RENEWABLE ENERGY SYSTEMS FOR ZERO ENERGY BUILDINGS IN FINLAND

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ABSTRACT

The topic of zero energy buildings (ZEB) is one of the most discussed in the current scientific world. All European countries more or less take steps to development the ZEB sphere. There are matters how households can apply current legislations and implement the existing best practicing for their demands. The goal of the Bachelor's thesis was to define the most suitable renewable energy systems applied to zero-energy households in the Finnish weather conditions. To achieve the goal, the topic of ZEB was discussed in terms of the current legislations concerning existing renewable energy systems mostly suitable for zero-energy households. In addition, the Danish approach to zero-energy buildings was analyzed.

The results of the thesis showed that there are many possibilities to use various renewable energy systems in Finnish households, but transition to ZEB households still requires some time due to not full appropriate legislation and weather conditions, which do not allow use the renewable energy systems without district systems. More development and research are required in this sphere.

Keywords Zero energy building, renewable energy systems, Finland, Denmark.

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1 INTRODUCTION

Nowadays the problem of worldwide ecology is particularly acute. A huge amount of carbon dioxide is emitted in the atmosphere polluting it. As a result, the nature globally changes including global warming and ozone holes. Also, since industrialization in Great Britain in the 19th century fossil fuels have actively been used. They are non-renewable energy sources and their reserves are not endless. These two reasons pushed population to thoughts that something must be changed.

Most countries, in one way or another, try to influence it and suggest different solutions to improve the situation. One of the most effective ways is to use renewable energy collected from nature resources such as wind, sunlight, geothermal heat, etc. instead of non-renewable ones. Even counties with huge resources of oil and gas are moving to use renewable energy resources. They are applied not only on industrial scales but also at households. These households are named with different definitions such as green buildings, low energy buildings, net zero energy buildings, zero energy buildings, etc. Their concept is to operate by installing renewable energy systems (or with their help) and consuming the generated energy. This helps to reduce energy consumption.

This is what average households can do for the worldwide ecology and that is why it is important to consider different renewable energy systems to choose the best ones. This thesis has a real practical application and great meaning for households; that is why this topic was chosen.

So, the definition of the most suitable renewable energy systems applied to zero-energy households in Finnish weather conditions is the goal of the thesis. To achieve the goal, following objectives were considered:

1. Definition of a ZEB concept and its need in Finland.
2. Consideration of different renewable energy systems suitable for ZEBs.
3. Comparison of existing renewable energy systems in case of their application in Finland.
4. Comparison of Finnish and Danish approaches to ZEBs.

In the thesis practical research methods were used to confirm the relevance of the topic and practical use of the thesis for households and all parties concerned.

2 A CONCEPT OF A ZERO ENERGY BUILDING

Zero energy buildings (or ZEB) are quite a popular topic among energy specialists. There is still not plenty of official documentation and only a few areas in the world can say they have real and well-working examples of ZEB. The topic is discussed by starting of its history and finishing with the current legislation and concepts of ZEB.

2.1 History of buildings with low energy consumption

As early as the 1970s people began to understand that fossil fuels pollute the environment and alternative types of energy are needed. At that time the first thoughts to replace fossil fuels were about nuclear energy. But some scientists understanding possible risks from nuclear fission did not stop searching for other alternatives. They decided to work from the beginning: the main question was where the vast amount of fuel was actually being used for, and found out that the most of energy came to buildings' heating. In fact, that energy consumption could be minimized and used more efficiently and that was the first step for the design of buildings with low energy consumption. (Krämer, The first Passive House interview, October 2016)

So, in 1991 Dr. Wolfgang Feist with help of three architects built the first passive house in Darmstadt, Germany. The German Institute for Housing and the Environment permitted the research and the Ministry of Economics of the State of Hesse provided funding. The Passive house was defined as "a building which has an extremely small heating energy demand even in the Central European climate and therefore needs no active heating". The building is shown in Figure 1. (The world's first Passive House, Darmstadt-Kranichstein, Germany)

Figure 1. The first Passive House in Darmstadt, Germany
(International Passive House Conference, 2016)

All elements of the building had a very low U-value equal from 0.1 W/(m^2K) for the roof to 0.7 W/(m^2K) for the windows. Heating consumption was 19.8 kWh/(m^2a) in the first year of operation which was 8% of the consumption of ordinary houses and less than 10 kWh/(m^2a) on average in the following years. (The world's first Passive House, Darmstadt-Kranichstein, Germany, 2019)

After that the industry of buildings with low energy consumption began developing very actively. Not only passive houses but net-zero, nearly zero, zero-energy buildings were designed and built. The most modern buildings include even net-zero energy skyscrapers. In fact, it is related mostly to industrial buildings but the sphere of residential buildings with nearly or zero-energy consumption is still developing. (The world's first net-zero energy scraper rises in Indonesia, 2014)

2.2 Appropriate definitions

As was mentioned before, buildings with low energy consumption can be named with different definitions according to their energy production and consumption. For instance, the first passive house was defined as a building that requires extremely small heating energy. Nowadays this definition is used with the addition of "use of passive methods of energy savings". Usually energy savings are achieved by reductions of buildings heat loss.

There are currently a lot of terms used to define a zero energy building. Generally, the definition of a zero-energy building means that all needed energy is produced by a house or almost all needed energy is produced by a house in case of nearly zero-energy buildings. In fact, the main terms were provided by the countries where zero energy buildings are mostly used:

1. "A highly energy-efficient building with all remaining operational energy use from renewable energy, preferably produced on site but also off-site production, to achieve net zero carbon emissions annually in operation". (The World Green Building Council, 2017).
2. In the USA: "An energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy". (The U.S. Department of energy, 2015).
3. In the European Union: "A building that has a very high energy performance with the nearly zero of very low amount of energy required covered to a very significant extent by energy from renewable sources, including energy from renewable sources provided on-site or nearby". (The Energy Performance of Buildings Directive 2010/31/EU)

For the European Union this Directive was the first one, which helped consumers to make a choice about energy efficiency and save energy and money. Also, it started a new trend for more energy efficient buildings as it includes information about energy efficiency requirements for the national building codes. This Directive was revised in 2018.

4. In Japan: "Building structures that have an annual primary energy consumption of net zero or almost zero through a reduction in the consumption of primary energy in building structures with improvements to the energy conservation performance of building structures and facilities, as well as by utilizing renewable energy on site". (Energy Conservation Policies of Japan, 2011)

To sum up, all the definitions give the following criteria for a zero-energy building:

- Energy efficient
- Operates with help of renewable energy systems working on-site or nearby
- High energy saving
- Energy generated is equal or greater than energy consumed
- Net zero carbon emissions

2.3 **Current ZEB regulations**

Nowadays, the fullest ZEB code regulations are suggested by the USA. The USA also subsidies a huge amount of money for ZEB construction development. For example, California State provides funding for housing customers in solar energy and solar thermal systems in the frame of the program New Solar Homes Partnership (Go Solar California).

Canadian R-2000 Standard is a voluntary national standard with the last edition in 2012. The main purpose is to improve energy efficiency of new buildings. The Standard contains technical requirements for building elements, measures for the efficient energy use, indoor air quality information, verification of heating, cooling, ventilation systems and uses as an addition to the National Building Code of Canada, Part 9. This Standard relates to all residential buildings' construction.

Europe also develops the new regulations related to ZEB. The Energy Performance of Building Directive gives a standard for ZEBs by 2020, clarifies that the technology is already proven, and also the program ZEBRA 2020 is used as a tool to give more practical details to ZEBs (ZEBRA 2020 – Nearly zero-energy buildings Strategy 2020, final report).

The program ZEBRA 2020 covers 17 European countries (Sweden, Denmark and Norway are included of Scandinavian countries). A coordinator of the ZEBRA 2020 Raphael Bointner presented the main targets of the project, which were divided according to the following groups: to collect numerous information and data of existing nZEB including professionals' opinions about the nZEB, Energy Performance Certificates (EPCs) and other issues related to the buildings. Based on these sources, new recommendations for construction optimization and new tools to estimate the market should be developed. The following results were obtained:

1. The European market of nZEB was researched and all the project members will research own national market in the future;
2. New approaches for better comparability of general and national regulations were found;
3. It was revealed that not all existing nZEB meet the nZEB definition of the EU directive on energy efficient buildings (EPBD) because their energy consumption is higher than "nearly zero or very low amount" and the rest energy consumption "should be covered to a very significant extent by energy from renewable sources". However, this is considered as a following step to clear the current definitions in EPBD. (EU directive on energy efficient buildings)
4. Economic and regional aspects were taken into account, which helped to make a cross-country comparison of best practices and barriers for ZEB construction. Based on the comparison, strategies for future ZEB market by 2030 and 2050 were developed.

The Finnish National Building Code includes some regulations related to energy efficiency. First of all, it is about thermal insulation and energy management: C4 - Thermal insulation, D2 - Indoor climate and ventilation of buildings, D3 - Energy management in buildings (with an energy frame calculator) and D5 - Calculation of power and energy needs for heating of buildings. At the moment, there are no at least nearly zero-energy buildings in the legislation. But European Energy Performance of building Directive requires all new buildings (public) from 2021 to be nearly zero-energy buildings, so there is still time to develop and implement the new legislation for the energy efficient buildings, not only public but also residential. (Nearly Zero-Energy Building Strategy 2020, ZEBRA2020)

2.4 Principles of ZEB operation

According to the definitions mentioned above, the principle of work of ZEB is based on a similar formula: energy consumed should be approximately equal to energy produced. Usually for different combinations of renewable energy systems are used, for example, solar heat and cool of the ground below the house can provide lighting in a house. But the most important details of getting a zero-energy building are to design of geometry: the placement of windows and doors, insulation type, depth of the construction; to think over the used building materials for windows, insulation, etc.; to calculate energy efficiency of any equipment according to the local climate. Fortunately, current 3D simulation tools can help to take into account all possible design variations and choose the best option with the most beneficial performance.

A level of heat losses and air leakage also should be taken into account for the calculation of necessary energy sources for houses. For instance, in case of Finland, especially winter time, heat losses can be quite big because of a big difference between outdoor and indoor environment/ Heating systems should be useful even in the cold weather.

The other feature of ZEB is a capability to harvest and save energy for future electricity, heating or cooling needs. Mainly the feature is related to PV panels, some solar heating systems and, to some extent, to heat pumps of ground and air sources. For sure, energy harvesting cannot be cost effective without energy savings by the used building materials as mentioned before. (Zero-energy buildings. Environment and Ecology)

Of course, behavior of the building occupants plays one of the most important roles: how occupants use electricity, hot water level, and electrical devices. Some studies show that the use of the same ZEB by different people can change energy use more than twice (Pilot evaluation of Energy Savings from Residential Energy Demand Feedback Devices).

After considering the main features of ZEB advantages and disadvantages of ZEB can be formulated as follows:

Advantages:

1. ZEB owners might be isolated from future energy price increases
2. Based on the first point, owners have reduced the total cost for the building maintenance and living
3. Owners get improved reliability because of long-term warranty for renewable energy systems
4. No government restrictions related to carbon emissions and appropriate taxes or additional costs

Disadvantages:

1. Currently, the process of getting the most beneficial design of ZEB and its construction can be very hard because there are not many engineers who have necessary skills and experience
2. Initial cost of buying and installation of renewable energy systems can be higher
3. The local climate has a very big influence on ZEB construction. As known, the climate is changed, and nobody knows which ZEB

design will be the best after some time. Also, not all climate zones can be used for ZEB construction.

3 ENERGY CONSUMPTION IN FINLAND

For better understanding the possibilities for construction and use of ZEB in Finland it is necessary to consider the total and household energy consumption. It will help to define the most applicable types of energy use and then assess a possibility of their partly or fully replacement by renewable energy systems as ZEB requires.

3.1 General energy consumption in Finland

As known, Finland is located in the Northern Europe. Its climate is quite cold and most of the time it is dark. It requires more heating and lighting comparing with other more southern European countries. According to the graphics (see Appendix 1), Finland needs more energy for heating even comparing with other Scandinavian countries such as Sweden and Norway. However, only countries of Southern Europe (Spain, Italy, Greece and Portugal) have of small energy need.

The picture (Appendix 2) shows the dynamics of energy sources consumption. It can be noted that energy consumption of all energy sources grows year by year with the exception of nuclear power use. But the new Finnish energy policy says about the carbon tax increase by 2030. Also, it is believed that commissioning of two new nuclear power reactors in Hanhikivi can partly replace the use of coal and thus, carbon emissions will be decreased (Nuclear Power in Finland, World Nuclear Association).

According to the picture (see Appendix 2), the following graphics of used energy sources by 2030 was created:

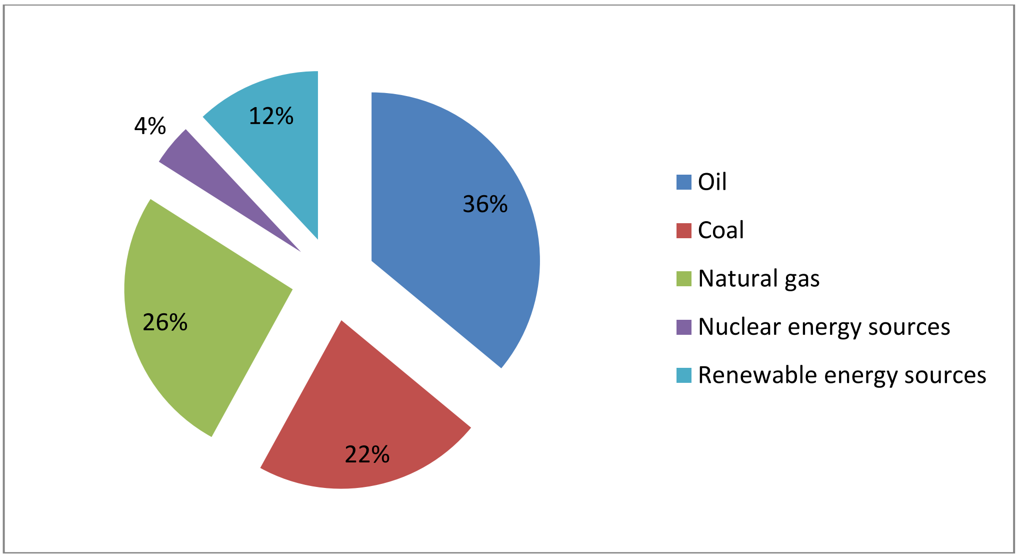

Figure 2. Energy sources consumption by 2030 (Energia Suomessa, p. 93)

As seen in Figure 2, the most popular energy source is still oil (36%) and the percentage of renewable energy sources exceeds only the use of nuclear power. The picture (Appendix 2) also shows that the consumption of natural gas and renewable energy sources is approximately equal while the difference between these indicators becomes bigger by 2030. It means that the consumption of renewable energy sources does not grow as rapidly as the consumption of natural gas. An output from these notes can be formulated as follows: the consumption of renewable energy sources is not as beneficial as the consumption of primary energy sources such as oil and natural gas.

3.2 Energy consumption in Finland by households

The use of renewable energy sources is not as big as other energy sources on the government level. The same trend can be seen at the households' level. According to Statistics Finland (Appendix 3), a graphics of consumption of energy sources by households (in total) in 2017 was created:

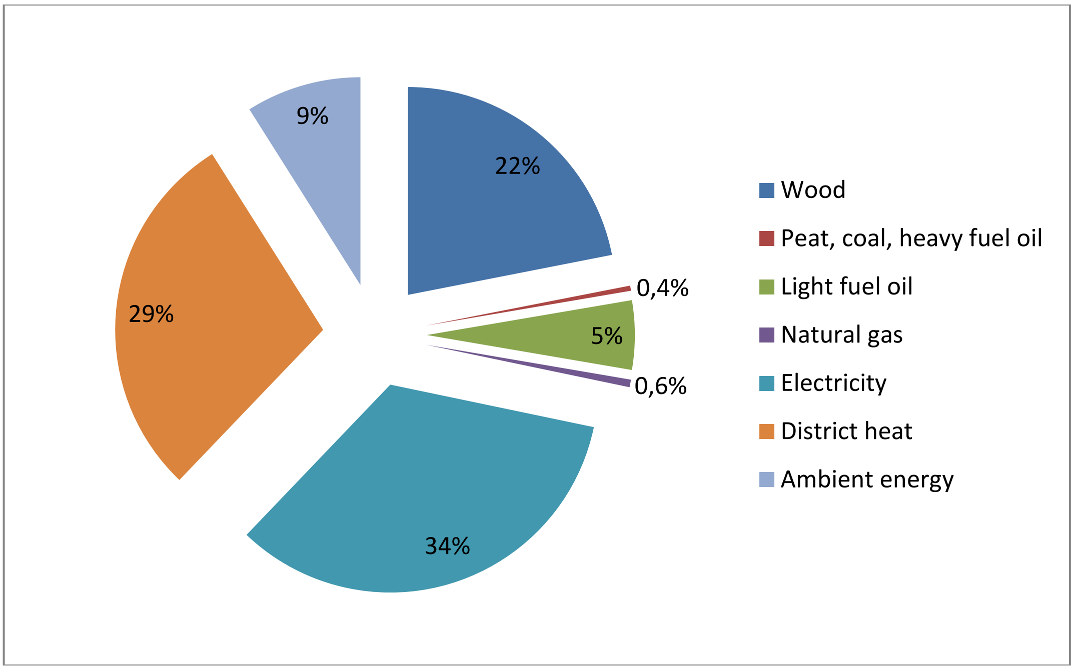

Figure 3. Energy consumption of energy sources in households (in total) in 2017 (Statistics Finland)

Ambient energy in Figure 3 refers to all energy extracted from the environment such as air, water or ground for housing heating. Comparing with Figure 2, the use of these energy sources is approximately the same as at the governmental level. But, of course, the biggest part of housing heating comes from more familiar energy sources like electricity devices and wood. Nowadays, the use of "heavy" sources, which pollute the environment, is very rare, and the use of ambient energy sources increases. For example, percentage of ambient energy sources has been increased from 5 to 9% since 2011 (see Appendix 4). But use of such popular energy sources as electricity, district heat and wood has the same percentage in 2011 comparing to 2017.

These facts tell that people use renewable energy sources in combination with clean fossil fuels, but the percentage of renewable energy sources use is increased. That can also help to reduce energy consumption by households.

4 FINNISH RENEWABLE ENERGY SYSTEMS IN ZEB

This chapter will describe possible renewable energy systems used for zero-energy systems and their comparison for the use by households. Obviously, solar systems can be used more efficiently during summer time since winter time in Finland is quite dark and then save energy produced for the future winter. Geothermal energy can be used during the whole year for heating in the winter and for cooling in the summer. In

Finland different seasons are more or less windy, so wind energy is beneficial for all seasons in case of energy savings.

There are two ways of solar power use: solar PV systems and solar thermal systems. The difference is in the final product of energy collected. Solar PV systems are used to generate the electricity, whereas solar thermal systems produce the heating for water and air. Both systems will be described in the next paragraphs.

4.1 Solar PV systems

Photovoltaic (PV) cells are semi-conductor devices that convert sunlight directly into electricity. (Solar home design manual for cool climates) They have advantages such as no needed fuel (no carbon emissions), little maintenance, reliability (when the sun is shining), relatively easy installed and have long useable lifespan (over 20 years). The cells can be chosen for every house depending on their installation angle relatively to the sun, amount of possible solar gain and the available area for installation.

PV modules can be installed off-grid or grid-connected. The fist type is very useful for houses located far away from the community. In this case to bring the electricity to the site is quite expensive, so PV panels help to get electricity at a lower or similar price. But the off-grid system requires more details such as, for example, low-voltage detector to define that the batteries need additional charging. (Solar home design manual for cool climates)

The principle of electricity generation is the following: PV modules consist of three layers: positive and negative layers made of special silicon materials, which allow electrons (from negative layer) to be freed from their atoms when a module is exposed to sunlight, and a junction to separate them. Together they create an electric field. When the freed electrons move through the material, electric current appears. It goes in one direction, in other words, it is called direct current. The amount of the current depends on how the cells in the module are wired: in series or parallel. This will affect the choice of necessary voltage. The scheme of PV cell structure is presented below in Figure 4. As seen, the upper layer consists of electrons which are freed because of sunlight and transform into direct current because of existing positive and negative poles.

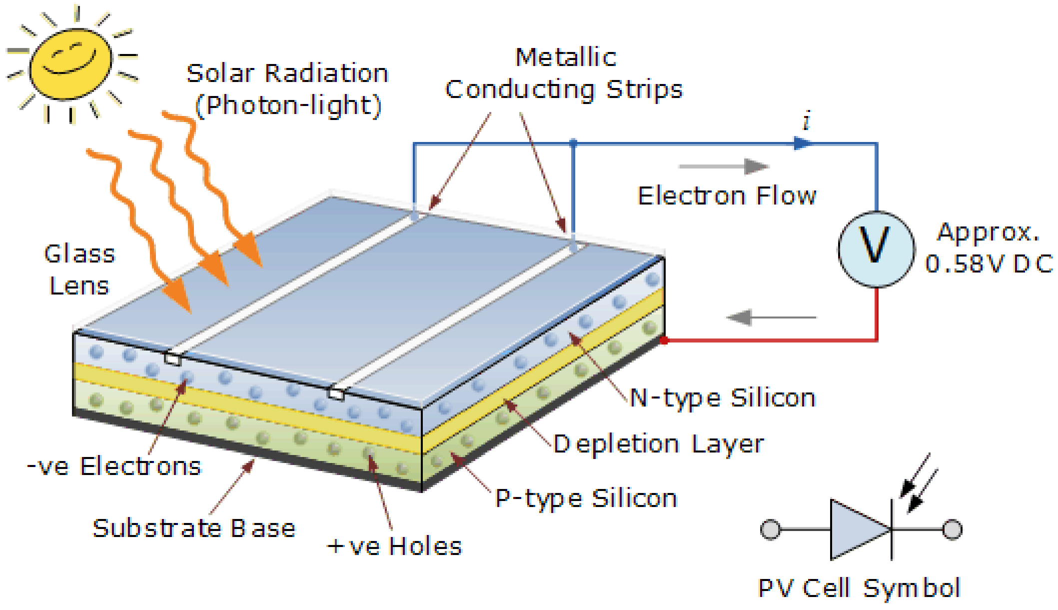

Figure 4. PV solar cell (Alternative Energy Tutorials)

Also, it is important to take into account that for cold climates the modules with low (14.5V) or medium (16V) voltage are the most optimal (Solar home design manual for cool climates) due to their good performance in cool climates and no need in a regulator, especially in cases when wires are too long and significant voltage loss occur.

For choosing an appropriate CV module the following formula can be used:

$$P_{max} = V_{out} * I_{max} \quad (1)$$

In Formula (1) P_{max} shows the maximum deliverable solar power (in Watts) which is equal to the cell output voltage V (in Volts) multiplied by the maximum current I (in Amperes) of the cell. (Photovoltaic Solar Cells, Alternative Energy Tutorials)

One of the leading providers of PV panels in the Finnish market is Neste Advanced Power Systems International (NAPS). The company was set up as a photovoltaic unit of the Neste Oil Company in 1981. Nowadays, they provide energy saving solutions for everyone, from households to business needs and not only for the Finnish market, but for Scandinavian countries, too. Besides there are more companies which have specialized in the solar energy systems such as Sun Energia, Aurinko Tekniikka, Green Energy Finland, Ympäristöenergia. Mostly there is not much information on their websites, it is supposed to discuss all details face-to-face and according to the discussion and the provided hourly electricity consumption the suitable system will be chosen for a client.

The company Ympäristöenergia provides more information about PV panels and also attaches the catalogue of photovoltaic packages (Figure

5). There are only grid-connected systems but other types of systems are available on request. Photovoltaic Packages from 1.06 kWp (kilowattpeak) to 5.3 kWp are presented on the website. The price is 1.5 Euro / Wp on average. The packages also include all necessary connectors, cables, aluminum conductor for grounding, etc. The full description of the product packages can be found in Appendix 5.

Figure 5. PV panels provided by the Ympäristöenergia company

To define the best solar panel for a house, first, the needed power in Watts should be calculated. The power equals to an average hourly wattage requirement for a house divided by the number of daily peak sunlight hours for the area of building's location. In Finland this number is 9-10 on average. Of course, all companies provide their services to define the best solar panels they have. (Finland's weather and light, This is Finland)

4.2 Solar thermal energy systems

Solar heating system works with a special solar collector. In Figure 6 below the whole process of the electricity production is presented:

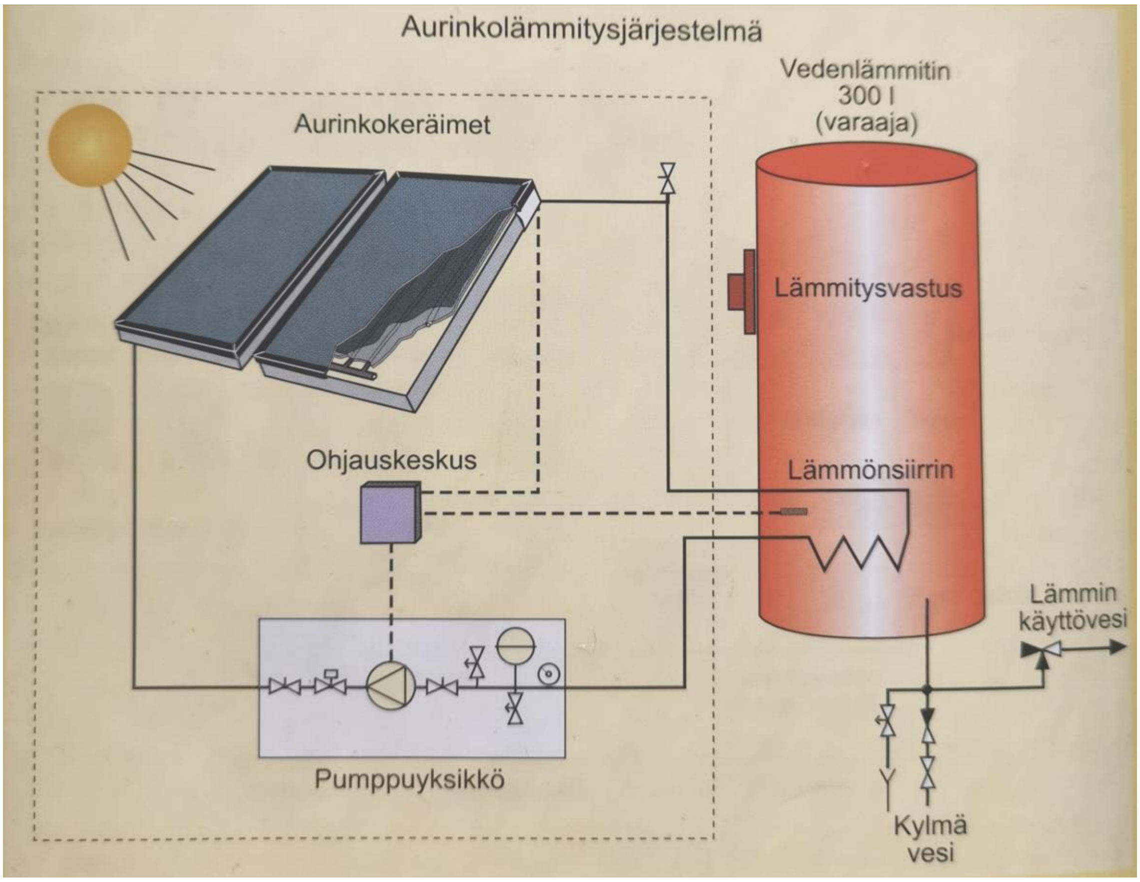

Figure 6. Solar heating system (*Energia Suomessa*, p. 268)

The solar heating system consists of two main elements: inside block of the sun collectors and inside block of the heating element. The heat collected by the collectors goes to the tank, heats the water and warm water goes to the customer.

Firstly, there are different types of collectors:

1. Flat-plate solar collector looks like a shallow rectangle box with a flat black plate behind a tempered glass cover. The collector absorbs the heat from sunlight by liquid circulated through the system. Special fins and copper are used to improve the effectiveness. Figure 7 below shows the structure of the flat-plate collector.

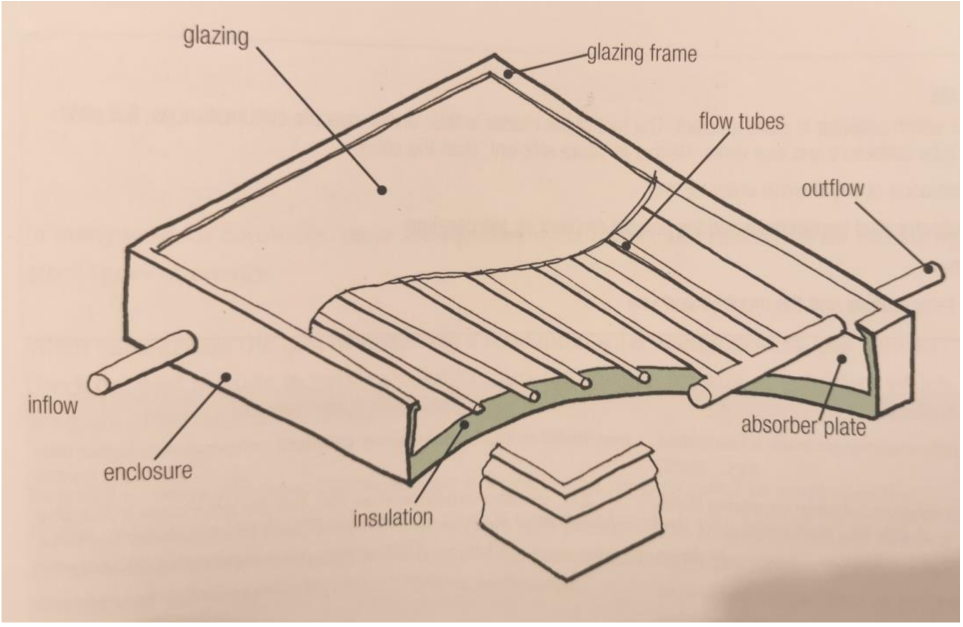

Figure 7. The structure of the flat-plate collector (Solar home design manual for cool climates, p. 137)

2. Heat-pipe evacuated tube solar collector is made of several individual glass tubes; inside of each tube is a heat pipe in a vacuum. These pipes transfer absorbed heat from the sunlight to a condenser through the top of each tube. Then the heat goes to and is collected in the manifold and transferred to the heat exchanger.

   In Figure 8 the cross-section of the evacuated glass tube is also presented.

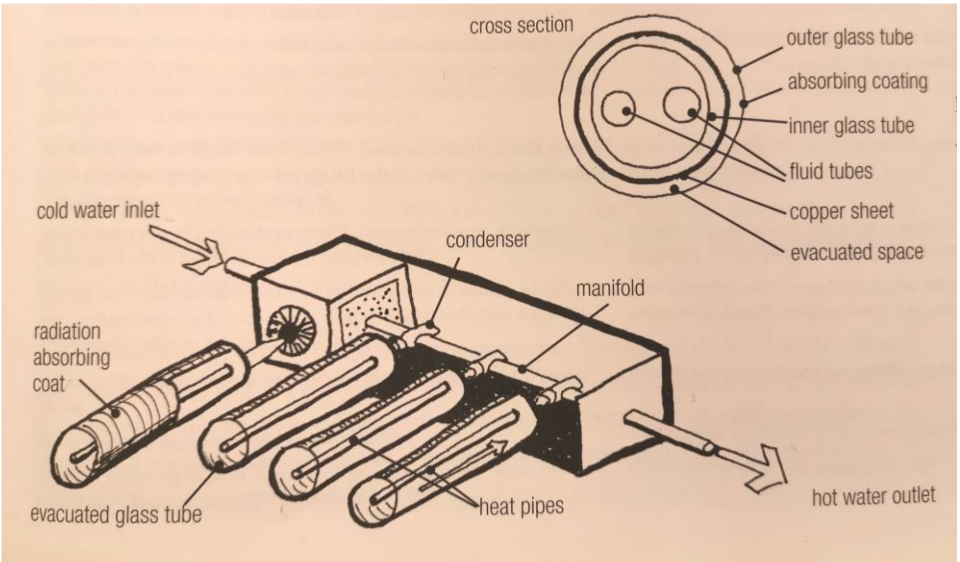

Figure 8. The structure of the heat-pipe evacuated tube solar collector (Solar home design manual for cool climates, p. 137)

The actual efficiency of the collectors can be calculated with the following formula:

$$\eta = \eta_0 - \frac{k * \Delta T}{E} \qquad (2)$$

In Formula (2) η_0 is a nominal effectiveness of the collector under normal conditions; k is a coefficient depending on the type of the collector; ΔT is a temperature difference between the collector and outside environment; E is a level of insolation (irradiation of the surface by solar radiation).

Vacuum collectors are considered as the most effective but the most expensive. The feature of the collector is an opportunity to collect solar radiation at any weather, its energy absorption rate is almost 98% but due to a reflective layer the rate is actually lower. But the effectiveness of the collectors in any case depends on the location area: the amount of available radiation and the temperature difference.

The main part of the system has two types: a closed loop and open loop. The only difference is that water itself is pumped through collectors whereas in the closed system the heat transfer liquid, usually a mixture of glycol and anti-freeze and water, is pumped from the collectors to the heat exchanger. For sure, in cold climates the closed system is safer, there is less chance of damage to the collector system due to freezing. The structure of the closed loop system is presented in the Figure 9 below:

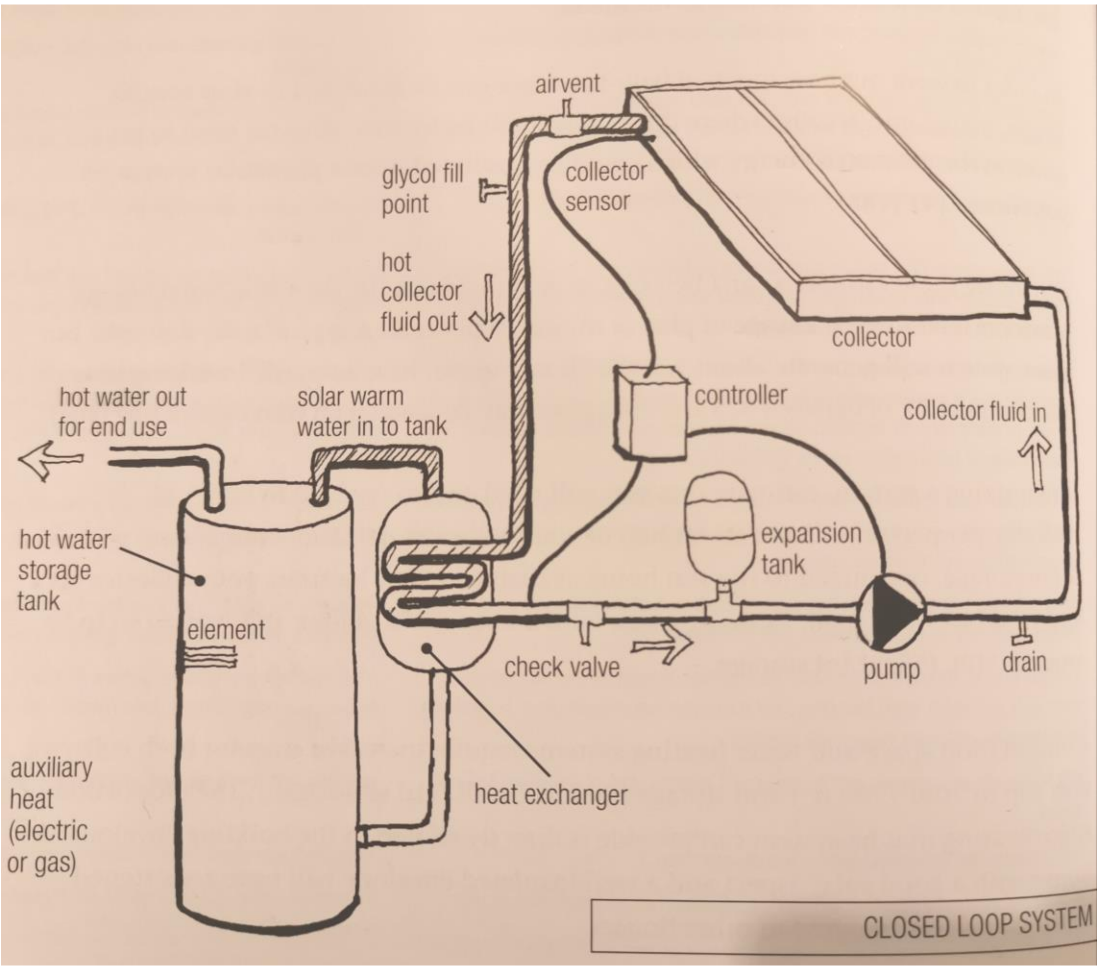

Figure 9. The structure of the closed loop system (Solar home design manual for cool climates, p. 140)

The structure of the open loop system is presented in Appendix 6 since the type of system is not so suitable for Finnish weather conditions as the closed loop system.

Some Finnish companies providing solar systems, were presented before. All of them also have solar heating systems besides PV panels. The following systems, provided by the Finnish company Ympäristöenergia, are presented: hot water systems, hybrid systems and systems without a charger. The last system will not be considered because it is used only in case of an already existing solar system as an addition.

1. Hot water systems are very suitable for domestic use. According to the catalogue, in Finnish conditions, the systems can produce about 90-100% of heating for water in summer, 50% in spring and autumn and 0-10% in mid-winter. The necessary dimensioning of the collector and the volume of the tank respectively is chosen according to the number of persons in a house. The picture of the system is presented in Figure 10 below. The full description can be found in Appendix 7. According to the description, the system is closed loop.

Figure 10. The structure of hot water system, closed loop type provided by the Ympäristöenergia company

2. Hybrid systems. The feature of the system is a possibility to store heat from various sources. In case of zero-energy buildings when only renewable energy systems are used, this kind system can be one of the most needed. Basically, the system has the common structure of the solar heating system, but it also includes special hybrid inverters and batteries to store energy for later use during the time without sun (winter and evenings). As disadvantages the system has higher costs (around 200-300 Euros if provided by the Ympäristöenergia company) and requires more space to be installed. Figure 11 shows the structure of the hybrid solar system.

Figure 11. The structure of the hybrid solar system provided by the Ympäristöenergia company

Comparing Figures 10 and 11, it can be noticed that the hybrid system needs almost twice more space for the hybrid accumulator. But the feature of collecting energy produced is very important in the Finnish weather conditions.

4.3 **Wind energy systems**

Electricity from wind energy is produced by wind turbines. The wind turbines are electric generators that convert kinetic wind energy into clean, free of emissions electrical power.

There are horizontal and vertical axis wind turbines. Horizontal axis means that the rotating axis of the turbine is horizontal; the turbine has blades like a propeller. Horizontal axis wind turbines are more common since one of their advantages is the ability to produce more electricity from a given amount of wind.

The turbine has the following elements: rotor, generator and surrounding structure.

1. The rotor includes a different number of blades for converting wind energy to low speed rotational energy. Its cost is approximately 20% of the turbine cost.
2. The generator includes the electrical generator (device that converts mechanical energy into electrical power), the control electronics, and a gearbox for a transmission function (for speed or moment changing) to convert the low-speed incoming rotation to high-speed rotation suitable for electricity generation. Its cost is approximately 45% of the turbine cost.
3. The surrounding structure mostly includes the tower, foundation and yaw system of the turbine. Its cost is approximately 25% of the turbine cost.

Figure 12 shows the full structure of the wind turbine. As seen, all generator elements are housed by the nacelle.

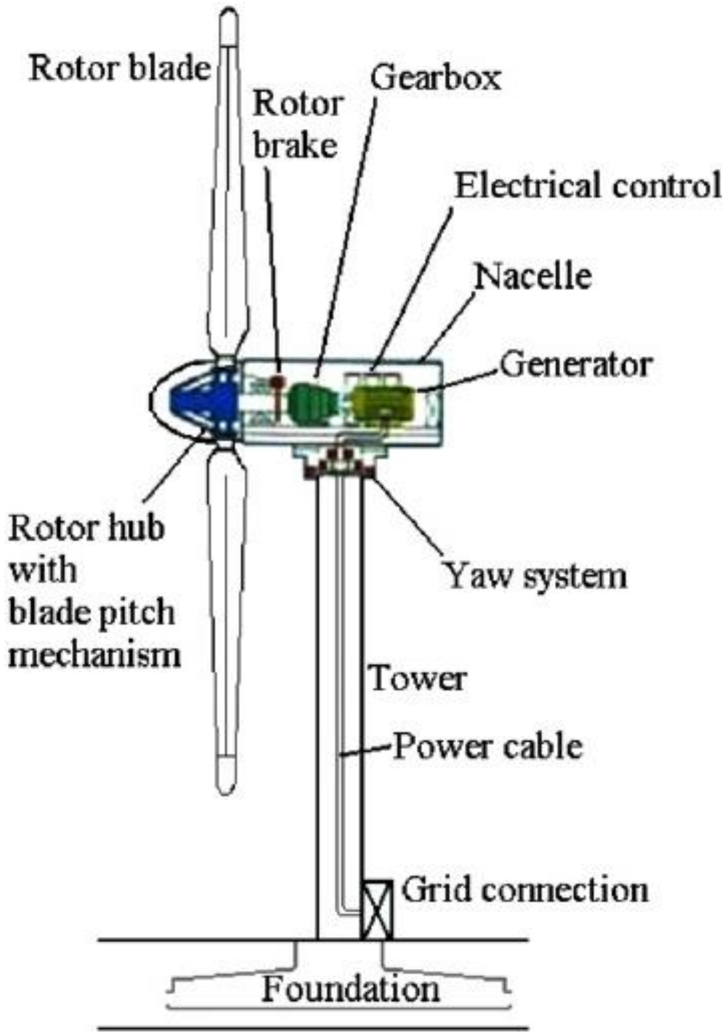

Figure 12. The structure of the horizontal axis wind turbine (Structural monitoring for a wind turbine system: A review of damage detection method, Research Gate)

The power of a wind turbine is proportional to the square of the diameter of the rotor blades and to the cube of the wind speed. (Eco-House Manual) This is presented in the formula below:

$$P = C * D^2 * A * V^3 \qquad (3)$$

In the Formula (3) P is a power of a wind turbine, C is a capacity factor, D is air density, A is an area swept by blades and V is wind speed. So, all these mentioned factors should be considered when choosing a suitable wind turbine.

To choose the best wind turbine is quite hard because of a wide variety of different turbines in the Finnish and international market. The turbines can be even found on Amazon or Ebay websites.

The following companies provide wind energy turbines in Finland: Vestas, Nordex Acciona, Siemens Gamesa. But all the turbines are for big projects; there is no information about small wind turbines for households. The outcome is that the practice of installation of personal wind turbines is not very popular; usually houses are connected to the grid system with electricity supply (can be produced of wind and PV power) at least at a local level. The fact will be checked in the next chapter where the examples of ZEBs will be considered.

As additional information, necessary generating capacity of the wind turbine should be chosen. Usually a home wind turbine with a 5 kW generating capacity meets all its energy requirements. The turbine of this capacity has a diameter of 4-5.5 m and should be placed in a place where strong winds often pass through. In case of Finland only sea shoes can be suitable to use this kind of turbine since there are no mountains in the country. However, the turbine is considered the most effective in terms of price to energy produced ratio. (Wind energy turbines report, Earthava LLC)

4.4 Ground heat energy systems

Ground source heat or geothermal energy is heat energy within the earth. It can be used for space heating (or cooling), district heating, etc. Depending on the depth of the system, energy can be taken within planet earth or solar energy saved by the ground (it is called “shallow geothermal” or “ground source heat”) or heat energy that reached the earth’s surface from deep within. In the paragraph the heat extracted from the ground will be considered. (Geological Survey, Ireland)

A ground heat pump (GSHP) circulates a mixture of water and antifreeze around loop of pipe, called a ground loop, which is buried in the adjacent ground. The length of the ground loop depends on the size of a house and an amount of needed heat. (Save energy at home, Energy saving trust) Then the heat is distributed in the house by the distribution system. Usually the ground loop is placed a meter below the ground level. The structure of the GSHP is presented below in Figure 13:

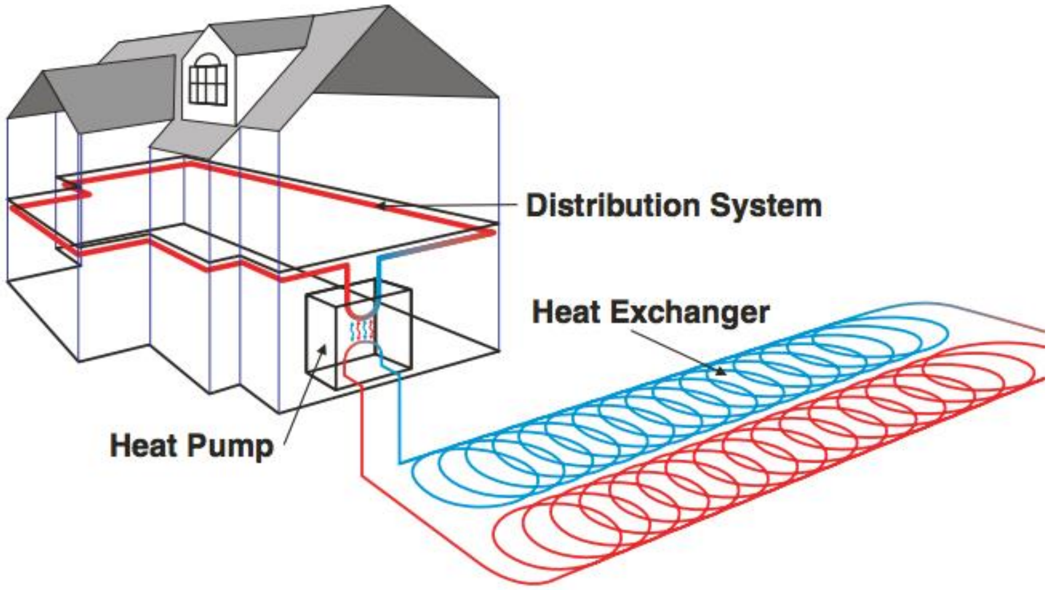

Figure 13. The structure of the ground source heat pump (Save energy at home, Energy saving trust)

The pumps have a very important feature: they require only minimal maintenance. They cost more than solar heating systems on average but work much longer (around 20 years) and are more sustainable during the whole year.

Ground heat energy systems are quite popular in the Finnish market, and there are a bunch of Finnish companies providing a wide variety of the systems. Ground heat pumps should be provided by the Finnish companies due to the weather conditions and, fortunately, there are such companies.

For instance, the company Lämpöässä has already been working for 30 years. It suggests compact and silent heat pump units with a huge storage tank, the minimum volume is 230 L, the maximum volume is 430 L. In addition, the company provides control screens managed remotely, which make the use of the system much easier.

Suggested ground heat systems are divided into four groups: vsi, vmi, t- and e- models. Vsi and vmi systems are suitable for houses with the area of 80-400 m^2. According to house owners' own needs, everyone can choose the best system based on the following criteria: sound power level, power supply, weight, dimensions, etc. All the suggested systems have the A+++ energy efficiency class.

Besides the Lämpöässä company, one of the most known is Oilon company, which also provides different energy systems including ground heat pumps. The company suggests pumps for private, terraced houses and block of flats no matter new or renovated ones.

Suggested pumps can be installed in houses with the area of up to 600 m^2, so the range is bigger than in the Lämpöässä company. For sure, the ground pumps can be installed for all regions of Finland even for the Northern region. The catalogue is not presented clear but the contact information of all managers is attached.

To sum up, the use of ground heat pumps grows very rapidly. Figure 14 shows that the use of heat pumps has increased to 670,000 units by 2014. This sphere is developing, and the ground heat energy can be a basis for future development of ZEB.

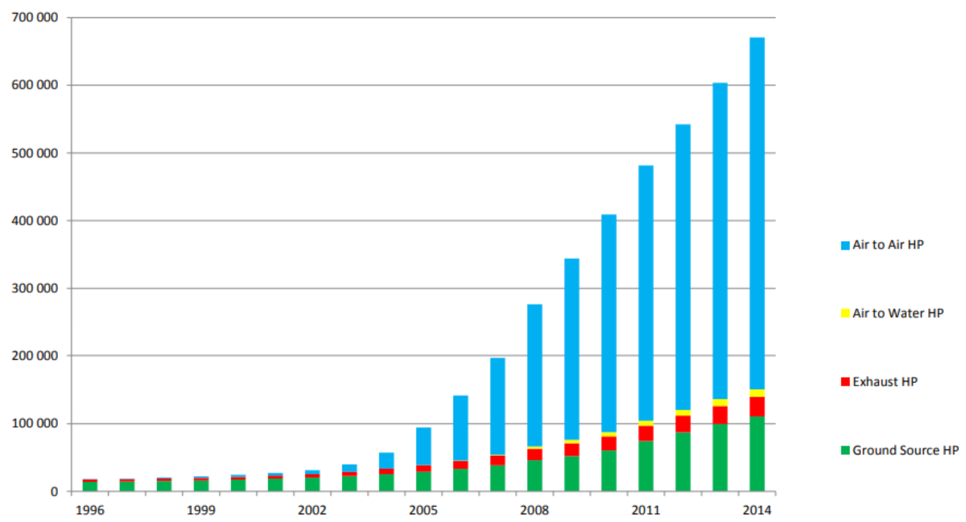

Figure 14. Growth of ground heat pumps in Finland by years (The Finnish heat pump Association)

In conclusion to this chapter, all considered renewable energy systems are used very actively. The Finnish market suggests many different solutions for all house requirements. If there is no suitable energy system, the Scandinavian market, especially Danish one, can suggest more options. It means that conditions for development of ZEB sphere are quite favorable and it is just a question of time how quickly zero-energy buildings will become commonplace for people.

5 EXAMPLES OF ZEB IN FINLAND AND DENMARK

There are quite many zero energy buildings worldwide. Some of them are used as pilots, some of them became public buildings. Pilots are very important to show people that it is already a real part of life, and the industry is ready to present and provide more buildings even for residential purposes. Nevertheless, approaches used for ZEB construction are different because of the legislations, weather conditions, etc. The comparison of a residential Finnish ZEB with one of the Scandinavian ZEB will give a better idea of possible construction design and used energy systems. For the comparison Denmark was chosen as a Scandinavian country with a wide range of buildings with low energy consumption including passive houses, green houses, nZEB, ZEB.

Beside of residential buildings, the consideration of single-family houses has its own meaning. According to the Danish Energy Agency, around 50% of all consumed energy in houses is used in single-family houses. Moreover, the consideration will help to check detailed renewable energy production and consumption with numbers and get the more accurate comparison of ZEB in Finland and Denmark.

5.1 ZEB in Finland

Finland is a country where ZEB are still not so popular because of the weather conditions. But first experiences have been obtained. One of the oldest nearly zero-energy buildings in Finland is a house in Pietasaari. It was built in 1993 and has weak characteristics comparing with newer houses. Generally, at the moment there are not too many nearly zero-energy buildings or passive houses. All existing buildings (nearly energy buildings in red dots and passive houses in blue dots) are presented in the picture below in Figure 15:

Figure 15. Location of the nearly zero-energy buildings and passive houses (VTT Company report)

Obviously, mainly they are located in the Southern or Central Finland since it is harder and harder to build sustainable houses based on renewable sources far away from the sun, which gives the energy for two types of systems.

In this paragraph residential zero-energy buildings in Kuopio and Järvenpää and a zero-energy single-family house in Hyvinkää will be considered.

The first considered residential zero energy building is located in Kuopio. It is shown in Figure 16.

Figure 16. Zero-energy building in Kuopio, Finland (VTT, Finland)

This building is an apartment house with the area of 2124 m^2. Its design is quite like most Finnish block of flats. According to the report of VTT Company, the levels of energy demand and production are collected and presented in Table 1 below:

Table 1. Comparing of energy demand and production by the residential zero-energy building in Kuopio, Finland (VTT, Finland)

Energy demand	**Value in kWh/m^2**	**Energy production by renewable sources**	**Value in kWh/m^2**
Space heating	12	PV panels	7
Water heating	13	Solar heating	16
Electricity for the facility	6	Ground heating	12
Total	**31**	**Total**	**35**

As seen in Table 1, the amount of energy production is greater than the amount of energy demand, but in Table 1 electricity demand by the residents is not considered. Obviously, this fact will affect the energy demand of the house and it can become greater than the amount of energy production in case if solar thermal system does not have accumulators to store the energy.

Another example of a residential zero energy building in Finland is a block of flats for elderly people in Järvenpää. This building has the similar design like the building considered above, which confirms the fact about strict design of residential buildings in Finland. Used renewable energy systems in the building are solar and geothermal heating systems, which cover heating demands of the building. PV panels cover its electricity demands. This building has the renewable energy contribution level of 100%.

The energy use of the building in a year is presented in Table 2 below:

Table 2. Energy demands and production by the residential building in Järvenpää, Finland (Concerted Action, Energy Performance of Buildings, report)

Heating	12 kWh/m^2
Hot water	25 kWh/m^2
Cooling	0 kWh/m^2
Ventilation	3 kWh/m^2
Outdoor electricity	4 kWh/m^2
Lighting and electrical appliances	Unknown
Total	**44 kWh/m^2**

This example is suitable for comparing needed heating and hot water for a residential building in Finland and Denmark.

As an example of a Finnish single-family house, a villa ISOVER located in Hyvinkää was chosen. The building is shown in Figure 17.

Figure 17. Villa ISOVER in Hyvinkää, Finland (Suomen Asuntomessut)

The villa ISOVER is a two-storey single-family house with an area of 241.5 m^2 excluding 21 m^2 of storage space. The building was designed based on an architectural competition for zero-energy buildings organised by the ISOVER company in cooperation with the architectural association SAFA and the VTT company in 2013.

The building has the Isover insulation with the thicknesses of 700 mm in the roof and 400 mm in the floor. The vacuum insulation Isover Vacupad is used for the walls. The windows of the building are triple-glazed. As a zero-energy building it has renewable energy systems such as the ground source heat pump, solar thermal system, photovoltaic system. Additionally, the building has a capability to save energy for further use. The ground heat pump is the main source of heating for the building. Together with the solar thermal system they cover all heating needs of the house. Also, the electricity demands are covered by PV system, which has three inverters, each rated for 3 kW power. It locates at the area of 80 m^2 on the southern façade of the building's roof; the angle of the roof is 15-30 degrees. The big area for the PV system helps to produce necessary amount of electricity even in the Finnish weather conditions, where number of sunny days is quite small.

All energy demands of the house in a year are presented in Table 3 below:

Table 3. Energy demands and production by the single-family house in Hyvinkää, Finland (Concerted Action, Energy Performance of Buildings, report)

Heating	11.3 kWh/m^2
Hot water	4.6 kWh/m^2
Cooling	0.2 kWh/m^2
Ventilation	4.8 kWh/m^2
Lighting	4.0 kWh/m^2
Electrical appliances (including outdoor lightning and car heating)	13.2 kWh/m^2
Total	**40.4 kWh/m^2**

It is also mentioned that the renewable energy contribution ratio is 100%, so that the whole energy needed for the house is covered by the renewable energy systems.

5.2 ZEB in Denmark

Denmark is one of the countries, which in a long term wants to achieve a status of a fossil-fuel-free country by 2050. The country began to develop and is developing the sphere of ZEB quite rapidly by new trainings and research in the sphere. The "strategic research centre for zero-energy buildings" was established in 2009 through the collaboration between two Danish Universities: University of Aalborg and Danish Technical University. The purpose was to develop a basis for the ZEB concept, especially for the private sector. (Zero-energy buildings, an overview of terminologies and policies in leadership world regions, 2015)

The first ZEB project in Denmark was developed in the 1970s. Since that, a bunch of “active houses” as demonstration units have been built. The first public certified as a green house was Green Lighthouse (Figure 18) in Copenhagen built in 2009 in the frame of the partner project between the Universities of Copenhagen, City of Copenhagen, The Danish Building and Property Agency and two companies VELUX and VELFAC which provide windows for the entire buildings. The concept was to create a building, which is CO_2 neutral and can operate with its own energy production. The total area of the building is 950 m^2. The Green Lighthouse became a part of the Faculty of Science at the University. It is used as a place where students can get any advice for their studies and conduct research. (Danish plans towards Nearly Zero Energy Buildings)

Figure 18. The Green Lighthouse in Copenhagen (Christensen & Co Architects office)

First of all, the Lighthouse is built with the shape, which is most suitable for collecting the sunlight since the energy concept of the building is to use a combination of PV panels and solar heating/cooling with a seasonal storage. So, the architectural design helps to reduce the energy consumption by 70%. The angle of the roof is inclined to the South and the round shape of the building helps to collect the sunlight during the whole course of the sun. In addition, geothermal heat pump and special LED lighting are also used. The heat pump helps to complete the full heating of the building with exception of wintertime; then urban district heating is added to cover all heat needs. Power and lighting are only produced by the PV system with the area of 76 m^2. Energy performance of the building is presented in Table 4 below:

Table 4. Comparing of energy demand and production by the Green Lighthouse building in Copenhagen, Denmark (Build up, The European portal for energy efficiency in buildings)

Energy demand	**Value in kWh/m^2**	**Energy production by renewable sources**	**Value in kWh/m^2**
Space heating	14	PV panels	20
Water heating	4	Solar heating + ground heating	7
Lighting, ventilation	10		
Total	**28**	**Total**	**27**

As seen in Table 4, energy demand of the house is almost equal to energy production by renewable energy systems. When the urban network is used, it produced 3 kWh/m^2; this amount fully covers energy demand of the building.

Another considered residential building to compare the needed heating and hot water is Sems Have house in Roskilde, Denmark. The building is shown in Figure 19.

Figure 19. Sems Have house in Roskilde, Denmark (Concerted Action, Energy Performance of Buildings, report)

This is a dormitory/day-care centre with 30 low-energy apartments. This building has renewable energy systems included in the district heating system and the PV panels which cover 50% of all building's electricity demands. Energy demands of the building are presented in Table 5 below:

Table 5. Energy demands by the residential building in Roskilde, Denmark (Concerted Action, Energy Performance of Buildings, report)

Heating	4.3 kWh/m^2
Hot water	14.2 kWh/m^2
Cooling	0 kWh/m^2
Ventilation	5.9 kWh/m^2
Lighting and electricity appliances	Unknown
Total	**23.4 kWh/m^2**

This building is not fully zero energy one, but it gives a ground to compare heating and hot water demands in Finnish and Danish residential buildings.

As an example of a single-family house in Denmark, a simple one-and-a-half-storey house located in Lystrup, a suburb of the Aarhus city, was chosen. It is shown in Figure 20. The building is already occupied by a family with 3 children.

Figure 20. A single-family house in Lystrup, Denmark (Denmark's zero-energy homes, Home For Life)

Its design includes big windows in all four walls and one more additional skylight in the inclined roof which gives more sunlight inside the house. It helps to reduce artificial lighting demand by using more daylight. In addition, the skylight is used for bringing more fresh air into the house. The building has the insulation made of polyurethane strengthened with thin glass threads. Also, the insulation is added to the windows' frames.

The solar thermal system is used for heating. The area of each solar collector is 6.7 m^2. Flat-plate collectors were chosen as they convert 95% of the solar energy into heat and can catch even indirect sunlight. Also, heating goes through the windows and from the air-source heat pump into the house. The air-source heat pump cannot be very efficient when it is cold outside, but this system was designed to be capable to preheat the cold winter air before it reaches the heat pump. In all, solar collectors and the heat pump can produce about 8000 kWh of heat a year.

The solar panels are used for getting electricity. They are installed at the area of 50 m^2 and can generate about 5500 kWh a year. According to the building's report, this is 20% more electricity than the house needs. During the winter time, an electric pump kicks in.

The energy demands of the building in a year are presented in Table 6 below:

Table 6. Energy demands by the single-family house in Aarhus, Denmark (Denmark's zero-energy homes, Home For Life)

Hot water and heating	32 kWh/m^2
Lighting	15 kWh/m^2
Electricity (2 TVs, washing machine)	18 kWh/m^2
Total	**65 kWh/m^2**

In Table 6 ventilation system is not mentioned since the natural automatic system is used. It opens the windows to control airflow through the house when needed. Also, electricity demand is quite high because, as the homemaker says, they need to use the washing machine all the time. Hopefully, all necessary energy demands are covered by renewable energy systems which helps the owners to reduce their living costs. As a disadvantage, sometimes the family should install lower temperature not to exceed the heat production.

Comparing the presented residential buildings in Finland and Denmark, the Green Lighthouse is more energy independent than the building in Kuopio. There are some possible reasons for that:

1. Finnish weather conditions are harsher, so buildings in Finland require more energy for heating. In the tables space heating for Finnish building is lower than for Danish building, but heating needs of building's residents were not considered. In total, the Finnish building definitely requires more energy than the Danish one.
2. There are many possibilities for PV systems in Denmark due to more southern location. Also, the design of the Danish building plays one of the most important roles; for example, the roof design gives more area for PV installation. These facts can be noted from comparing the appropriate table parts concerning energy production by PV panels: 7 kWh/m^2 for the Finnish building vs. 20 kWh/m^2 for the Danish building.

To confirm the fact about required energy for residential buildings, comparison of other residential buildings in Finland and Denmark were provided. The comparing table of energy demands of the buildings is presented below:

Table 7. Comparing table of the energy demands for residential buildings in Finland and Denmark

	Finland	**Denmark**
Heating	12 kWh/m^2	4.3 kWh/m^2
Hot water	25 kWh/m^2	14.2 kWh/m^2
Cooling	0 kWh/m^2	0 kWh/m^2
Ventilation	3 kWh/m^2	5.9 kWh/m^2
Outdoor electricity	4 kWh/m^2	Unknown
Lighting and electrical appliances	Unknown	Unknown
Total	**44 kWh/m^2**	**23.4 kWh/m^2**

According to Table 7, Finnish residential zero-energy building requires almost 2 times more energy than the Danish one. An indicator of heating demand is 3 times greater, as well as an indicator of hot water demand is 2 times greater for the Finnish building. The difference is that the Finnish building has renewable energy systems to cover all energy demands (excluding demands of building's occupants), while Danish building covers only a half of energy demands by own renewable energy systems.

Comparing the Finnish and Danish single-family houses, it can be noted that both are independent from district systems. All needed energy demands are covered by the own renewable energy systems. So, energy demands are considered as equal to the renewable energy production. To compare the energy demands of the Finnish and Danish single-family houses, the following Figures 21 and 22 were created:

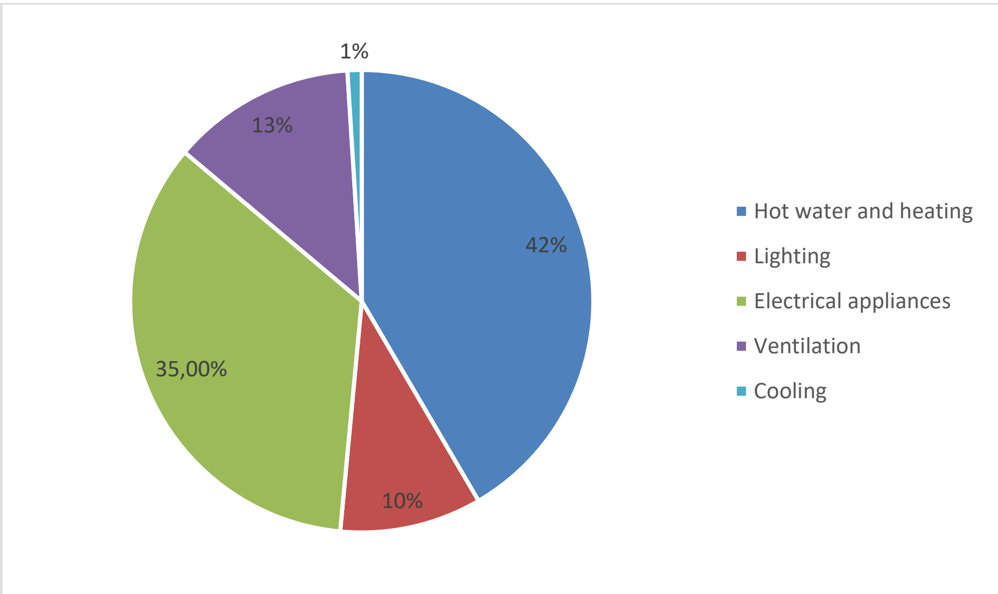

Figure 21. Distribution of energy demands by the single-family house in Finland

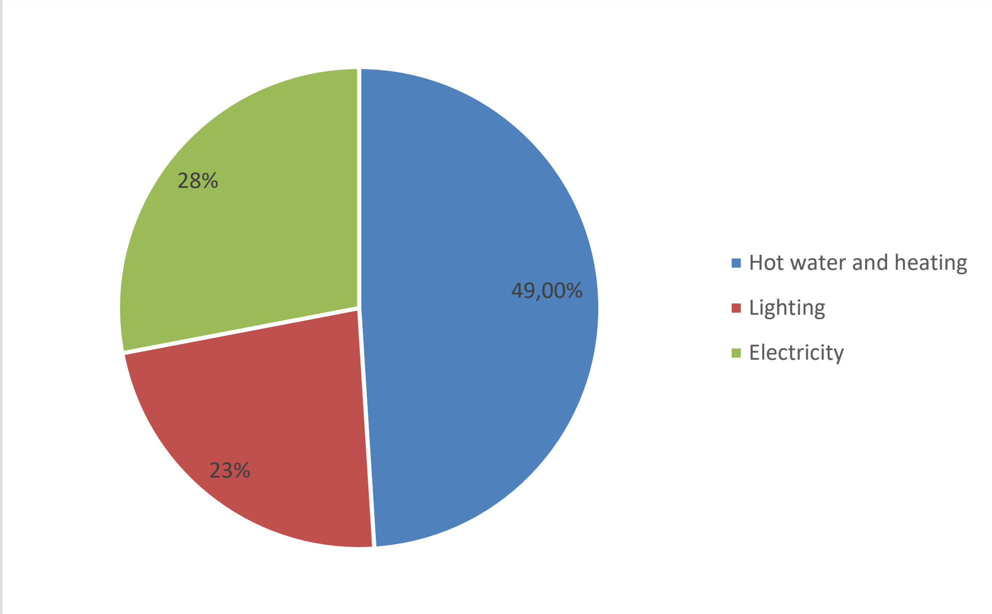

Figure 22. Distribution of energy demands by the single-family house in Denmark

Comparing the Figures 21 and 22, it is seen that the demand of hot water and heating in the Danish building is greater than in the Finnish one. The possible reason for that is used materials, including insulation. Even using big windows in each wall, the percentage of needed lighting in the Danish building is twice greater than in the Finnish one. But all obtained energy values mostly depend on houses' occupants. The main outcome is that the both Finnish and Danish single-family houses can cover all needed energy without a grid connection, especially if the used systems are adapted to the owners' needs and the weather conditions (for example, the solar thermal system in the Danish house, which can preheat the cold air before it reaches the heat pump).

6 CONCLUSION

ZEB concept in Finland is not fully developed because at the moment Finnish legislation does not include information about ZEB and their implementation. But after consideration of background for ZEB development (renewable energy systems suitable for ZEB), it can be confirmed that the sphere will be developed further.

The Finnish market suggests different renewable energy systems for all demands. Some of them are more popular, but, in fact, the consumption of the renewable energy by households is increasing, which means more and more reduction of energy consumption.

Comparing Finnish and Danish approaches to ZEB, Danish ZEB are different. They include more varieties of renewable energy systems from the combination of systems to unusual building designs to collect more energy from the sun. It is explained by a longer history of ZEBs in Denmark and legislations related to them. Danish weather conditions are more favorable for ZEB operation; for example, during the whole year Danish weather is very windy and this is already one more or less meaningful energy source. Also, Denmark is not such a cold country, even during winter time, the outside temperature is around 0°C. It means warmer ground and less snow that helps to collect more sunlight as solar panels can also operate when the sky is cloudy. Nevertheless, the Danish approach can be applied in Finland in case of legislation creation but with own references to the Building Codes and the local weather conditions. In the end, the Finnish industry of ZEBs is developing, and people understand and accept these changes as a better possibility for the future.

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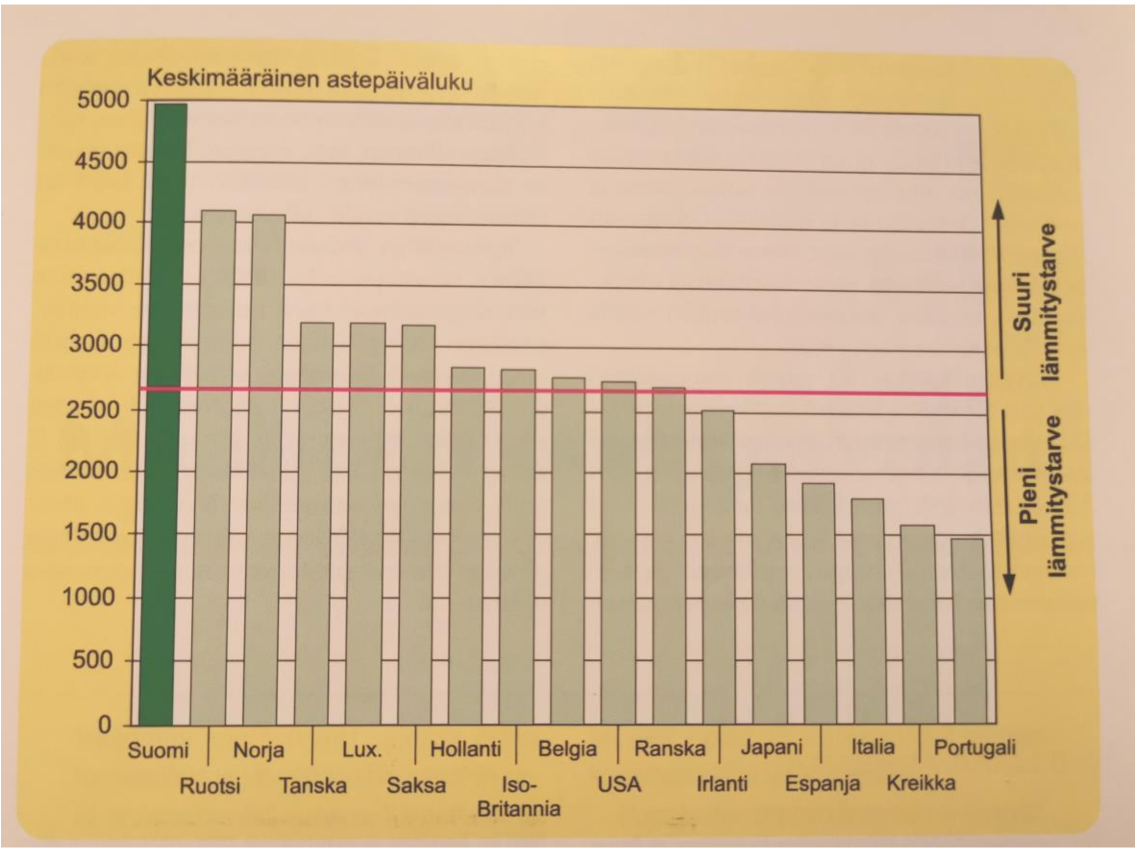
Appendix 1

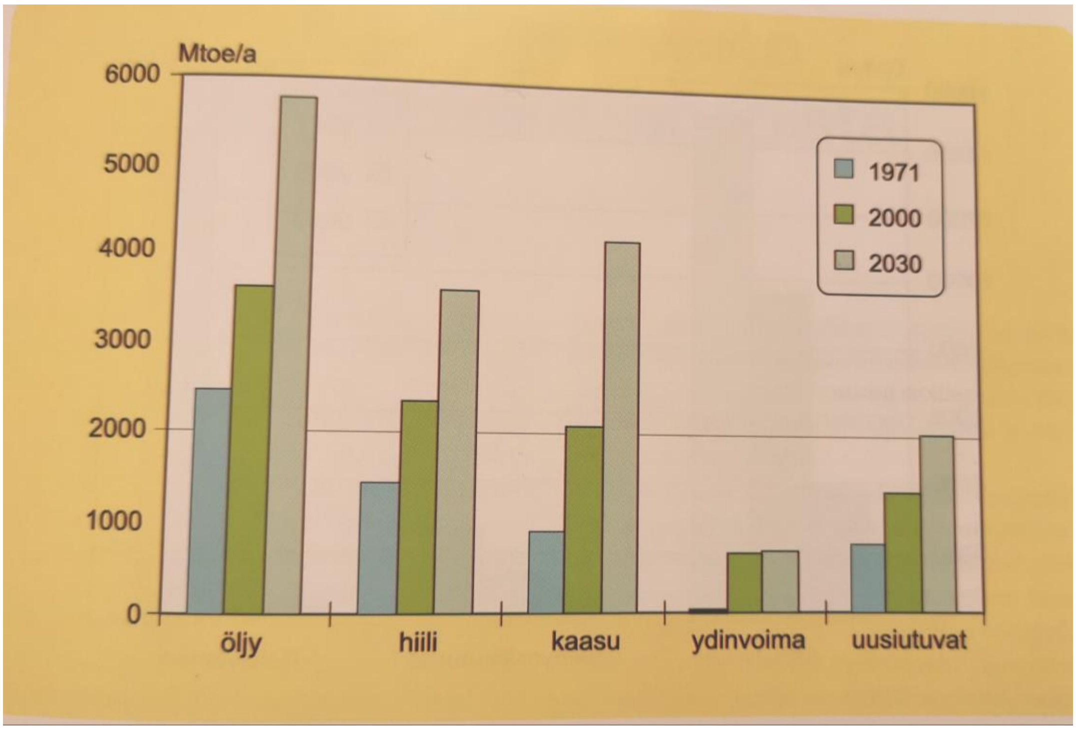
HEATING DEMAND BY EUROPEAN COUNTRIES



Source: Energia Suomessa, p.89

Appendix 2

CONSUMPTION OF ENERGY SOURCES IN FINLAND



Source: Energia Suomessa, p. 93

Appendix 3

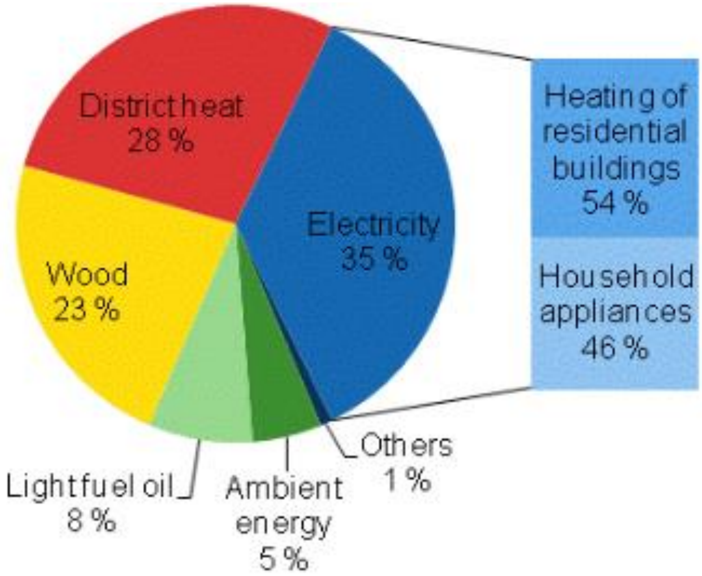
ENERGY CONSUMPTION IN FINNISH HOUSEHOLDS BY ENERGY SOURCES IN 2017

Data	Energy source									
	Wood	Peat	Coal	Heavy fuel oil	Light fuel oil	Natural gas [1]	Ambient energy [2]	District heat	Electricity [3]	Total
Housing, total	14,812	41	2	32	3,569	392	5,815	19,310	22,513	66,4
Heating of spaces	12,539	27	2	22	2,922	239	4,989	13,882	10,727	45,3
Residential buildings proper, total	11,171	27	2	22	2,880	238	4,814	13,879	9,843	42,8
- Detached houses	11,004	23	2	0	2,492	62	4,240	1,884	7,797	27,5
- Terraced houses	122	1	0	0	95	55	505	2,225	1,124	4,1
- Blocks of flats	45	3	0	22	293	121	69	9,770	922	11,2
Free-time residential buildings	1,368	0	0	0	42	1	175	3	884	2,4
Household appliances	..	..	..	..	..	92	..	..	8,034	8,1
- Lighting	..	..	..	..	..	..	..	..	1,633	1,6
- Cooking	..	..	..	..	..	92	..	..	581	6
- Other electrical equipment	..	..	..	..	..	..	..	..	5,820	5,8
Heating of saunas	1,835	..	..	..	..	..	..	..	1,222	3,0
Heating of domestic water	438	14	0	10	647	61	826	5,428	2,530	9,9

Source: Statistics Finland
https://www.stat.fi/til/asen/2017/asen_2017_2018-11-22_tau_002_en.html

Appendix 4

ENERGY CONSUMPTION IN FINNISH HOUSEHOLDS BY ENERGY SOURCES IN 2011



Source: Statistics Finland https://www.stat.fi/til/asen/2011/asen_2011_2012-11-16_kuv_001_en.html

Appendix 5

EXAMPLE OF A PV PACKAGE FROM THE YMPÄRISTÖENERGIA COMPANY

Photovoltaic Package 1.06 kWp, 1-phase

Product no.: 30000

In Stock (Stock: 1)

€ 2,780.00

VAT included (24%). Terms & Conditions

Maksa kiinteissä kuukausierissä.

Klarna. Lue lisää

1 Add to Basket

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Recommend | Ask

Description

All photovoltaic packages include solar panels, ceiling mount rails and ceiling mount kits, cables and connectors, an inverter with high efficiency and performance, and the required safety equipment and accessories. The delivery contents are described in detail below.

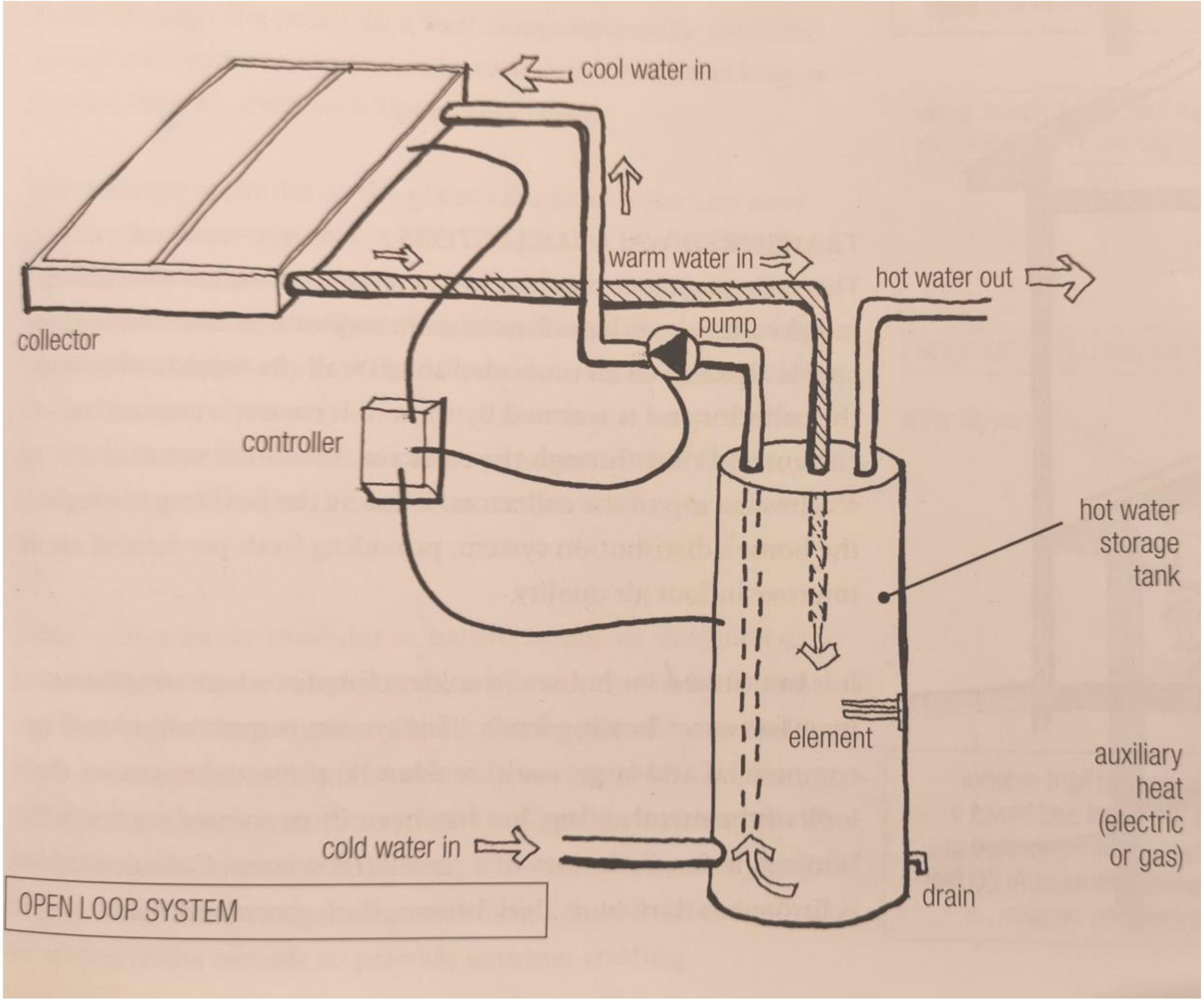
1.06 kWp GEF Photovoltaic Package 1-Phase (2.6 Euro / Wp)

4 PCS GEF Multi-Crystal Panels 265 Wp
1 Fixing
System
(Ceiling) 1 Roof Mount Kits 2 Photovoltaic Cable 1 x 4 mm2, 20 m
1 quick connector Tyco PV4, male
1 pc quick connector Tyco PV4, female
1 pc ground cable mounting bracket
1 pc ac circuit breaker (safety switch)
1 piece aluminum conductor for grounding
1 piece ABB inverter UNO-2.0-I-OUTD-S 2000 W
Price incl.

Source: Ympäristöenergia company
https://www.energiakauppa.com/epages/energiakauppa.sf/fi_FI/?ObjectPath=/Shops/2014082005/Products/30001

Appendix 6

THE STRUCTURE OF THE OPEN LOOP SOLAR HEATING SYSTEM



Source: Solar home design manual for cool climates, p. 141

Appendix 7

EXAMPLE OF A SOLAR HEATING SYSTEM PACKAGE FROM THE YMPÄRISTÖENERGIA COMPANY

Wagner Solar solar heating system with 5 m^2 300 L hot water tank

Product no .: 11102

In Stock (Stock: 2)

price comparison ~~€ 3,890.00~~

€ 3,390.00

You Save 13%

VAT included (24%). Terms & Conditions

Maksa kiinteissä kuukausierissä.

Klarna. Lue lisää

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Recommend Ask

Description

Solar heating system with accumulator (5.2 m^2 gross / 4.8 m^2 net) incl.

2solar collector Wagner Euro L20 AR

aluminum rails and collectors for collectors

ceilingbrackets and bushing kit

15 m insulated (20 mm) double heat transfer pipe DN16 and 4 pcs brackets

collector sensor surge protector SP1 junction box

10 L Heat transfer fluid DC20

pump and control unitFlowSolB BS / 4

?? 18 L expansion vessel, includes service valve, outlet hose ALS10 and wall bracket

connectors between collectors and pump

400 l enamelled hot water tank.

Source: Ympäristöenergia Company
https://www.energiakauppa.com/epages/energiakauppa.sf/fi_FI/?ObjectPath=/Shops/2014082005/Products/11113