for the better airflow rate and better ventilation, Paul Maxi Flat 1000 was installed. [17.]

Table 8 below describes the full properties of the PAUL ventilation system used in the passive house. Although the mechanical ventilation heat recovery unit is PAUL maxi flat 1000 and the airflow can vary between 1000-1000 m3/h, in this house, the airflow of 250 m3/h is used, as it is sufficient for a residential building in Finland. This unit is more economical than using other ventilation systems although it is more expensive at first. This system is the best solution for a passive house and some low energy buildings in the Nordic region.

Table 8. Properties of PAUL heat recovery ventilation system [20.]

Airflow			100-1000 m3/h		
Dimension			(1.5*1.10*0.4) m		
Weight			172 kg		
Duct connection			DN 250		
Electrical connection			Fans and control device 1*230 V Electric pre-heating 1*230V		
Power input			1500W		
IP Code (DIN 40050)			IP 44 (fans) IP 20 (RC TAC4 REC)		
Operating range			-25ºC to +50ºC		
Heat exchanger			Aluminum cross counter-flow heat exchanger		
Fans			EC direct current radial fans		
Filter			G4 (intake air and extract air)		
Housing			Compact housing including anodized aluminum structure and acoustically and thermally insulated panels in painted steels outside and galvanized steel inside		
Condensate Drain			Stainless steel drip pan, condensate pump and condensate hose of diameter 6mm		
Summer operation			Motorized summer bypass, temperature-controlled and the heat exchanger is shut off		
Operating data used in this building					
Air flow (m3/h)	Heat exchanger efficiency %	Supply air temperature (after exchanger) ºC	Supply fan power (W/m3/h)	Power absorbed (W)	Sound pressure level dB(A)
250	95.5	20.6	0.08	21	16.6

The system uses TAC4 DG controller with RC TAC4 display. The system features:

- Automatic management to pass cooling air during summer
- Automatic management of inlet dampers
- Boost function
- Display of all operating parameters
- Antifreeze protection system
- Analog display of airflow and pressure
- Alarms on defects, over airflow and overpressure
- Fire alarm airflow management [20.]

Ground heat is the main source of energy in the Kerava passive house as it utilizes energy coming from the ground in pre-heating and cooling. A 150m of 40mm pipe is installed in the ground and at the end of the stem, the tubes are passed through the well with a 20m 20mm 1mm plastic tube with plastic insulation. The ground well contains 560 liters of water and it is ensured that the water flows frequently from a pit. The water is passed to a nearby ditch at a certain time. In this Kerava passive house, the supply air is led through the ground pipe loop during winter, which increases the temperature to +15ºC. So, in the winter if the outside air temperature is -20ºC, the ground pipe circulation raises the temperature to about -5ºC, playing a part in saving energy needed to warm air. The flow in the pipes is done through circulation pump of power 8W, which is installed in ground floor near to the system. [17.]

An example of a heat gain with this method was on October 21, 2017, when the outside temperature was 0.4ºC. The temperature of the water in the pit was measured to be 10.2ºC. So, when the air is circulated with the circulation pump through the ground-heating coil, the temperature of air entering the ventilation unit was 7.4ºC. This can be useful even in the summer when the outside air temperature is warm. The supply air temperature can be reduced in summer. [11,17.]

5.3 Heating System using Firewood Stove

The heating system in Kerava passive house is different than a regular passive house. During the winter, the Hoxter water-heating stove is used, and the solar collector is used during the summer. The Hoxter is easy to ignite and the Härmä Air chimney pulls extremely well even though the barrel is cold. The Hoxter water-heating stove is basically a modernized firewood stove. It is made of P265 GH grade heat resistant steel, which is used in the production of pressures pipes. The specific features of Hoxter Haka 67/51 Wlh, which is tested according to EN 13229, are listed in table 9 below. [21.]

Table 9. Technical Data of Hoxter Fire Stove [21.]

Nominal heat power	11/8.1 kW
Efficiency	>80%
Consumption of wood	3 kg/h
Mass flow of flue gas	8 g/s
Average temperature of flue gas on the output	202ºC
Heat distribution Fireplace inserts Door glass Water	 10% -/17% 73%
Required chimney pressure	12 Pa
Minimum supply sir grating cross-section	250 cm2
Minimum outgoing air grafting cross-section	300 cm2
Required amount of combustion air	30 m3/h

The water heating fireplace is placed in the living room where it provides a nice visual impact inside the building and provides heat for domestic water heating and other heating systems. The room where the Hoxter system is installed is designed so that there is no overheating. The glass used in the system is double-glazed which allows an increase in the average firebox combustion temperature by 120ºC. To allow heat movement inside the pipes, insulation was used in the barrel. The barrel is stacked, and then pressed against each other with a small headband. The Härmä Air chimney for the smoke released by Hoxter stove was installed above the stove and barrel and pipes are hidden. 90% of the blades are hidden in the attic, and to avoid problems of blow waves, the plastic shield named härmäAir Barrel, was used as the barrel. Warm air from the Hoxter heater comes outside which helps the warm the indoor surroundings. [17.]

The hot water is transferred to the storage tank with the help of hot-water exchanger, which is installed on the ground floor. The tank is insulated to ensure minimum heat loss, and the water is further used for heating purposes. Maximum air pressure for water exchanger is set to be 2.5 bar. Automatic control system is used to pass the water heated by the Hoxter stove to the storage tank. When the water is heated up to 55-60ºC, the water is led through the water tank, which acts as a heat storage, with the help of motor-driven mixing valve. The whole heating system is controlled by the Resol Deltasol MX, which is an exquisite device and offers control ability for floor heating, water circulation, solar collectors, and even air conditioning circuit. Additionally, the Resol Deltasol MX can be programmed in 14 relay outputs as well as 12 inputs for temperature sensors allow monitoring of temperature. Grundfos Alpha pump is used to recirculate water through the under-floor heating circuits. The pump’s electricity consumption is 35 watts. The automation installed in the building takes care of hot water and floor heating. Automation ensures that hot water is transferred to the tank and is available for domestic hot water and underfloor heating. [17.]

Figure 3. Heating System with Hoxter heating Stove [21.]

Figure 3 above shows how the system for heating is done with the Hoxter heating stove in the Kerava Passive house.

5.4 Solar Collector

The solar collectors in the Kerava passive house is used for heating domestic water and for floor heating. The collector is Wagner Euro L20 AR, a very powerful German product. The collector is a combination of anti-reflective glass with the purest glass blend. It ensures a high penetration rate i.e. 96%. The highly selective vacuum-packed level absorber is placed in the collector to minimize heat emission. All structures of this collector are insulated with strong thermal insulation, which ensures the minimization of heat losses. This product is the best and most powerful collector available and it has a 10-year warranty. [22.]

The details in the table 10 represent the specific data of the solar collector (Euro L20 AR) according to EN 12975. It is sufficient to just install 3 solar collectors for a residential building, and they can provide up to 2400 KWh of almost free energy. However, in the Kerava Passive house, four solar collectors are used for the extra production of free energy. One more solar collector contributes almost 800 KWh of free energy. Therefore, the total production of energy from the solar collectors is about 3200 KWh and it can increase depending on the weather situation. [22;23]

Table 10. Euro L20 AR Technical Data [23.]

Total area / aperture area	2.61/2.36 m²
Dimensions	2.151*1.215*0.110 m
Collector efficiency	84.8 % K1 = 3.46 W/m²K; K2 = 0.0165 W/m²K²
Incident angle modifier (50 °)	Kdir = 95 %, Kdiff = 88 %
Annual collector yield	521 kWh/m²a
Specific heat capacity	4.7 kJ/(m²K)
Glass Roof	4 mm solar safety glass with anti-reflection surface: τ=96%
Absorber	Pipe register absorber; aluminum heat conductor sheet; 12 closely spaced copper pipes
Absorbent coating	Highly sensitive vacuum coating; α = 95%, ε = 5%
Absorbent content	1.5 liters
Heat carrier	DC20 (corrosion inhibitors mainly with propylene glycol); mixing ratio depends on weather conditions
Operational pressure	Max. 10 bar
Stagnation temperature	209ºC
Certification mark	Solarkey-mark; CE-mark; Blue Angel RAL-UZ 73
Sensor pocket inner diameter	6 mm
Weight	48 kg

The major reason for installing a solar collector is to reduce the use of a wood stove and it also helps to warm the water on sunny winter days. The water is led through collectors using the insulated pipes to the pump which is installed on the ground floor. As it was important to ensure that there is no air leak, air leakage tests were conducted, and this system was free from leaks. The pump is installed for water circulation and connected to the Resol control system installed in the house. [17.]

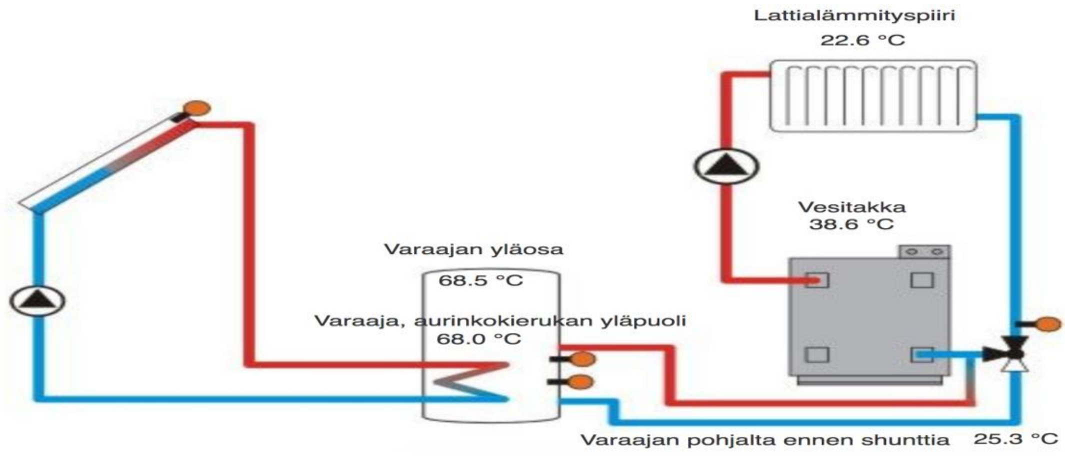

Figure 4. Temperature while the solar collector is working. [17.]

Figure 4 above illustrates the temperature inside the Kerava passive house. Varaajan yläosa in figure above indicates storage tank upper part temperature that is 68.5 ºC, Varaaja, aurinkokierukan yläpuoli indicates water temperature after water is passed through solar collectors which is 68.0 ºC, Varaajan pohjalta ennen shunttia indicates the water temperature before it is used for heating purposes that is 25.3 ºC, Lattialämmityspiiri indicates the under-floor heating temperature which is 22.6 ºC and finally Vesitakka indicates the temperature of water tank that is 38.6 ºC. A sensor is installed to control the temperature of each system installed in the building. [17.]

6 Interview and Discussion

The owner of Kerava passive house, Mr. Simo Lääveri, was interviewed about the process of construction and thermal comfort inside the building. According to the Mr. Lääveri, the building is convenient, and the living comfort is high. He was happy with the output of the building. The building only consumes renewable energy, which is supplied by the Kerava energy and produced with wind power. Although it is slightly more expensive than normal electricity, it does not make a difference for this kind of a building, which uses a very small amount of electricity. [24.] The energy cost of the Kerava passive house is one third of that of a regular building even when it uses renewable energy. The levels of both primary energy and heating energy are much lower than the requirements for a passive house. The benefits of a passive house were listed in the interview:

- Moderate life cycle cost
- Comfortable to handle the system

- Better thermal comfort all year
- Better noise protection than in a regular building
- Better indoor quality
- Reduction of carbon dioxide emissions and energy use [24.]

It is true that the construction cost of the passive house is more expensive than that of a regular building, but the payback period of a passive house can be shorter than that of a regular building. [6.]

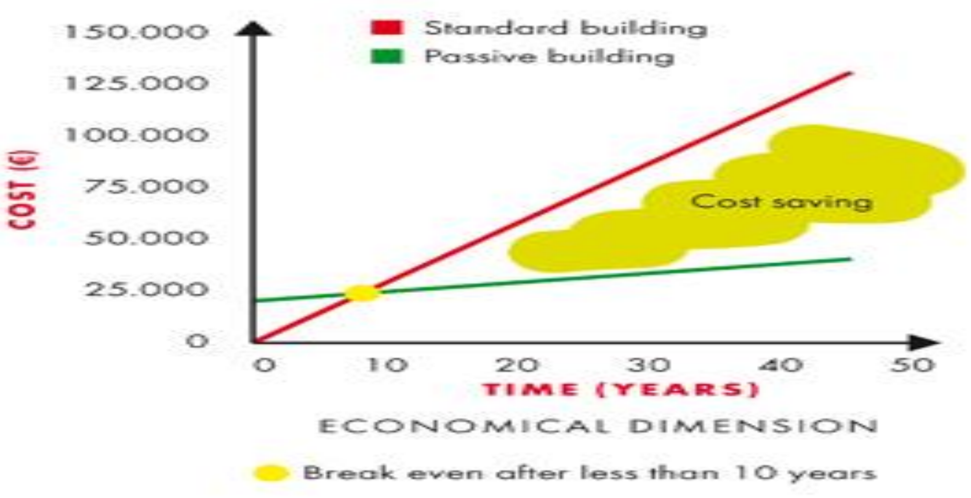

Figure 5. Economical comparison between a regular house (red line) and a passive house (green line). On vertical axel costs and horizontal time [6.]

Figure 5 above clarifies the cost differences of a passive house and a standard building. A regular passive house can be more beneficial even costwise. In fact, the first passive house ever built is now 23 years old and it still functions like a new one. This clearly indicates that the passive house has a longer life cycle than a regular building. [2.]

The payback time can be calculated with a simple formula:

$$\text{Payback time} = \frac{\text{Initial outlay for property}}{\text{Energy saving per month}} \qquad (4)$$

The EU commission has set the target for emission cuts at 80 % by 2050. It seems that the passive house is the solution that ensures that the targets are fulfilled, as regular buildings are responsible for around 48% of total emissions globally. Lately, there have been rapid changes in public awareness about the energy consumption, related emissions, and problems associated with the environment. [8.] The passive house concept is increasing gradually as companies, like VTT are involved in the development of a passive house. The passive house concept can be used in construction of office buildings, schools, and social homes. The development of building a passive house is increasing day by day and it can be used as a tool for energy saving. Public awareness has influenced environmental issues. The growing environmental factor is related to building emissions and carbon emissions so there has been huge financial backing as well as government policy towards emission less environment in different countries. To promote the construction of a passive house, the following aspects must be considered:

- Suggesting renovation ideas for a regular building using passive house concepts
- Promoting industries which produce passive elements
- Offering training and awareness programs for architects, engineers, developers and people in the construction industry
- Funding research programs that compare ventilation systems and comfort of passive houses with existing buildings [11;14]

7 Conclusion

This thesis shows that it is possible to meet the requirements set by Passivhaus Institute even in cold climate conditions. The use of district heating can be fully avoided in a passive house and still maintain the standard through different methods of heating. The alternatives for ventilation, heating and renewable energy sources that were discussed in this thesis are regular, everyday systems and they fulfill the requirements of the passivhaus standard. Not all the equipment used in a passive house is expensive, especially when considering the life cycle cost compared to systems required in a regular house, and their energy cost. [25.]

The passive house requirements can be completely fulfilled by using highly insulated building materials, ensuring the air-tightness of the building, using mechanical ventilation with high-efficiency heat recovery, using solar energy from solar collectors or solar photovoltaic cells and an alternative source for heating and cooling. The passive house solves all major problems of regular buildings. The passive house suits the European policy of reducing energy use in residential building, as the total buildings are responsible for around 40% of energy use in the European Union. [3.]

Compared to a regular building, the passive house is more environmentally friendly, and have the best result in indoor comfort. The heat loss in the passive house is negligible compared to a regular building, as special care is taken in joints and barriers during the construction process. Poor weather conditions during the construction phase may result in moisture-related problems in building, so it is important to check the properties of materials used in construction. Most European countries have done major significant work in reducing their energy use, but the energy loads can still be reduced in most of the countries. [3.]

In my view, it is more logical to build a passive house as a community, so it helps more to reduce operating cost and energy use. Even the electricity can be produced at a local level using renewable energy such as wind or biogas. A lot of progress has been made in Finland, regarding the passive house concept. But still user expectations, clear benefits, and attitudes towards the passive house are important aspects to pay attention to grow the market of passive house construction. It is best to buy the quality product for once than buying product for many times. This principle is perfect for a passive house with an initial investment that feels very high at first but guarantees payback and best quality afterwards. [2;14]

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Appendix

Pictures from the Kerava passive house

The pictures in this appendix are taken by Simo Lääveri, the owner of the Kerava Passive house.

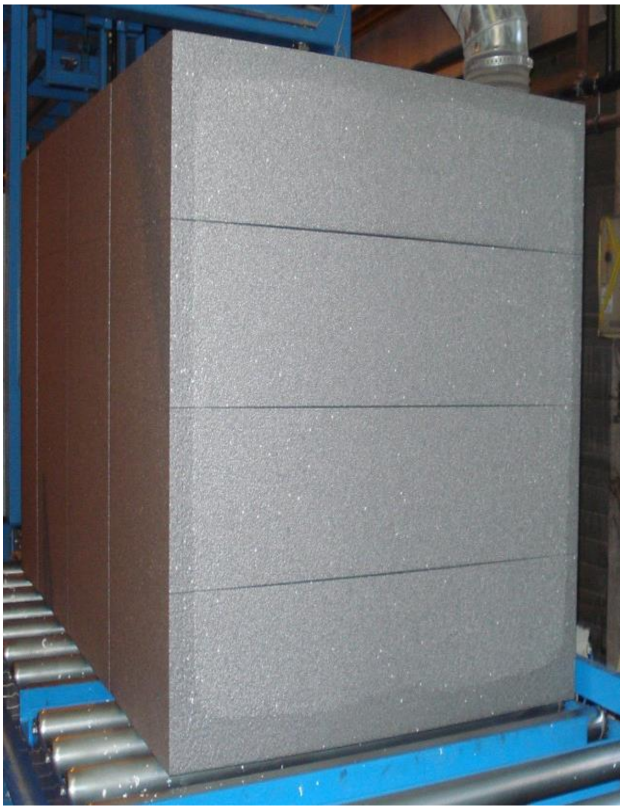

Figure 1. 250 mm Insulation used in the building

Figure 2. PAUL heat recovery system which is placed in ground floor

Figure 3. Hoxter firestove which is used for heating

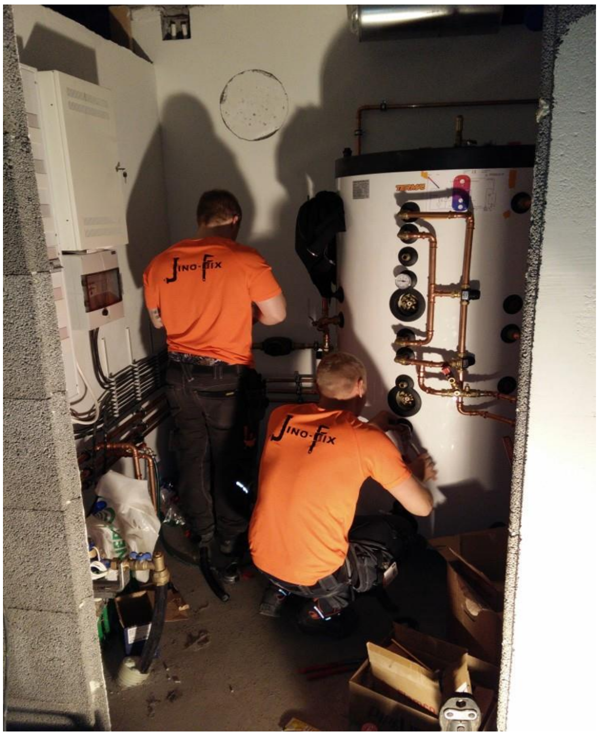

Figure 4. 750 liters water tank installation

Figure 5. Underfloor heating pipe installation

Figure 6. Temperature Data

The S3 sensor indicates the top of the charger temperature. S4 tells the temperature of water that comes from the charger and is before shunts in the water tank circuit. S5 tells the temperature of the water tank which is near the fire place.

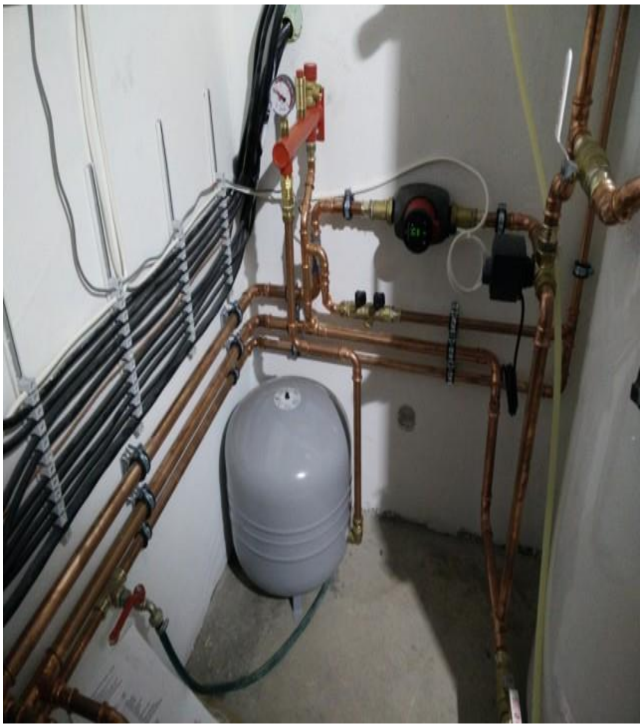

Figure 7. Pump used for the circulation of hot water for ground-floor

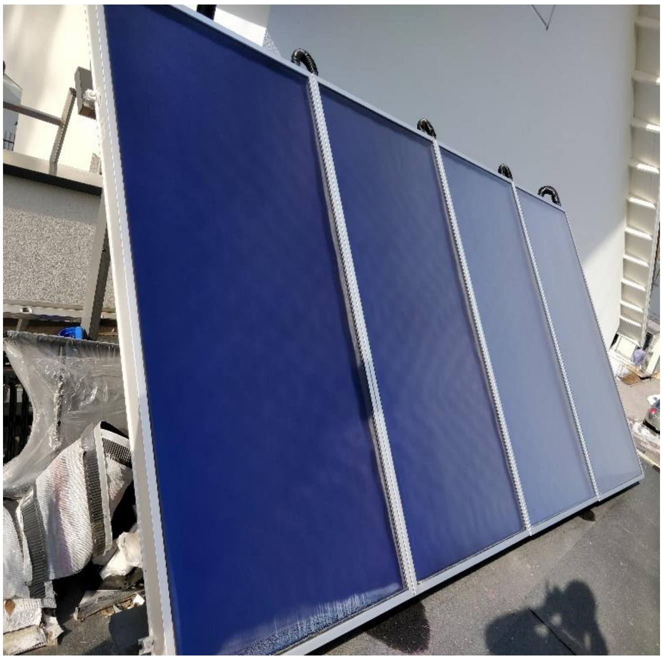

Figure 8. Solar collectors

The solar collectors are placed facing south with angle of inclination at 40°.

Figure 9. Temperature Data

The figure shows the temperature of the water entering the heating circuit on the control panel display (S10). The values item S9 and S11 is 888.8 since they are not yet connected.

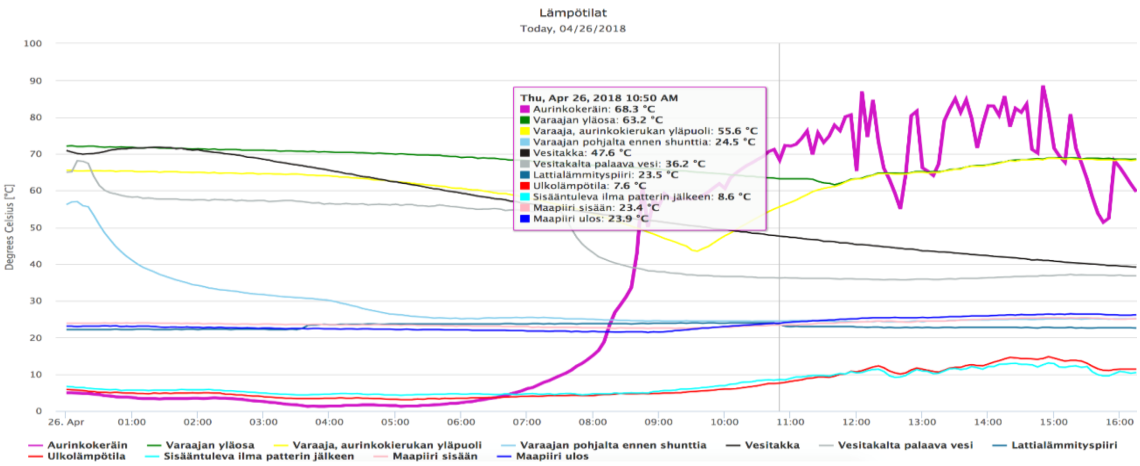

Figure 10. Temperature chart (1)

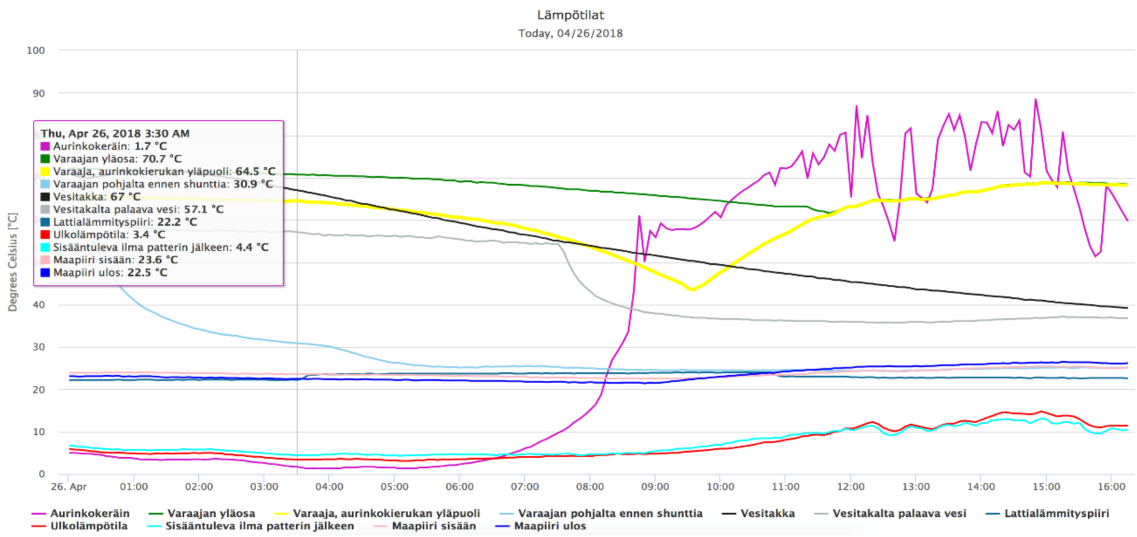

Figure 11. Temperature Chart (2)

Figure above is the data collected on 26th of April and it shows the temperature of all the system used in the building that is: -

- Solar collector
- Charger lower part
- Charger top part
- Charger returns
- Water tank temperature
- Water temperature which comes out of tank
- Floor heating temperature
- Outside temperature