TAMPERE UNIVERSITY
OF APPLIED SCIENCES

REVIEW OF HEATING SYSTEMS OF A SINGLE-FAMILY HOUSE

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ABSTRACT

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KATJA RÄSÄNEN:
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One of the most pressing challenges the world is facing is the growth of our population. With the growing trends of urbanisation comes a growing stress on the environment and the resources available, such as water, food and energy. Energy and electricity consumption has increased drastically since the 1970's fossil fuels contributing to a majority of production causing carbon dioxide and greenhouse gas emissions. Our dependence on said finite fuels is unsustainable as they will eventually be depleted. Both international and national efforts have been taken to mitigate the effect the actions of humankind have on our planet.

Electricity and heat production contributed to approximately 60 percent of global greenhouse gas emissions in 2016 and were the largest contributor of CO_2 emissions globally. Choosing heating methods, which use renewable energy sources as a fuel source reduce the demand for fossil fuels and furthermore reduce the emissions caused by the housing sector.

The purpose of this thesis was to study various sources of energy and evaluate the potential they have as a fuel source for various heating methods of single-family houses. The potential of the studied heating systems was evaluated using a case property built in 1958. The comparison of said systems was done considering the cost, CO_2 emissions and use of the system over a period of 20 years. Also, whether the primary heating system, oil heating, of the house should be changed was considered and the option of installing a complementary heating system was reviewed. As a conclusion, the pros and cons of all heating systems were gathered together and an alternative system was chosen.

From the point of view of cost, the combination of oil heating and an air-water heat pump system was the most inexpensive option. The highest cost of both fuel and cost of the system over 20 years was caused by the oil heating system and the combination of oil and solar heating systems. The lowest CO_2 emissions were created by the pellet heating system and the highest emissions were caused by the existing oil heating system. From the point of view of the consumer, geothermal heating was considered the easiest to use.

Key words: single-family house, heating system, renewable energy, emissions control

CONTENTS

ABBREVIATIONS AND TERMS

CHP	Combined heat and power- Describes a system, in which steam is generated as a by-product in heat energy production
PV system	Photovoltaic system- Photovoltaic technology converts sunlight into electrical energy
CSP system	Concentrating solar power system- Technology converts sunlight into heat
COP	Coefficient of performance- A value, which indicates the performance efficiency of a heat pump
SCOP	Seasonal coefficient of performance- A value similar to COP, however SCOP takes into consideration seasonal temperature changes
EER and SEER	Energy efficiency ratio- A value, which measures the efficiency of a cooling or heating appliance (in this report an air heat pump). The value is indicated as the ratio of output per hour to the energy consumed, expressed in British thermal units (BTUs) per watts (W). The higher the EER value, the more energy efficient the unit is. SEER indicates the seasonal energy efficiency ratio of an appliance. The SEER value indicates the energy efficiency of a (in this case) air heat pump accounting for seasonal changes, whereas the EER value is calculated using constant temperatures and seasonal temperature changes are not considered.
U-value	A measure of heat transmission through a building part, such as a window or wall: the lower the value, the better the insulating ability.

1 INTRODUCTION

One of the most severe problems the world is currently facing is the growth of our population. According to the United Nations, our population is estimated to reach 8.5 billion people by 2030. With this growing population and trends of urbanisation comes an increasing stress on the environment and the resources available, such as food, water and energy.

The demand for energy and electricity production has grown dramatically since the 1970's. The majority of the demand for said resources is produced using fossil fuels, such as oil, natural gas and coal. The sector of energy and electricity production by fossil fuels contributes to approximately 60 percent of greenhouse gas emissions and is the cause for the largest portion of global carbon dioxide emissions. Both international and national efforts have been taken to mitigate climate change and decrease our unsustainable dependence on these finite fuels.

The aim of this thesis was two-fold. Firstly, various energy sources were studied and their potential as a source for heating systems for single-family houses was discussed. Secondly, the potential of the studied heating systems was evaluated using a case property. The case property chosen for this study was a house built in 1958, which is installed with an oil heating system. As per wishes of the owner of the property, a comparison of various primary heating systems was done considering the limitations of the property and as a result, an alternative heating system was chosen.

In chapter 2, the global energy challenge and emission control efforts are discussed. The consumption of energy and electricity in Finland is also introduced. International and national legislation is reviewed.

In chapter 3, various sources of energy are discussed. The potential of geothermal energy, solar power, wood fuels, ambient air used by various air heat pumps and light fuel oil is evaluated as a source of energy for a heating system of a single-family house. The heating systems discussed are geothermal heat pumps, PV and CSP systems, various air heat pumps, pellet heating and oil heating.

In chapter 4, the case property is introduced. Basic information on the property, such as the structure of the house, the heating method and the consumption of energy, electricity and water are presented. A timeframe of 2015 and 2017 is used for the annual data of energy, electricity and water consumption. In addition, the CO_2 emissions from 2015 to 2017 caused by the current fuels in use are calculated.

In the discussion section a comparison of heating systems is done taking into consideration the limitations of the chosen case property. The evaluation and comparison of said systems is done taking into consideration the cost, CO_2 emissions and use of the system over a 20-year period. Also, whether the primary heating system of the house, oil heating, should be changed is considered and the option of installing a complementary heating system is reviewed. As a conclusion, the pros and cons of all heating systems are gathered together and an alternative system for oil heating is discussed.

2 LITERATURE REVIEW

2.1 Energy Challenge

The population of the world is increasing at a rapid rate. According to the United Nations, the population is estimated to reach 8.5 billion by 2030 and a further 9.7 billion in 2050. We will hit a population of 10 billion only six years later in 2056. With this increase in population comes an increased stress on our environment. (Department of Economic and Social Affairs Population Division, 2015.) In 2016, an estimated 54.5 per cent of the world's population lived in cities and the amount is growing. There were 512 cities with at least 1 million residents globally (in 2016) and the number of these big cities is estimated to increase to 662 by 2030. The trend of megacities, with inhabitants of more than 10 million people, is also projected to increase to 41 from the current 31 by 2030. This overwhelming growth in trends of urbanisation leads to a stress on available resources, such as water, food and energy. (United Nations, The World's Cities in 2016)

As the world's population grows, so does the global energy demand. According to a report published by the International Energy Agency regarding our world's energy statistics, the total consumption of fuels has doubled from the year 1973 to 2014. Due to the increase in demand, naturally a growth in supply can also be seen; the total primary energy supply has also doubled during the same time. The main contributors to said energy supply of 13 699 Mtoe were oil, coal and natural gas, covering over 80 per cent of total energy production. Similarly, a great growth in electricity generation can be seen from the report; from the years 1973 to 2014 there has been an increase of almost 300 percent. Of the 23 816 TWh of electricity produced world-wide in 2014, coal, oil and natural gas were again the dominant fuels used, accounting to over 60 per cent of the world electricity generation. This dependence on these finite fuels is unsustainable, as they will eventually be depleted. (Energy Information Administration, Key World Energy Statistics, 2017)

The sector of energy and electricity production by fossil fuels contributes to approximately 60 per cent of the greenhouse gas emissions responsible for climate change. Clean energy technologies are constantly under development in many countries and a transition from fossil fuels to more sustainable options can be seen. However, due to carbon intensive energy technologies being heavily subsidised, it is difficult for cleaner forms of energy to supply a larger portion of the demand. (United Nations Foundation)

2.2 CO_2 and Climate Change

The use of fossil fuels has taken a toll on our environment. Since 1900 carbon dioxide emissions have increased tremendously and a rapid increase in emissions can be seen starting in the 1970s. (United States Environmental Protection Agency, 2017) Between the year 1973 and 2014 carbon dioxide emissions have more than doubled from 15 458 Mt to 32 381 Mt of CO_2. (Energy Information Administration, Key World Energy Statistics, 2017) Fossil fuel combustion and industrial processes contribute to approximately 80 per cent of the total greenhouse gas emissions since the 1970s. In 2010, the largest contributors to global CO_2 emissions was caused by the production of electricity and heat, accounting for 25 per cent. Buildings (e.g. single-family houses), including on-site energy generation and burning fuels for heat, contributed to a further 6 per cent of the emissions causing total electricity and heat production to account for over 30 per cent of total global emissions. (United States Environmental Protection Agency, 2017)

A severe consequence greenhouse gas emissions have on the environment is an increase of the planets temperature. Over time, the temperature on Earth has varied naturally due to, for example subtle shifts in its orbit or energy changes of the sun, however a more serious and direct impact has been caused by human activity. According to studies performed by the Goddard Institute for Space Studies, between 1906 and 2005 the global average surface temperature rose 0.6-0.9 degrees Celsius. In addition to the increase in temperature, the rate the temperature is increasing is alarming. In the past 50 years, the rate has nearly doubled. (Riebeek, Holli. 2010)

An increase of on average approximately one degree Celsius might not sound like a lot, however scientists are worried that an increase of only two degrees Celsius can have drastic effects on our planet. By studying our environment, scientists have been able to prove that the global average temperature stays stable for lengthy periods at a time and thus a seemingly insignificant change can cause enormous changes in the environment. According to the Intergovernmental Panel on Climate Change, the effects of climate change vary in individual regions, however effects such as more frequent wildfires, longer periods of drought, stronger tropical storms and rising sea levels can be found in the entire global environment. (Earth Science Communications Team, NASA, 2018)

2.2.1 Calculating CO_2 Emissions of Properties

Motiva has developed a guidebook for calculating the CO_2 emissions of various properties, such as single-family houses. In addition, the CO_2 emission data can be used to estimate the affect existing or planned energy saving measures have on the total CO_2 emissions caused by a property. The guide presents emission factors for electricity and various fuel types, which are used to estimate CO_2 emissions caused by the use of energy. This data can be helpful when, for example, choosing a new heating method for a property. The emission factors in the guide take into account the CO_2 emissions of the fuel type in question. The effect all other greenhouse gas emissions have on the environment, such as methane and nitrous oxide are not taken into consideration. (Hippinen, Ilkka and Suomi, Ulla. 2012)

Emission factors of various fuel types are shown in TABLE 1 below. The CO_2 emissions caused by each fuel type is calculated by multiplying the amount of fuel used with the emission factor. When estimating the effect energy saving measures have on a property, the annual efficiency of the heat production method needs to be taken into consideration (e.g. the efficiency of a boiler).

TABLE 1. Emission factors of various fuel types.

FUEL TYPE	**EMISSION FACTOR** $\mathbf{kgCO_2/MWh}$
Heavy fuel oil	284
Light fuel oil	261
Natural gas	198
Liquid gas	234
Peat	381
Coal	341
Coke	389
Wood based fuels	0

(ibid)

The emission factor for electricity is updated annually by Statistics Finland (Tilastokeskus). The factor is calculated using a five-year floating average. In 2017, the emission factor for electricity was $181\ \mathrm{kgCO_2/MWh}$. (Motiva. CO2-päästökertoimet, 2017)

An example of calculating CO_2 emissions can be seen below.

A town hall in Eastern Finland was heated using a light fuel oil boiler. In 2011, 76,4 tonnes of light fuel oil was used, equivalent to 900 MWh/a. The annual efficiency of the boiler was 80 percent. Plans were to change the light fuel boiler to a pellet burning boiler and an estimation of the CO_2 emission savings to be achieved by the fuel change were needed before planning could continue.

The total CO_2 emissions of the light fuel oil boiler were calculated my multiplying the amount of fuel consumed (in form of energy) with the emission factor:

Light fuel oil emission factor: $261\ \mathrm{kgCO_2/MWh}$

$$900\ \mathrm{MWh/a} \cdot 261\ \mathrm{kgCO_2/MWh} = 235\ \mathrm{tCO_2/a}$$

The total CO_2 emissions caused by heat generation were $235\ \mathrm{tCO_2/a}$.

The annual efficiency of the new pellet burning boiler was 85 percent. The $\mathrm{CO_2}$ emission savings were calculated with the following calculations:

Emission factor for light fuel oil: $261\ \mathrm{kgCO_2/MWh}$
Emission factor for pellets: $0\ \mathrm{kgCO_2/MWh}$
Net heat use, 80% annual efficiency: $900\ \mathrm{MWh/a} \cdot (80/100) = 750\ \mathrm{MWh/a}$
Heat production using pellets: $720\ \mathrm{MWh/a} \cdot (100/85) = 847\ \mathrm{MWh/a}$

Light fuel oil consumption decreases: $900\ \mathrm{MWh/a}$
Light fuel oil $\mathrm{CO_2}$ emissions decrease: $235\ \mathrm{tCO_2/a}$
$\mathrm{CO_2}$ emissions of the pellet burner:

$$847\ \mathrm{MWh/a} \cdot 0\ \mathrm{kgCO_2/MWh} = 0\ \mathrm{tCO_2/a}$$

$\mathrm{CO_2}$ emissions produced by heat production with pellets decrease by $235\ \mathrm{tCO_2/a}$. (Hippinen, Ilkka and Suomi, Ulla. 2012)

2.3 EU Regulations Concerning Climate Change Control

Many international efforts to mitigate the effects of climate change have been underway over the years. In 1992, the UN Framework Convention on Climate Change was adopted at the Rio Earth Summit. The aim of the treaty was to form a mutual understanding between all signing countries to work together to reduce the effect humankind has on the climate system. Although a treaty was signed, it was difficult for the world to find a common ground as to how the treaty was to be implemented in practice. Further steps were taken in 1997 when the Kyoto Protocol was introduced. This agreement committed countries to reduce greenhouse gas emissions by 5 to 7 percent. (United Nations Foundation)

A key step regarding climate change was taken with the Paris Agreement in December 2015. The aim of the agreement was to mitigate the effect humankind has on climate change by keeping the global temperature increase well below the beforementioned 2 degrees Celsius above the pre-industrial levels, an amount considered vital for human activities, such as food production. The agreement was opened for signature on Earth Day, 22nd of April 2016 and it became official in November 2016. As of May 2017, 147

Parties have ratified it. According to the United Nations Framework Convention and Climate Change (UNFCCC), in addition to keeping the global temperature at a stable level, the agreement aims to assist countries in adapting to the impacts of climate change. By developing a new technology framework and redirecting an appropriate financial flow towards climate resilient development and decreasing greenhouse gases, the goals of the agreement can be achieved. (United Nations, 2017.)

As mentioned in chapter 2.2, the production of heat and electricity are the largest contributors to global CO_2 emissions thus significantly contributing to climate change. In Finland, the heating of buildings, including single-family homes, which is the focus of this report, contributes to approximately a third of the final energy consumption and is thus a large emitter of said emissions. (Gynther, Lea. Energian loppukäyttö, 2017) Steps not only on an international, but also a national level have been taken to ensure energy and electricity production is done with an increasing amount of renewable energy sources to mitigate negative effect on the environment. This topic is studied further in the following chapters.

2.3.1 Energy Reviews in Finland

CO_2 and greenhouse gas emissions can be mitigated in several ways. As an example, a new law concerning energy certificates came into force in 2013 (Laki rakennuksen energiatodistuksesta 50/2013). The law aims to increase the energy efficiency and use of renewable energy in buildings. 50/2013, for example regulates the contents and requirements of energy certificates. It also regulates the monitoring of requirements and the consequences of violating said requirements. A major requirement of the law is that from 2013 all construction work subject to license must be documented. (Laki rakennuksen energiatodistuksesta 50/2013)

Energy certificates have been in use in Finland since 2008 in all new construction and since 2009 when purchasing or renting larger properties and new single-family homes. Since the new law came into force in 2013, energy certificates are also required when selling or renting older properties of all sizes. The requirement of energy certificates for different properties came into force in stages. In July 2017 the last stage, buildings built before 1980, joined the regulation. (Ympäristöministeriö, 2018.)

An energy certificate is a tool used to compare and improve the energy efficiency of buildings. It is an important document when purchasing or renting a property and is valid for ten years once it has been granted. An energy certificate is always compiled by a qualified professional after they have conducted a thorough inspection of the building, its elements and technical systems. During the visit, energy saving methods suitable to the case are reviewed. The building is also given an energy efficiency class. This energy certificate inspection is called an energy review. A list of qualified people who conduct said inspections can be found on the webpage of the Housing Finance and Development Centre of Finland. (ibid)

When conducting construction work on a property, it is important to ensure that all permits and documentation are in order. An energy review cannot be conducted on a property which has undergone renovation work without the required documentation. Renovation work subject to license is considered, for example, an extension to a building and/or various repair work to technical systems. (Rane, Energiatodistus)

The energy efficiency of a building and its construction work can be demonstrated in several ways. Firstly, structural elements and technical systems are updated to meet the current legislative requirements. Windows and doors are modernised, and the permeability of air of the roof and outer walls evaluated and rectified, if necessary. The U value is determined and, if necessary, corrected using insulation to meet the current requirement of 0,17. (ibid)

Secondly, the estimated energy consumption per heated net square meter is determined before and after construction work. For this evaluation the habits of the residents are not taken into account. The consumption of energy and energy production method are considered. Thirdly, the overall energy efficiency of the building is determined and depicted using the e-factor. It is determined with the following equation: the purchased energy multiplied with the coefficient of the form of energy divided by the heated net area. The possible energy production of the property is taken into account in the assessment. (ibid)

The energy efficiency rating of a building can be considered a grade for energy efficiency. The rating is given on a scale from A to G, A being the best rating and G being the worst. New smaller buildings usually receive a C rating and older buildings a C-G rating. A rating can be improved, for example, by improving the thermal insulation, by adding a heat recovery unit to the ventilation, or by using renewable energy sources. (Ympäristöministeriö, Kysymyksiä ja vastauksia energiatodistuksesta, 2018)

2.4 Energy in Finland

Finland is taking steps to becoming a carbon neutral nation. A New Energy and Climate Strategy was published on 24th of November 2016. It sets clear outlines of action, which will enable Finland to attain energy and climate targets by 2030 set by the Government Programme and adopted in the European Union. One of the main goals is to reduce greenhouse gas emissions by 80-95 percent from 1990 levels by 2050. A goal set by the EU to increase the share of renewable energy in end consumption to 38 percent by 2020 was achieved already in 2014. The goal is to further increase this amount to 50 percent. (Ministry of Economic Affairs and Employment, 2017.)

According to preliminary results, the total consumption of energy in 2016 was approximately 1335 petajoules, which was equivalent to approximately 243 gigajoules per resident. A two percent rise can be seen in consumption compared to consumption in 2015. This increase is theorised to be due to cooler weather conditions compared to the previous year. Regardless of the increase in consumption, the total consumption was still the second lowest of that in the 2010s. Total consumption of energy per source of energy can be seen in FIGURE 1 and a comparison of data from 2015 and 2016 can be seen in FIGURE 2. (Gynther, Lea. Energian kokonaiskulutus, 2017)

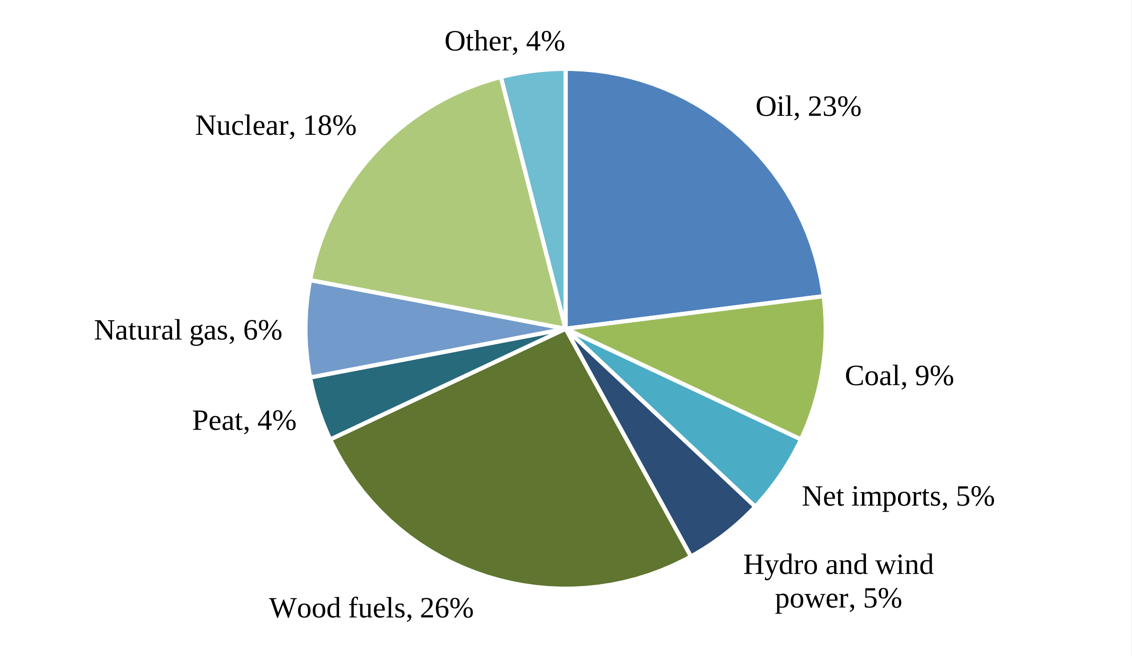


FIGURE 1. Total energy consumption per source of energy in 2016. (Gynther, Lea. Energian kokonaiskulutus, 2017)

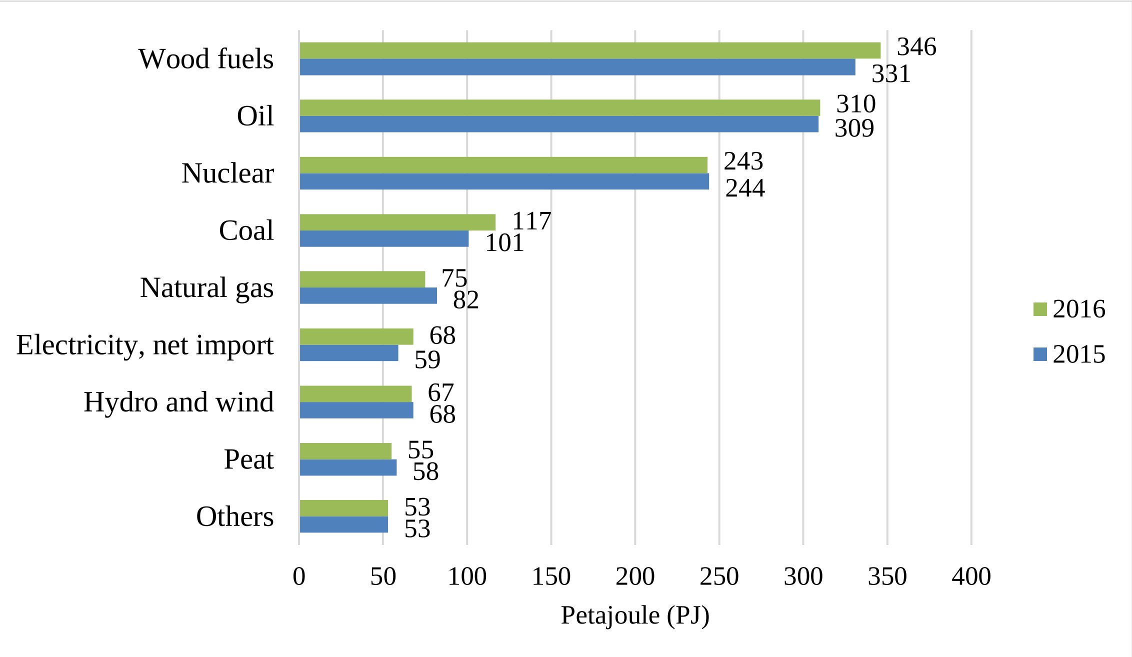


FIGURE 2. Comparison of total energy consumption per source of energy in 2015 and 2016. 2016 preliminary data. (Gynther, Lea. Energian kokonaiskulutus, 2017)

The final consumption of energy in 2016 according to preliminary data was 1081 petajoules, equivalent to 196 gigajoules per resident. (Gynther, Lea. Energian loppukäyttö, 2017) The final consumption of energy differs from the total consumption of energy. The final consumption measures the energy consumed disregarding energy transmission and distribution losses. It depicts the amount of energy accessible by businesses, households and other consumers. (Tilastokeskus) Final energy consumption increased 2,5 percent from the previous year. The division of energy consumption per sector can be seen in the following figures. (Gynther, Lea. Energian loppukäyttö, 2017)

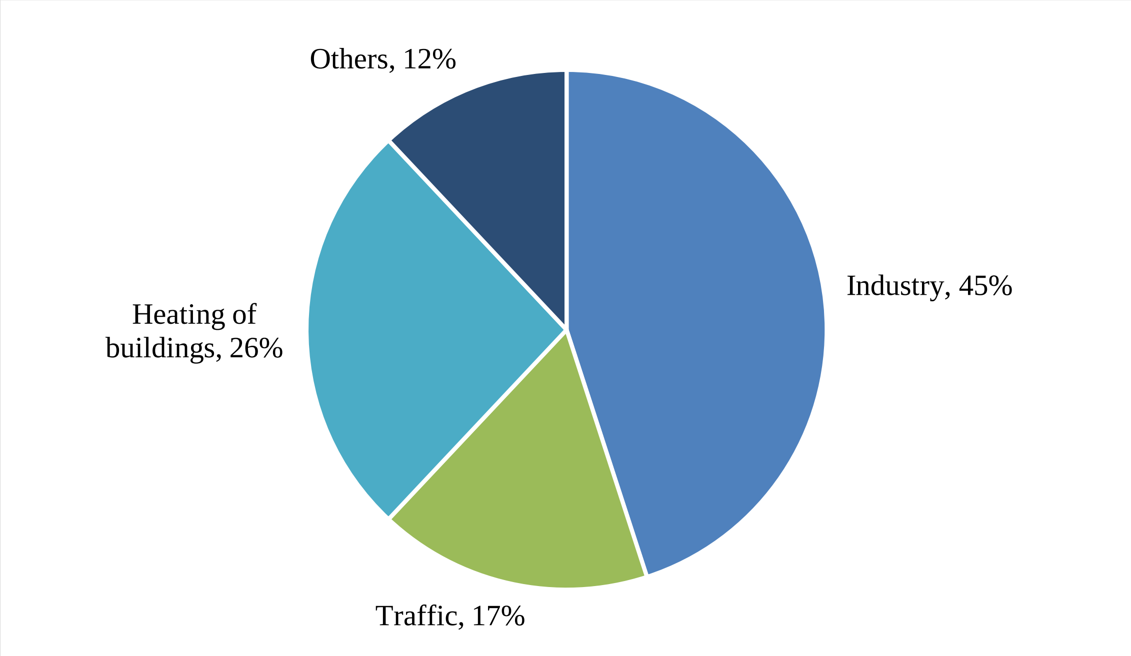


FIGURE 3. Final energy consumption per sector in 2016. (Gynther, Lea. Energian loppukäyttö, 2017)

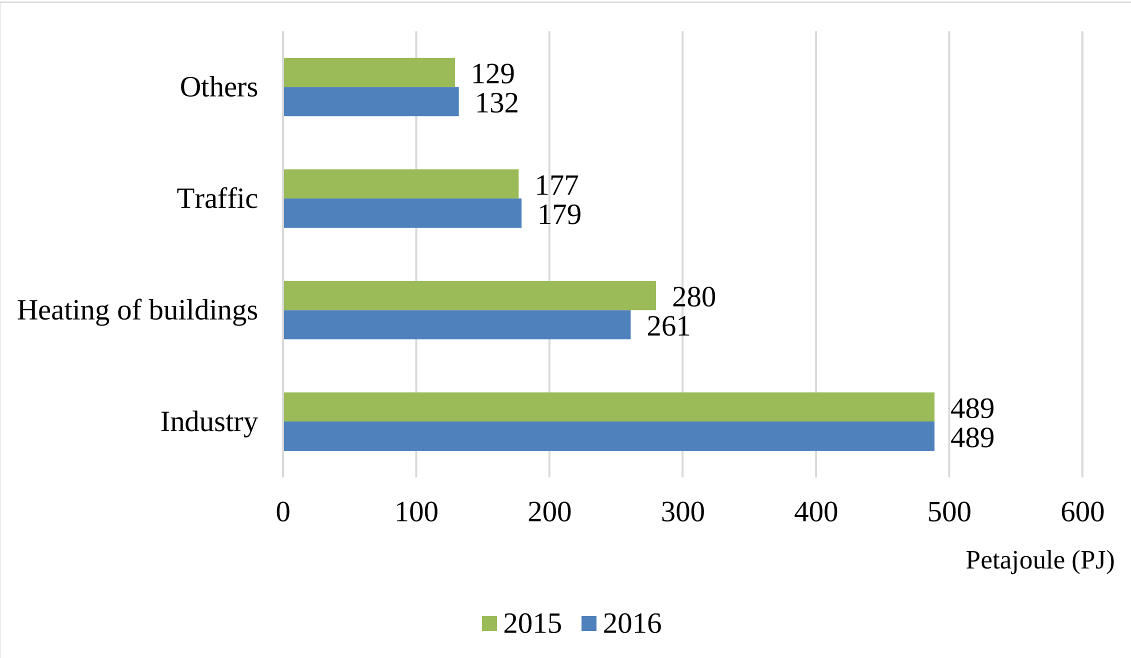


FIGURE 4. The final consumption of energy per sector in 2015 and 2016. 2016 preliminary data. (Gynther, Lea. Energian loppukäyttö, 2017)

Finland is one of the top countries in Europe when discussing the use of renewable energy sources in the production of energy. Our main renewable fuel sources are wood fuels and bio-based recycled fuels. According to preliminary results, the share of renewable energy fuels in the total consumption of energy in 2016 was approximately 34 percent. This is approximately one percent less than the year before. The division of energy sources of total energy consumption can be seen in the following figure.

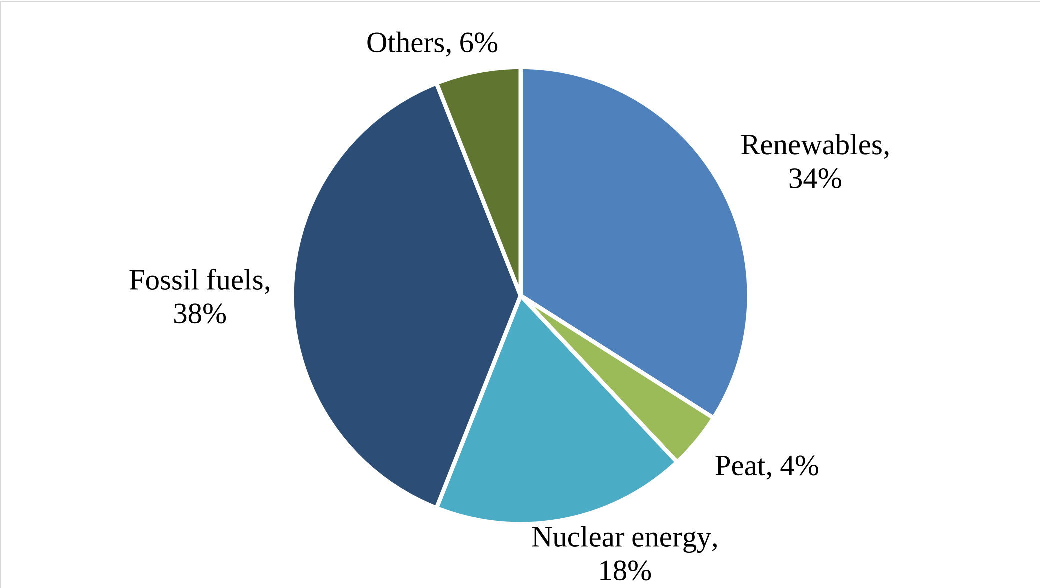


FIGURE 5. The share of various fuels in total consumption of energy, 2016. Preliminary data. (Määttä, Timo. 2018)

The total consumption of electricity in 2016 (according to preliminary data) was 85,1 TWh, equivalent to 15,5 MWh per resident. In 2015, the consumption was approximately three percent less, 82,5 TWh. National electricity production in 2016, excluding transmission losses, was 66,1 TWh. Most of our electricity was produced by nuclear power. Its share in total production was 34 percent. Hydro power and biomass were the second largest producers at 23,6 percent and 16,3 percent. CHP, combined heat and power, is a commonly used production method in Finland. In 2016, the share of CHP in total electricity production was 31 percent. The following figure shows the production of electricity in 2016 per energy source. (Gynther, Lea. Sähkön hankinta ja kulutus, 2017)

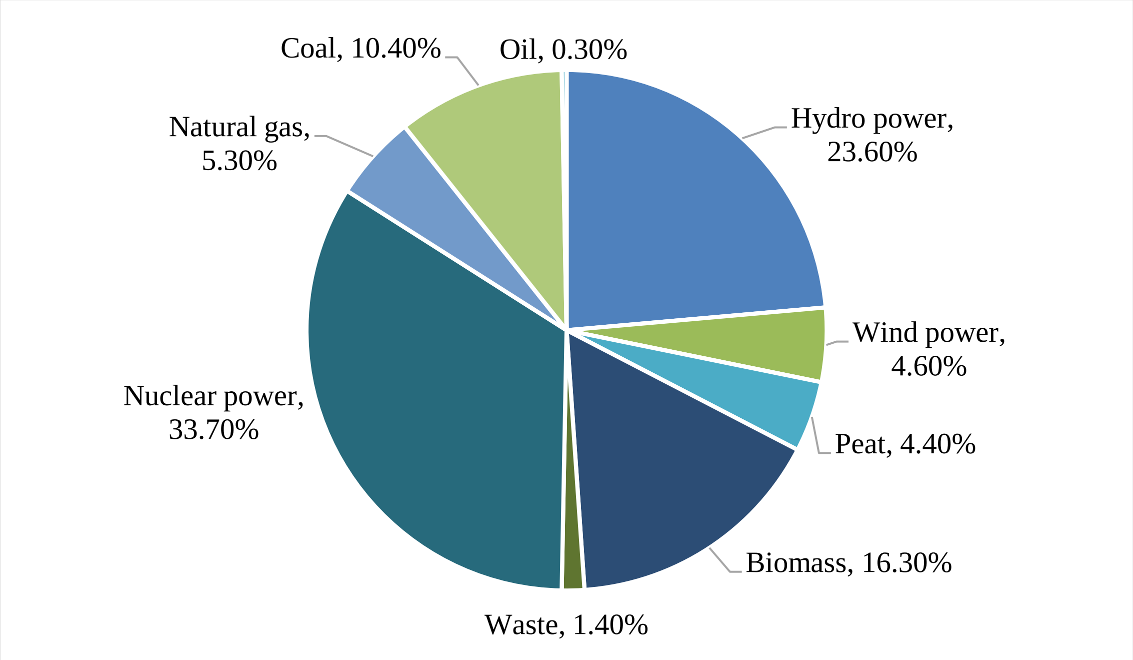


FIGURE 6. Total electricity production (66,1TWh) per energy source in 2016. (Energiateollisuus, Sähköntuotanto, 2017)

The most significant sources of energy for electricity production in 2016 were nuclear and hydro power, coal, natural gas and wood fuels. In 2016, our share of net imports of electricity was 19 TWh, which was the most it has ever been. Compared to 2015, an increase of 16 percent can be seen. The percentage of net imported electricity in total consumption of electricity was 22 percent. The division of electricity consumption can be seen in the following figure. (Tilastokeskus. Energian hankinta ja kulutus, 2017)

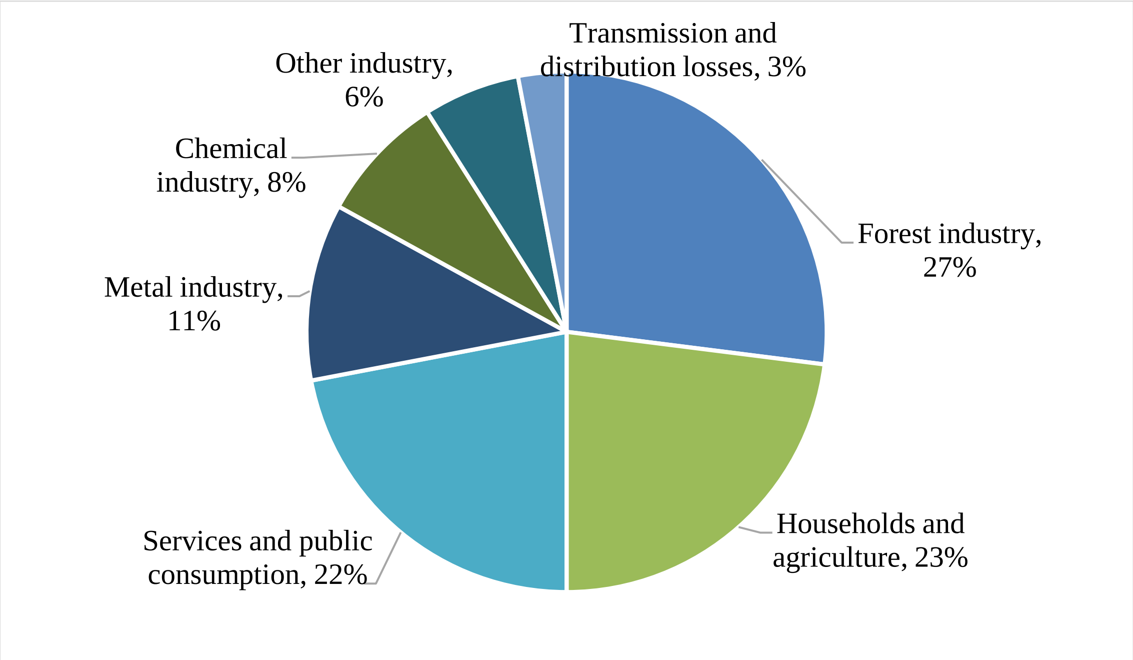


FIGURE 7. Division of the consumption of electricity in 2015. (Gynther, Lea. Sähkön hankinta ja kulutus. 2017)

The most significant consumers of electricity are the forest industry, households and agriculture, and service and public consumption, totalling over 2/3 of total consumption at 72 percent of total consumption. (ibid)

2.4.1 Energy and Electricity Consumption by Households in Finland

In 2016, households consumed 66 TWh of energy. Energy consumption increased by 8 percent from 2015. According to a publication by Statistics Finland, from 2015 to 2016 a 10 percent increase can be seen in the energy consumed for heating households. The use of energy for domestic electric appliances also increased by five percent during the same timeframe. The following figure depicts household energy consumption during the years 2010-2016. (Tilastokeskus, Kylmä sää nosti asumisen energiankulutusta vuonna 2016. 2017)

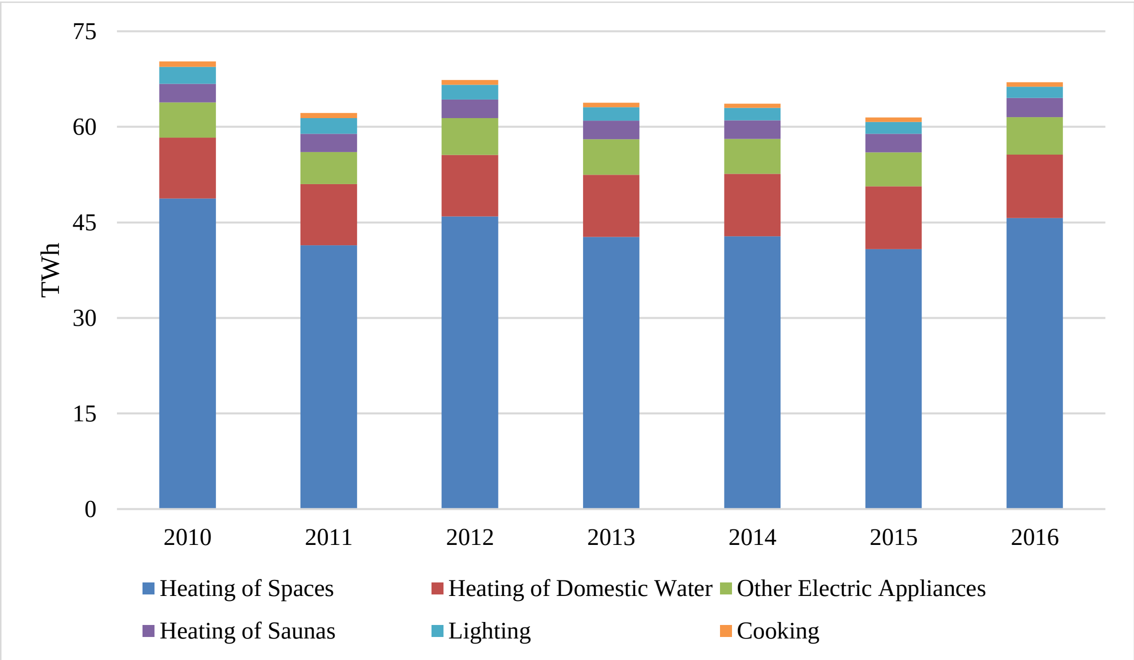


FIGURE 8. Household energy consumption of various factors 2010-2016. (ibid)

In 2016, from the total household energy consumption 68 percent was used for heating residential buildings, 15 percent was used for heating domestic water and five percent was used for heating saunas. The share of other electric appliances, lighting and cooking was approximately 13 percent. The amount of electricity consumed by households in 2016 was approximately 23 TWh. Of the electricity consumption, 47 percent was used on heating residential buildings and 36 percent was consumed by household appliances. The remainding amount of electricity was consumed by the heating of domestic water and saunas. (ibid)

The heating of residential buildings consumed 45 TWh of energy in 2016. The most common energy sources used for said heating were district heating, wood and electricity, comprising 85 percent of total energy production. The next most common energy source was ambient energy. Ambient energy refers to the energy obtained by heat pumps from the environment, such as from the ground, air or water. Heat pumps require electricity to work and thus ambient energy is the difference between the heat produced by a heat pump and the electricity it consumes. The following figure shows the energy consumption of households per energy source in 2016. (ibid)

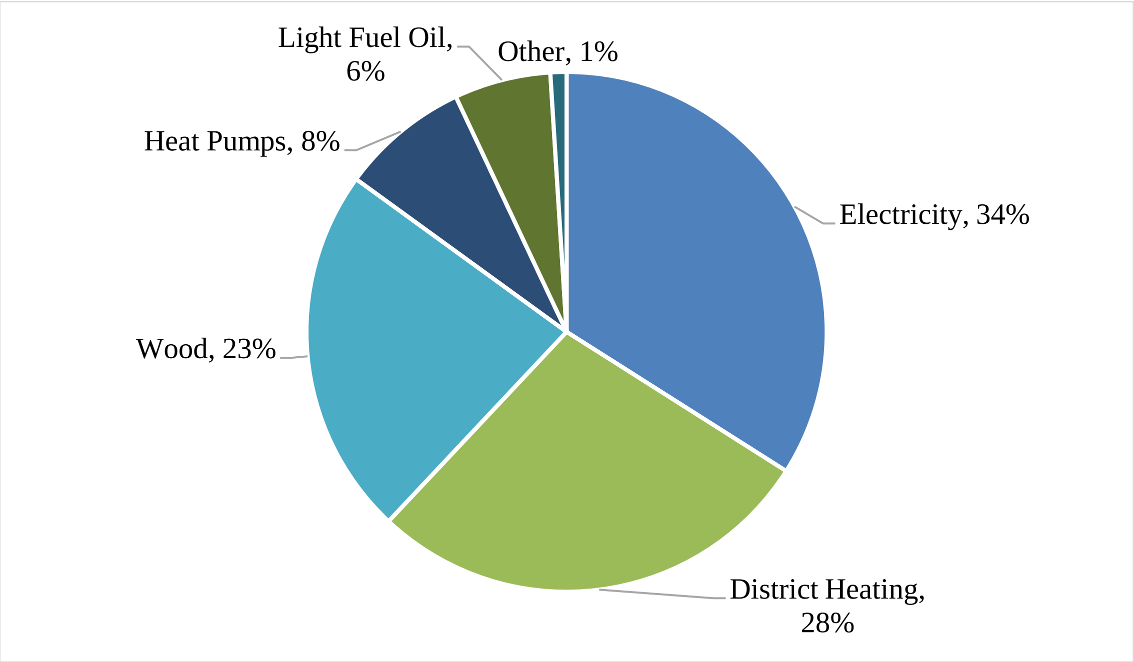


FIGURE 9. Household energy consumption of households per energy source in 2016. (ibid)

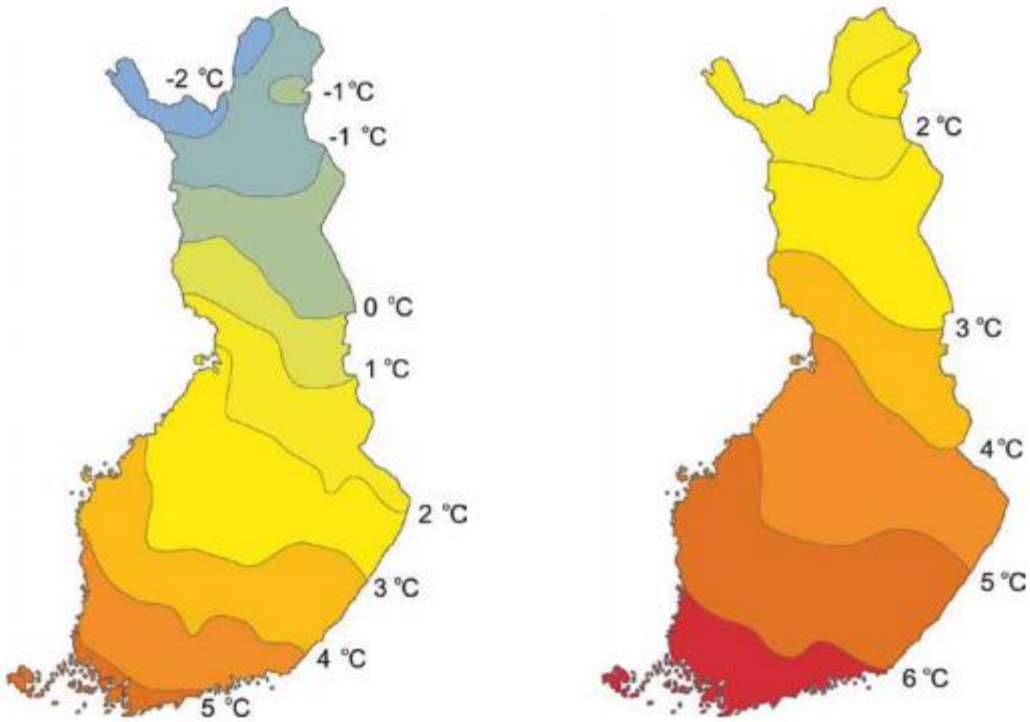
3 HEATING METHODS

3.1 Sources of Energy

The following chapters discuss various sources of energy used in heating single-family houses. Topics, such as the origin of the energy sources and their use in Finland are discussed.

3.1.1 Geothermal Energy

Geothermal energy is the heat energy found stored in the Earth. The heat stored in the upper layers of the earth is heat from the Sun. Heat in the lower layers is produced by the slow decay of radioactive particles in the earth’s core. Although the temperature of the outside environment fluctuates, the temperature of the earth stays fairly constant. The energy from the Sun stored in the topmost layers of the earth and the fission energy found in the deeper layers of earth can be harnessed with the use of heat pumps. (Energy Information Administration, 2017) The annual average temperature of the earth is approximately two degrees Celsius warmer than the average annual air temperature. Temperatures differ depending on the location. In the following map, the annual average temperatures of the earth and air can be seen during the years 1971-2000. (Ministry of the Environment, Juvonen and Lapinlampi, 2013)



PICTURE 2. The annual average temperature of air (left) and the annual average temperature of the earth (right), corresponding period 1971-2000. (ibid)

3.1.2 Wood Fuels

The majority of renewable energy used in Finland is produced using wood based biomass. A large portion of wood based fuels are produced using by-products produced in industry, such as bark, cutting chips, grinding and saw dust and black liquer formed during the production of pulp. (Motiva Oy, Puuenergian käyttö, 2016)

Wood based fuels are used in both industry and for heating single-family homes. In addition to using by-products from the wood industry to make wood fuels, lumber felled from forests can be used directly as a fuel. The consumption of wood chips made from this felled wood has increased over the past decade, approximately 400 000 solid cubic meters annually. It is consumed by wood heating appliances of households, heating plants, The increase of wood fuel consumption, for example in the field of industry, is due to the construction of many new heat and power plants. The consumption of wood fuels to heat single-family homes has decreased over the years due to the development and increase in the use of district heating and electricity. (Motiva Oy, Energiaa metsästä, 2017)

When studying the use of wood as a fuel, wood fuels used to heat single family homes is the second largest form of use after industry. In 2012, the amount of energy produced by the small combustion of wood fuels was 17 terawatthours, equivalent to approximately 4 percent of the national total energy consumption and 15 percent of the national production of renewable eneergy. (Motiva Oy, Puulämmitys kiinteistöissä, 2017)

Pellets are a popular wood fuel used to heat single-family houses. Pellets are made from compressed organic matter or biomass. In Finland, pellets are often made from by-products produced in industry, such as cutter chips and grinding and saw dust. (Bioenergian Pikkujättiläinen) Pellets are cylindrical in shape and approximately 6-12 mm in diameter and 10-30 mm in length. The uniform shape of the pellets ensures an even feeding of the fuel and makes it easier to control an even burning process. (Motiva Oy. Pelletit, 2017)

Pellets have been produced in Finland since the late 1990s. In 2013 there were approximately 27 factories in Finland, which were in the trade. Factories are often situated near the source material needed for pellet production. Often the production line is integrated into a factory which uses wood materials, thus making transporting the materials easy. The production process begins with removing all impurities, such as stones, metal and plastic from the source material. The optimal moisture percentage of the material is 10-15 percent. If the material is too moist, it must be dried before the production of pellets can begin. For example, the moisture percentage of saw dust can often be over 50 percent. (Bioenergia)

After the source material is processed and dried, it is lead into the grinding process. Grinding is often done with a hammer mill. After grinding, the material is pressed through a mould and cut into size. During this phase, the temperature is increased which causes the natural resin and lignin to slightly soften. This and the fibrous elements help the material to stick together. The lignin creates a shiny surface on the pellets and causes the pellet material to stay together. After the pellets have been pressed and cut into shape, they are cooled. The pellets undergo a screening process to remove excess particles. These particles are recycled into the process. The screening ensures a more homogenous fuel. (ibid)

Pellets have a high heat value as well as a high energy content. The energy content of pellets is approximately 4,75 kWh/kg. As a comparison, one cubic meter of light fuel oil is equivalent to approximately 3,3 cubic meters of pellets. (Bioenergian Pikkujättiläinen)

Pellets can be used in central heating similarly as, for example, oil. Both use a burner, boiler and are often connected to a hot water radiator system.

PICTURE 3. Pellets. (Image: Juha Rautanen, Motiva Oy, Pelletit)

The price development (cnt/kWh) of pellets can be seen in the following figure from the years 2002 to 2015. (Bioenergia)

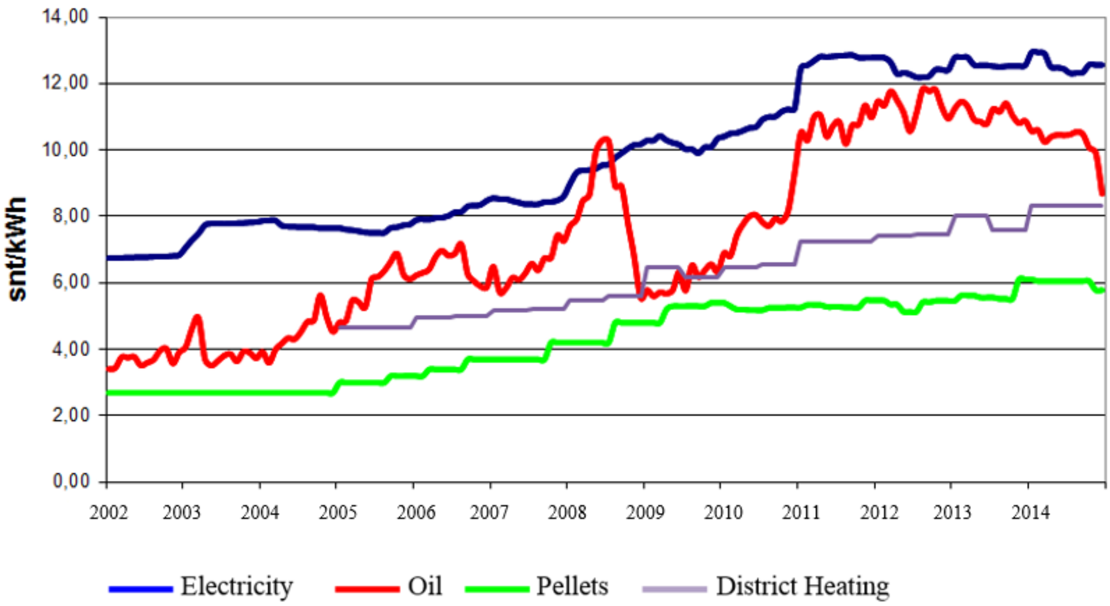


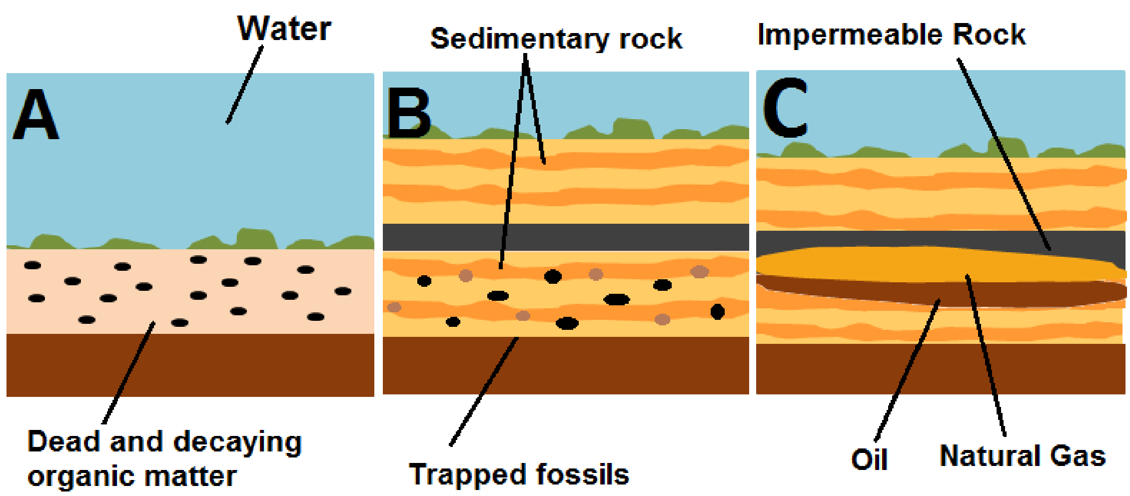
FIGURE 10. The price curve of pellets can be seen in green, data from 2002-2015. (ibid)

According to Statistics Finland, the price of pellets in February of 2018 was 5,63 cents/kWh. The price of pellets in 2017 was documented quarterly (see Appendix 1).

Compared to, for example oil, the price of pellets has stayed fairly constant throughout the years. (Producer Price Index, Statistics Finland, 2018)

3.1.3 Light Fuel Oil

The formation of oil takes a significant amount of time. Approximately 70 percent of oil deposits today were formed 252 to 66 million years ago in the Mesozoic age, 20 percent in the Cenozoid age 65 million years ago and 10 percent 541 to 252 million years ago in the Paleozoic age. The formation of oil happens when organisms, such as plankton, algae and bacteria die and fall to the ocean floor to decompose (see PICTURE 4, picture A). The organic matter is mixed with in-organic, clay-like materials, which forms organic-rich mud. Over time this mud is broken down in an anoxic environment and covered by sediment, which becomes sedimentary rock. This turns into organic shale. Organic shale is a source rock for oil and gas deposits. (see PICTURE 4, picture B) Over time new sedimentary layers are deposited on the source rock. Oil and gas can move out of the deposits due to the porous nature of the shale. As oil is lighter than water, it moves upwards. These deposits of oil and gas are called conventional reservoirs. For an oil reservoir to stay trapped in one place, an impermeable rock layer is formed on top to seal it (see PICTURE 4, picture C). To extract the oil from the reservoir a method of drilling is used. (Cey, Edwin et al)



PICTURE 4. The formation process of oil. (ibid)

Oil shale is produced when the source rock and sedimentary layers are exposed to high temperatures and intense pressure. Oil shale contains large amounts of kerogen and is a source of oil. (ibid) Extracting oil from oil shale has serious environmental effects thus many oil shale deposits are not actively used. (Cey, Edwin et al) The largest deposits of oil have been found in the Middle East. The largest deposits in Europe are in the North Sea. After drilling and extracting the oil, the raw material is refined into various products, such as petroleum, diesel oil, heating oil (e.g. light fuel oil), liquefied petroleum gas and products for the petrochemical industry. (Energiateollisuus ry, Öljy)

As can be seen from the data from 2015 and 2016 in chapter 2.4, oil is a large contributor in the total energy consumption in Finland. In 2017 in Finland, approximately 190 000 houses were heated using an oil heating system. Together, these homes consumed an estimated 460 million litres of light fuel oil, which is equivalent to two percent of the total energy consumption in Finland. Due to fluctuating trends in oil prices and the growing concern for the environment, annually approximately 5000 to 6000 houses change from oil heating to another heating method. Oil heating is a rarely used heating method in new construction. (Lampila, 2017) As can be seen in FIGURE 9 in chapter 2.4, light fuel oil contributed to a share of six percent of the total household energy consumption in Finland in 2016.

The price of oil products varies. This can be seen in the following figure from Statistics Finland, which indicates the price of three oil products during 2008 to 2017.

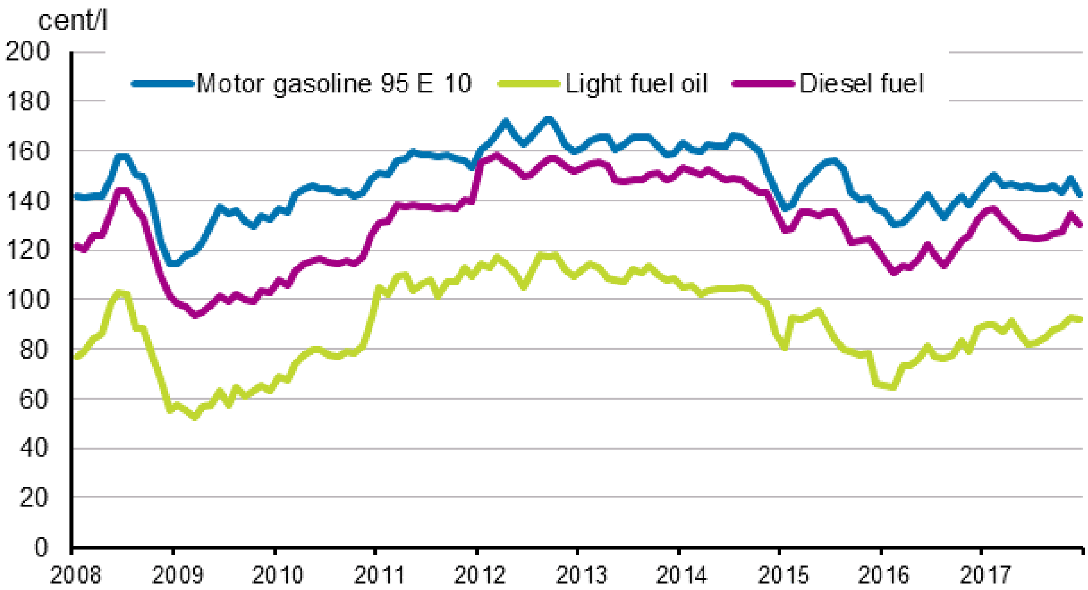


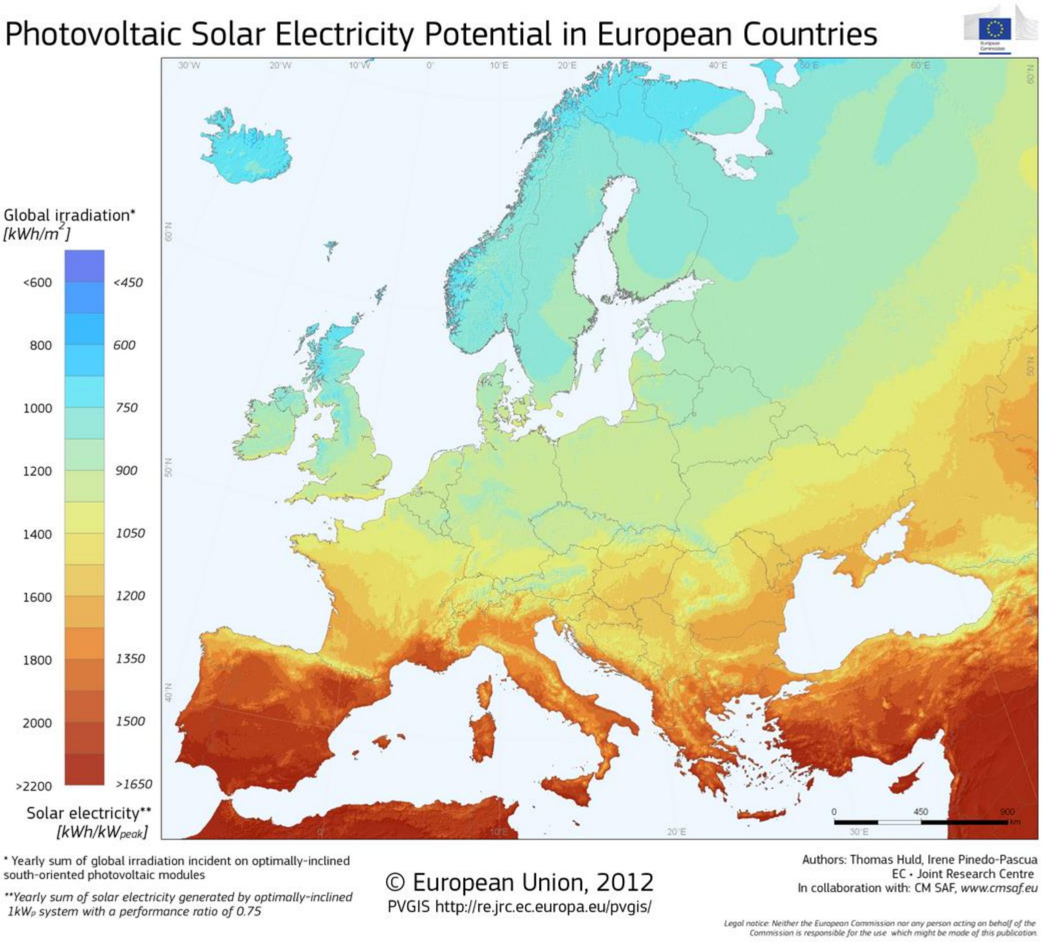
FIGURE 11. The price variation of light fuel oil is indicated in green. (Statistics Finland)

According to Statistics Finland the price of light fuel oil in December of 2017 was 0,92 cents/kWh. The average of the entire year was 0,876 cents/kWh (see Appendix 2). (Statistics Finland, Energy Prices, 2018)

3.1.4 Solar Energy

Solar energy has immense potential to solve the energy problem our world is facing. The amount of sunlight that hits the planet's surface in a matter of one and a half hours could meet the worlds demand for energy for an entire year. Solar technology is a rapidly developing field and constant advances are underway. (Office of Energy Efficiency and Renewable Energy)

In Finland, the share of diffuse irradiation of total irradiation is large; in Southern Finland the share is approximately 50 percent. Electricity production with solar panels can be achieved with both diffused and direct irradiation. However, the amount of diffused radiation creates a challenge when choosing a solar energy system; for example, tracking mounting systems are based on the efficient use of direct irradiation from the sun and are thus generally not seen as cost-effective solutions in Finland. (Motiva Oy. Auringonsäteilyn määrä Suomessa, 2017) The photovoltaic solar electricity potential in Europe can be seen in the following map.



PICTURE 1. Photovoltaic solar electricity potential in European Countries. (European Commission)

The amount of annual total solar irradiation in Finland is approximately the same as in Northern Germany. However, in Finland the irradiation is higher during the summer season and thus the amount of power produced fluctuates more between the seasons. (Motiva Oy. Auringonsäteilyn määrä Suomessa, 2017) According to the Finnish Meteorological Institute, the amount of irradiation on a horizontal surface in Helsinki is approximately $980\ \mathrm{kWh/m^2}$. In Northern Finland in Sodankylä, the amount of irradiation is approximately $790\ \mathrm{kWh/m^2}$. (Ilmatieteen laitos, 2017) By directing panels at a 45-degree angle, irradiation can be increased by 23-30 percent annually in comparison to horizontally installed systems. (Motiva Oy. Auringonsäteilyn määrä Suomessa, 2017)

3.2 Utilising Various Energy Sources

In the following chapters, the use of the beforementioned energy sources is discussed from the point of view of heating single-family houses. Primary heating systems, such as geothermal heating, pellet heating and oil heating and complementary heating systems, such as solar energy systems, various air heat pumps and fireplaces are discussed.

A heating system of a house consists of multiple parts: heat generation devices (e.g. heat pump, boiler), heat storage equipment (e.g. hot water tanks), heat distribution system (e.g. a water circulating underfloor heating network, a water-circulating radiator network, electrical heating), and control equipment. (Energiatehokas koti- hanke, 2017)

The most popular heating system chosen for new buildings during the years 2006 to 2015 has been geothermal heat pumps. In 2014, geothermal heat pumps exceeded a 50 percent market share of heating systems. In 2015, the second most popular heating system chosen for new buildings was an exhaust air heat pump. Direct electric heating was the third most popular heating system. A more exact distribution of the market share of various heating systems can be seen in the following figure. The data is collected by PRKK (Pientalorakentamisen kehittämiskeskus ry) (ibid)

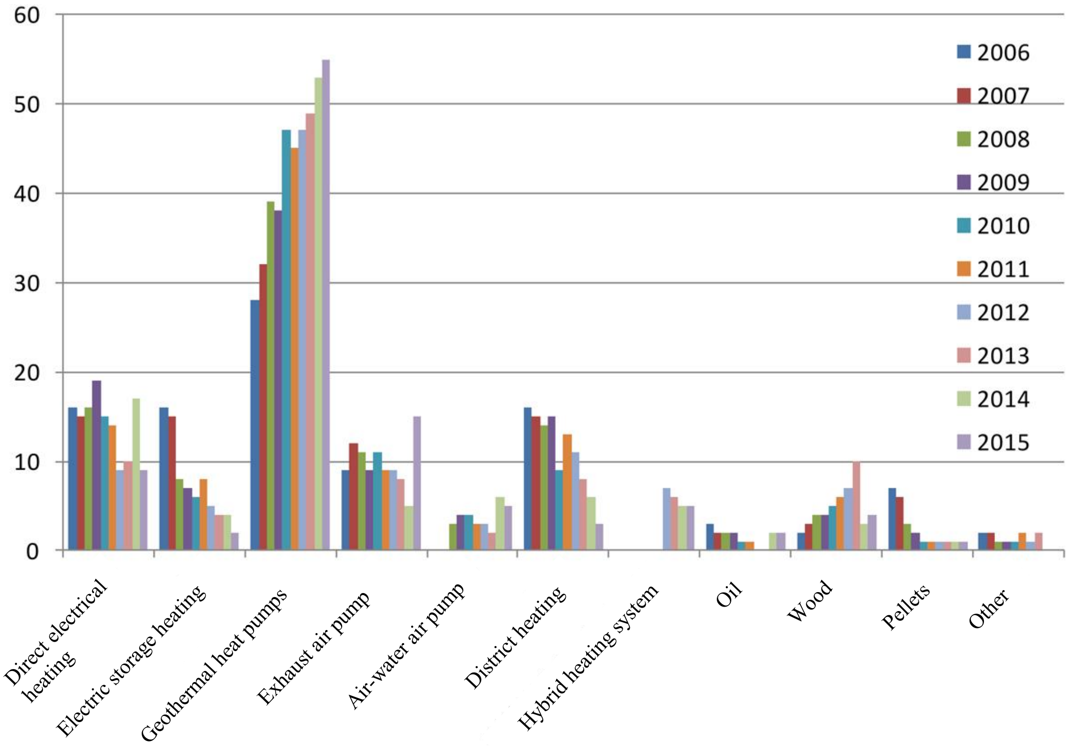


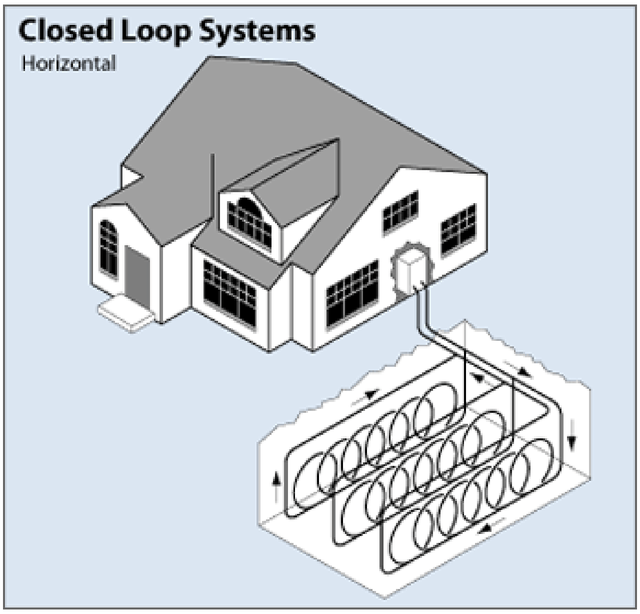
FIGURE 12. The market share of various heating systems during 2006-2015. (ibid)

3.2.1 Geothermal Heat Pumps

Geothermal heat pumps use the heat stored below the earth's surface or in water. The energy can heat and cool a house as well as provide it with hot water. The naturally occurring temperature difference between the ground temperature and above-ground air temperature serves as the base of the technology. The system consists of a heat pump connected to a series of underground pipes. The pipes can be installed in either horizontal trenches approximately one metre deep or in a deep vertical borehole or boreholes. The depth of the borehole depends on the case and is calculated based on, for example, the energy demand and ground material. (United States Environmental Protection Agency, Geothermal Heating and Cooling Technologies, 2016) There are multiple types of geothermal heat pump systems; three of them, horizontal, vertical and pond/lake are closed systems and one type is an open-loop option. Each case is designed separately, and the system is chosen based on factors, such as climate, soil conditions, available land, local installation costs and local legislation. (Office of Energy Efficiency and Renewable Energy, Geothermal Heat Pumps)

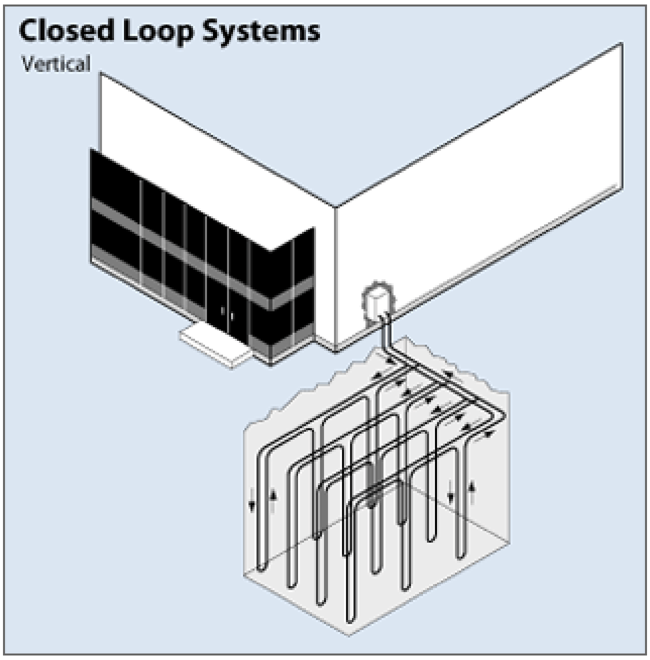
Closed-loop geothermal heat pumps circulate a heat-conveying non-freezing fluid (refrigerant) in pipes, which are installed in the ground or submerged in water. This fluid moves heat from point to point. A heat exchanger transfers the heat between the non-freezing fluid and refrigerant. As the refrigerant in the heat exchanger begins to heat, it also begins to steam. The pressure is then increased using a compressor, which also causes the temperature to rise. The steam is then condensed in a condenser and the heat stored in the fluid is released into the network or water supply. (SULPU ry)

As mentioned, the closed loop system can be horizontal, vertical or pond/lake configuration. In a horizontally installed system pipes are installed horizontally approximately a metre under the ground surface. (Office of Energy Efficiency and Renewable Energy, Geothermal Heat Pumps) Pipes are at least 500 meters long in small projects. (Ministry of the Environment, Juvonen and Lapinlampi, 2013)



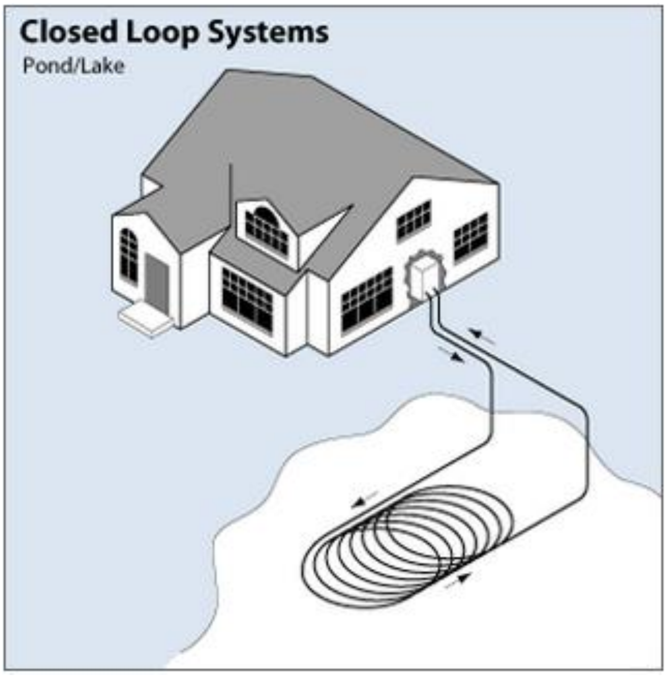
PICTURE 6. Horizontal installation of a geothermal system. (U.S. Department of Energy, 2016)

Vertical installation requires a borehole or multiple boreholes to be drilled multiple metres into the ground. Boreholes are usually less than 300 metres deep in small projects, however each case is planned separately according to, for example energy consumption. (Ministry of the Environment, Juvonen and Lapinlampi, 2013) Pipes are installed into the hole/holes and are connected at the bottom with a U-bend to form a loop. If the system has many boreholes, they are connected together with a horizontal pipe/pipes, which is/are then connected to the heat pump in the building. Boreholes have become the most common method for harnessing geothermal energy in Finland. (Office of Energy Efficiency and Renewable Energy, Geothermal Heat Pumps)



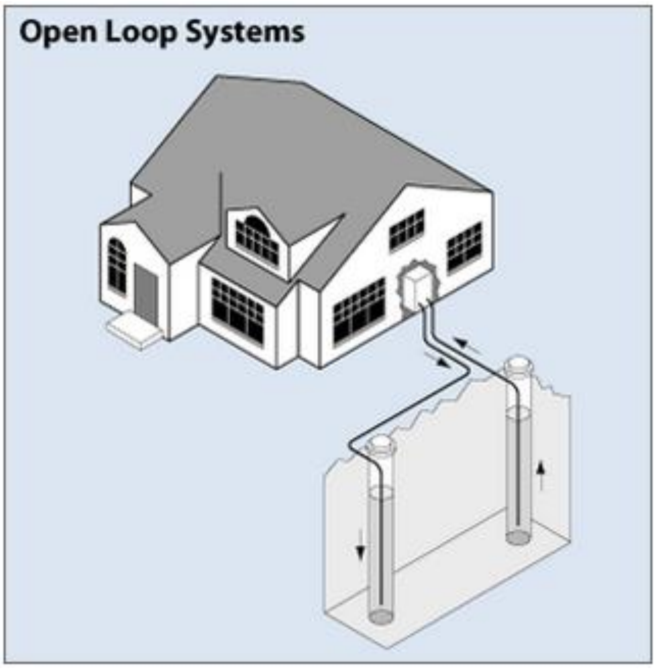
PICTURE 7. Vertical installation of a geothermal system. (U.S. Department of Energy, 2016)

In a pond/lake system, a supply line is installed underground and run to a water source. Pipes are then coiled into circles and installed a few meters under the surface to prevent freezing. (Office of Energy Efficiency and Renewable Energy, Geothermal Heat Pumps)



PICTURE 8. Pond/lake configuration of a geothermal system. (ibid)

In an open-loop system pipes are installed in a water source. Instead of using a heat exchange fluid, the water from the source is directly pumped into the geothermal system. The water is then pumped back into the ground via the well, a recharge well, or surface discharge. An open-loop system can be used only when there is an adequate supply of water. Also, local legislation must be studied; for example, in Finland, there are strict regulations about using geothermal energy in ground water areas. (ibid)



PICTURE 9. Open loop geothermal system.

When planning a geothermal energy system, the sizing of the system must be taken into careful consideration. The compressor of the system requires electricity to work and thus 2/3 of the heat produced by a heat pump is from geothermal energy and 1/3 is produced by electricity. (SULPU ry) Since 2011 in Finland, installation of geothermal pipes has required a planning permit. When applying for a permit, factors such as underground structures, groundwater areas and safety distances to surrounding buildings, plot boundaries and other geothermal wells are taken into account. (Seuna, Sami. 2018)

A geothermal heating system can be sized for part of the power demand or to cover the power demand in full. When operating at part load, the system is sized to approximately 60 to 80 percent of the peak output of the house. This will produce 95 to 99 percent of the yearly energy demand. The remaining 1 to 5 percent is produced using the heating resistor of the system. When operating at full load, the system is sized to produce the power demand in full using the compressor. (Seuna, Maalämpöpumput, MLP, 2018)

The seasonal coefficient of performance (SCOP) is a value used to describe how efficiently a pump produces heat with relation to the amount of electricity it consumes. The coefficient of performance is better when the temperature difference between the energy source (in this case the temperature of the earth) and the temperature of the heat distribution pipes is low. Underfloor heating is considered an efficient heat distribution system for geothermal heating. In comparison to a water circulating radiator system, the water in an underfloor heating network does not need to be as high improving the SCOP value of the pump. (Motiva Oy, Hanki hallitusti maalämpöjärjestelmä)

Geothermal energy is, so called, free energy, however geothermal heat pumps require electricity to function. The cost of energy is thus formed from the price of electricity. As mentioned, geothermal energy is 1/3 electricity and thus it can be assumed that the price of geothermal energy is 1/3 of that of direct electrical heating. The price trend of electricity during the years of 2008 to 2017 can be seen in the following figure.

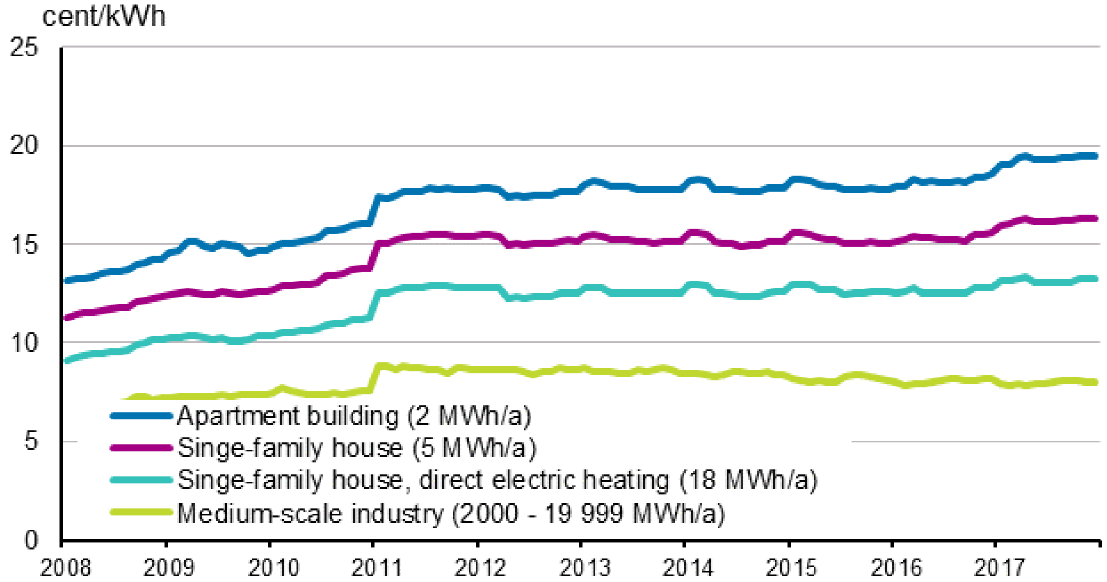


FIGURE 13. The price trend of electricity during the years 2008-2017. (Statistics Finland)

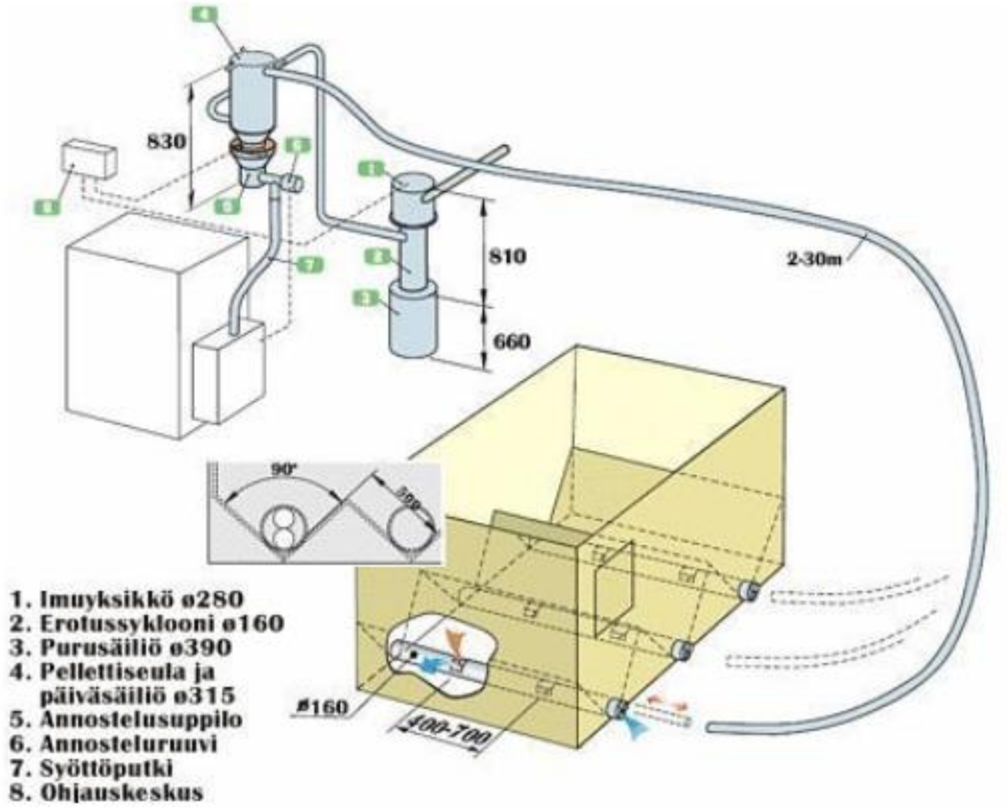
The price of household electricity in December of 2017 was 12,35 cents/kWh and has stayed fairly constant through-out the years. (Statistics Finland, Energy Prices)

3.2.2 Pellet Heating

A pellet heating system includes a burner, a boiler, a storage unit, a feeder device and an automated control system. The system also includes an expansion tank and water boiler, if necessary. Boilers often have a section for hot water production, however if the demand for hot water is high, a water boiler is a necessary addition to ensure an efficient amount of water. To produce heat, pellets are burned in the burner, which is connected to the boiler. A feeder device, such as a screw conveyor feeds the fuel into the burner. The heat output is determined on how much and how quickly the pellets are fed into the system. (Turvallisuus- ja kemikaalivirasto, 2017)

Pellets can be stored in multiple ways; storage units can be built above or underground in various sizes. Pellets are stored in a separate storage unit, for example a small silo. The silo can be, for example, in the form of a weigh-hopper with a V-shaped structure. The shape of the silo is determined according to the available space and demand of the amount fuel. The pellets must be protected from moisture as the optimal moisture content of the fuel is important for a successful and efficient burning process. Pellets stored in a silo outdoors keeps for approximately a year before the quality decreases. The silo must also be dustproof and built from the correct materials. (Motiva Oy. Pelletin säilytys ja siirto, 2017)

Pellets are moved from the storage unit into the burner using a feeder device, such as a screw conveyor. The screw conveyor is attached to the bottom of the silo. However, if the storage unit is situated further away, a sort of vacuum can be used. Using this technique, pellets can be moved as far as 30 metres. Pipes required for this system can be installed, for example underground and so out of sight. The vacuum moves the pellets to the burner. The pellets go through a sieve, which separates the fuel from unwanted particles such as dust. A cyclone, or dust collector collects the dust into a separate container. (ibid)



PICTURE. 14. Pellet feeding system from the storage unit to the boiler and burner. (ibid)

Pellets can be ordered in smaller bags of 15 to 20 kilograms and larger bags of 500 to 1000 kilograms. The availability of the fuel is good as it is produced as a by-product of the wood industry. (Bioenergia ry, Miksi pellettilämpöä?)

3.2.3 Oil Heating

An oil heating system requires a boiler, burner, control equipment and one or more oil storage tanks. The system can be used to heat the water for the water circulating heating network and the domestic water of a house. An oil boiler is equipt with electrical resistors to ensure heat production in case of a malfunction. Regular maintenance of the oil heating system ensures that the burning process stays clean and efficient. Soot removal and burner maintenance should be done annually and oil tanks should be cleaned every five to ten years. (Energiateollisuus ry, Öljylämmitys)

According to Motiva, the life expectancy of a boiler of an oil heating system is approximately 20 to 30 years and the expectancy of a burner is between 10 to 15 years. The cost of a new burner is approximately 1000 euros. (Energiatehokas koti-hanke, Lämmitysjärjestelmien elinkaari)

3.2.4 Solar Energy Systems (as Complementary Heating Systems)

Solar energy systems can be adapted to meet a broad range of needs. Systems range in size and shape; they can be found on residential rooftops as well as larger sites. Businesses are realising the potential of solar energy and are opting to install solar panels to reduce their energy costs and carbon footprint. There are two main types of solar energy technologies: photovoltaic (PV) and concentrating solar power (CSP). The most significant difference between the two systems is that photovoltaic systems produce electrical energy and CSP systems produce heat energy. (ibid)

Photovoltaic technology converts sunlight into electrical energy. Solar radiation consists of small particles called photons. As the photons hit the solar panels, they transfer their energy to lose electrons to the material of the panel. The cells of the panels then convert these electrons into an electric current. (Motiva Oy. Auringosta sähköä, 2017)

Photovoltaic systems utilize panels, which consist of cells. Each PV device, known as a cell, is small, ranging from the size smaller than a post stamp to a few centimetres across. Solar cells are thin, only as thick as a few human hairs. Multiple cells are linked together to form chains to create larger units called modules or panels. To withstand the outdoors, the panels are protected by multiple layers of glass and/or plastics. Panels can be used individually, or several panels can be connected to form arrays. The PV system is then completed by connecting it to the electrical grid. (Office of Energy Efficiency and Renewable Energy. Solar Photovoltaic Technology Basics, 2013)

Due to the PV technology’s simple structure, systems can be built in many shapes and sizes to meet various needs ranging from small residential systems to large power stations. However, panels are only one part of a PV system. Systems also require mounting structures along with an inverter or inverters used for converting the direct-current (DC) electricity produced by the panels to alternating-current (AC) electricity consumed by the end user. (ibid) In situations where the electricity cannot be used immediately, it can be stored in batteries. The power can then be used when needed. Excess electricity produced can also be fed into the grid network. (Motiva Oy. Auringosta sähköä, 2017)

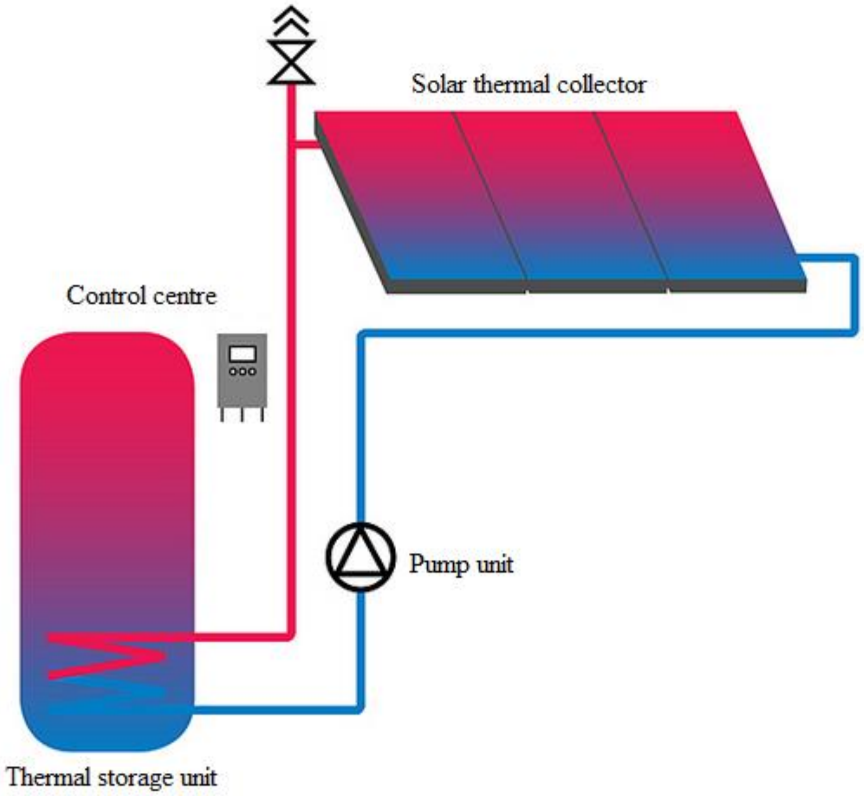
A PV system is commonly installed on a rooftop, however mounting structures for walls are also used. The mounting structure ensures that the full potential of the panel is used by tilting it at an optimal angle towards the sun. The angle is determined by, for example, the local latitude and the orientation of the structure. Panels installed in Finland, are often pointed due south to obtain the highest annual energy output. (Motiva Oy, Aurinkopaneelien asentaminen, 2016) To further provide more energy, tracking systems in mounting structures can also be used. One-axis trackers follow the sun from east to west, whereas two-axis trackers follow the sun throughout the day. (Office of Energy Efficiency and Renewable Energy. Solar Photovoltaic Technology Basics, 2013)

The nominal power of a solar panel is denoted by a watt-peak, W_p. The nominal power is determined in a laboratory under standard test conditions (STC), where the solar irradiance is $1000\ \mathrm{kWh/m^2}$ and the temperature of the panel is $25°\mathrm{C}$. In Southern Finland, a $1\ \mathrm{kW_p}$ system produces approximately 800-1000 kWh of electricity a year. A system of this size typically requires an area of 6 to 8 square meters. (Motiva Oy. Aurinkosähköjärjestelmän teho, 2017)

The power of a solar panel is affected by its efficiency. This refers to the portion of energy from sunlight that can be converted into electricity via photovoltaics. It is calculated by dividing the nominal power of a panel with the panel area and solar irradiance under standard test conditions. For example, the efficiency of a panel with a nominal power of $200\ \mathrm{W_p}$ is calculated with the following formula: $200\ \mathrm{W_p}/(1{,}5\mathrm{m^2} \cdot 1000\ \frac{W}{m^2}) \approx 13\%$. In addition to efficiency, electricity production is affected by temperature, the angle of the panel, the efficiency of the inverter, shadows cast on the system and cleanliness. (ibid)

Concentrating solar power (CSP) converts sunlight into heat. The technology utilises focused sunlight. Concentrating solar power systems use mirrors to focus the sun's energy onto a receiver. The energy is collected and used to heat a high-temperature fluid and can be further converted to electric power using a turbine or power engine that drives a generator. (Solar Energy Development Programmatic EIS) CSP systems utilise multiple technological approaches: linear concentrator systems, dish/engine systems and power tower systems. CSP technologies are generally used for utility-scale projects. (Office of Energy Efficiency and Renewable Energy, 2013)

Active solar heating systems can be used to convert sunlight into heat for single-family houses. The system consists of solar thermal collectors, thermal storage and a heat exchanger, insulated piping, a pump unit, an expansion tank and control centre. Solar radiation is received by a collector which converts it into heat. A heat transfer fluid (usually a non-toxic propylene glycol) is used to transfer the heat onward in the system in a closed circuit. As the heat is received from the collector, it is transferred into the heat storage unit through a heating coil or heat exchanger and used later when needed. The heat transmission line is equipped with a pump unit and control system. The pump unit is equipped with protective devices (e.g. relief valve in case of excess pressure) and an expansion tank. The systems control centre controls, for example the power of the pump. (Office of Energy Efficiency and Renewable Energy. Active Solar Heating Systems)



PICTURE 5. An active solar heating system, which uses a heat transfer fluid. (Motiva Oy. Aurinkolämpöjärjestelmät, 2018)

An active solar heating system can be used, for example as a complimentary heating system in a home. Solar energy can be used to heat the water supply, however, if possible, a greater benefit is achieved when the system is connected to a water circulating heating system. (Motiva Oy. Tukilämmitysjärjestelmät, 2016)

3.2.5 Air-air, Air-water and Exhaust Air Heat Pumps

Heat pumps including air-air source heat pumps, air-water source heat pumps, exhaust air heat pumps and geothermal heat pumps have become a popular heating method in single-family housing. In 2014, 70 000 heat pumps were sold and at the end of the same year 700 000 units were in use. (Seuna, Lämpöpumput. 2017) The amount of heat pumps in use from 1996 to 2015 can be seen in the following figure.

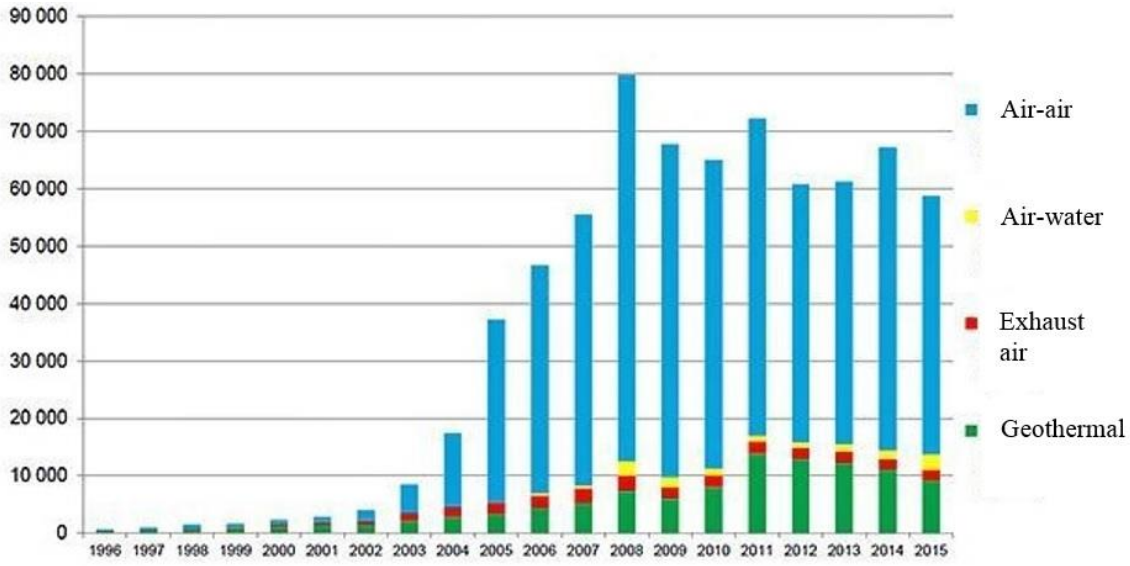


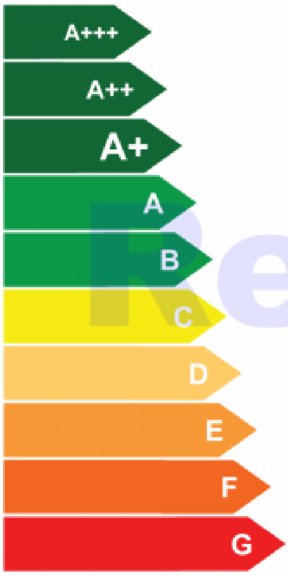
FIGURE 14. Amount of heat pumps in use in Finland during 1996 to 2015. (Seuna, Lämpöpumput. 2017)

The technology of air-air, air-water and exhaust air heat pumps is similar to the before-mentioned geothermal heat pump technology. The heat energy in air is recovered using a heat exchanger and transferred to a non-freezing heat-conveying fluid (refrigerant) system. The heat energy is transferred to a compressor, where the refrigerant begins to steam due to a high temperature. The pressure is increased, which further increases the temperature. After the refrigerant reaches a high enough temperature, it begins to condense in the condenser. The heat stored in the fluid is then released into the network and the refrigerant, after being reverted back to a fluid state, is ready to start the heat collecting process again. (Sulpu ry)

A heat pump requires electricity to for example, work the compressor and motor of the fan. The performance efficiency of a heat pump is indicated using a coefficient of performance value. This value indicates how efficiently the pump produces heat energy when considering the amount of electricity it requires. Known value types are COP (coefficient of performance) and SCOP (seasonal coefficient of performance). The COP value is always measured in +7 degrees Celsius. As an example, COP 3 indicates that with 1 kW of electric power 3 kW of heat power can be produced. Due to the COP value being measured in a specific temperature, it is not an efficient method to indicate how efficient the heat pump is in, for example winter weather. (Ref Group, Energian säästö ja lämpökertoimet)

To ensure a more realistic indication of performance efficiency over an entire year, a new decree based on an EU directive was enforced in 2013. This decree demands that all new air source heat pumps of 0-12 kW fulfil a new SCOP value. The SCOP value indicates the annual performance efficiency of the heat pump and takes into consideration the mean temperatures of all seasons of the year. In addition to considering seasons, the SCOP value takes into consideration the location of the pumps installation. Europe is divided into three climatic zones. The calculations are based on various climatic conditions: the warm zone calculations in southern Europe on conditions in Athens, in Central Europe on conditions in Strasbourg, and cold zone calculations in Northern Europe on conditions in Helsinki. The location of a pumps installation effects the energy label of the product: the same pump can have three different energy ratings depending on which of the three climate zones the pump is installed in. (ibid)

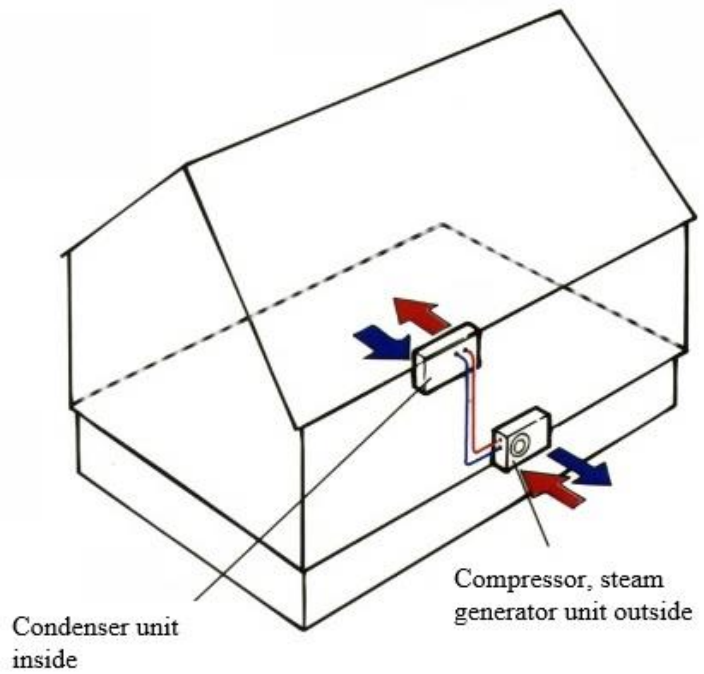
In addition to a SCOP value, a heat pump is given an energy efficiency ratio (EER), in other words a cooling efficiency factor. As an example, an EER value of 4 indicates that with 1 kW of electric power, 4 kW of cooling power can be produced. A good EER value is over 3,5, however the higher the value, the better the energy efficiency of the pump. As with the coefficient of performance, the energy efficiency ratio also has an annual efficiency value called SEER. The SCOP and SEER values are indicated on the energy label of the heat pump. The energy class of a pump is given based on the beforementioned information. The SCOP and SEER values and their corresponding energy classes can be seen in PICTURE 11. (ibid)



	SEER	SCOP
A+++	SEER ≥ 8,50	SCOP ≥ 5,10
A++	6,10 ≤ SEER < 8,50	4,60 ≤ SCOP < 5,10
A+	5,60 ≤ SEER < 6,10	4,00 ≤ SCOP < 4,60
A	5,10 ≤ SEER < 5,60	3,40 ≤ SCOP < 4,00
B	4,60 ≤ SEER < 5,10	3,10 ≤ SCOP < 3,40
C	4,10 ≤ SEER < 4,60	2,80 ≤ SCOP < 3,10
D	3,60 ≤ SEER < 4,10	2,50 ≤ SCOP < 2,80
E	3,10 ≤ SEER < 3,60	2,20 ≤ SCOP < 2,50
F	2,60 ≤ SEER < 3,10	1,90 ≤ SCOP < 2,20
G	SEER < 2,60	SCOP < 1,90

PICTURE 10. SEER and SCOP values and their corresponding energy classes. (ibid)

An air-air heat pump utilises the heat energy in the air to either heat or cool the air inside a house. The heat pump is comprised of two (or more) units; one (or more) is situated on the inside and the other on the outside of the house. The air on the inside of the house is heated using the heat energy of outdoor air. The system can also be used to cool a house by using the heat pump in the opposite direction. (Sulpu ry) The performance efficiency of an air-air heat pump is best when the temperature difference of the outdoor and indoor air is low. (Seuna, Lämpöpumput. 2017)

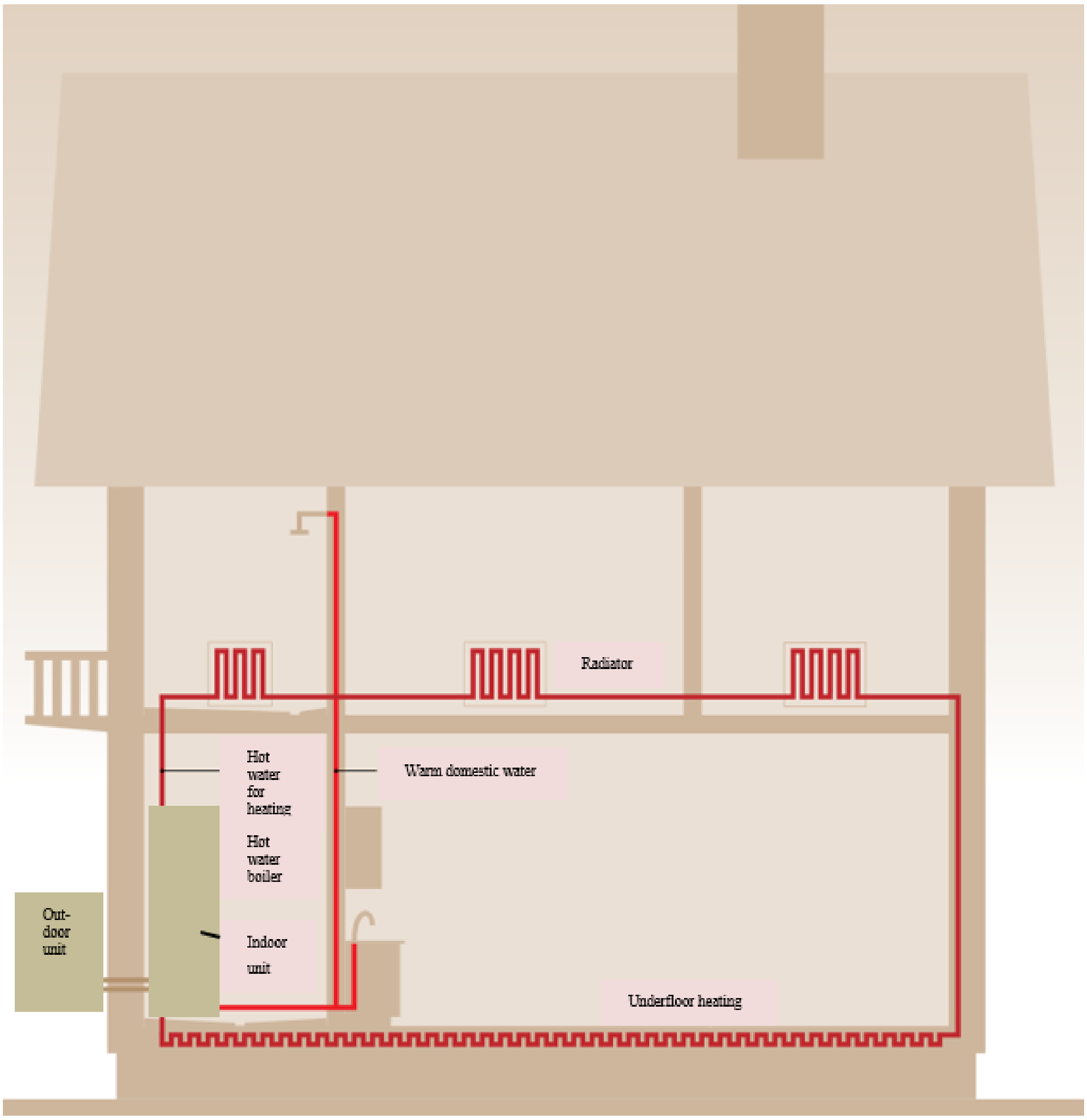


PICTURE 11. An air-air heat pump of a single-family house. (ibid)

An air-air source heat pump can be used as a complementary heating system. It cannot be used to heat domestic water, nor can it be connected to a water circulating heating network. (Motiva Oy, Lämpöä ilmassa, 2012) One indoor unit supplies heat for a 30 to 100 square meter area, depending on the structure and size of the house. Dividing walls and a complicated structure of a house restrict the flow of air between rooms. (Seuna, Ilmalämpöpumppu tukilämmityslähteenä, 2018) In Finland, the coefficient of performance value of a heat pump varies, however the average value is around 2. This means that the heat pump produces double the amount of energy in comparison to the amount of electricity it consumes. For example, if the coefficient of performance value is 2, the pump consumes one kilowatt of electrical energy and produces two kilowatts of heat energy. (Motiva Oy, Lämpöä ilmassa, 2012)

An air-water heat pump can be used as the main heating method of a house for most of the year. The pump can be connected to a water circulating heat distribution network and can also be used to heat the domestic water supply. The pump is efficient up to temperatures of $-15 \ldots -20°C$ after which a supporting heating system (e.g. a heat storing fireplace) is needed to supply the heating demand. (Motiva Oy, Lämpöä ilmassa, 2012) Oftentimes, additional electrical resistors are used to boost the heating ability of the pump. These components are included in the air-water heat pump system. (Sulpu ry) When considering, for example updating a heating system of a house, this system is best suited for a house equipped with a water circulating heat distribution network, which uses oil, electricity, pellets or geothermal energy. (Motiva Oy, Lämpöä ilmassa, 2012)

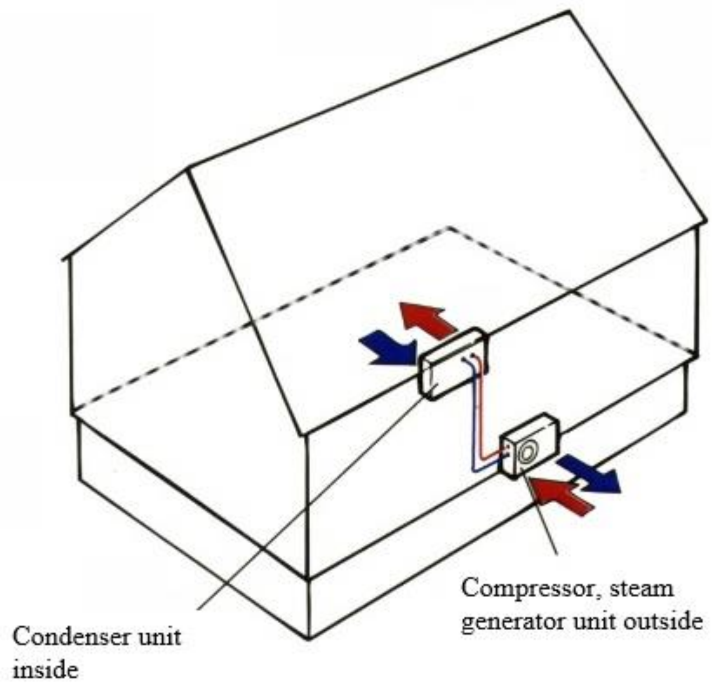
An air-water heat pump is a heating method often chosen when installation of a geothermal heat pump is not possible. As a geothermal heat pump, an air-water heat pump can be connected to an existing system and used as a complementary heating system together with, for example oil heating. In a system where air and oil are used to heat a house, the air-water heat pump can be used as the main heating system and during the colder season the oil boiler can be used a supporting system, if necessary. (Seuna, Ilma-vesilämpöpumput, 2018) The coefficient of performance value of an air-water heat pump in Finland is between 1,4 and 2,7. (Energiatehokas koti-hanke, 2018)



PICTURE 12. An air-water heat pump in a single-family house.

An exhaust air heat pump uses the heat energy of exhaust air from ventilation ducts of a house to heat its indoor spaces. It can also be used to heat both the water of the water circulating heating network and the domestic water of a house. The system requires supply air and exhaust air ducts. (Energiatehokas koti, 2017) Due to the source of heat energy being a constant flow of exhaust air with a temperature of 21 to 25℃, an exhaust air heat pump produces a constant output of heat throughout the year. The temperature of the exhaust air indicates how much heat energy was obtained from the extract air; the colder the exhaust air, the more energy was obtained. Equipment today can achieve an exhaust air temperature of −15℃. Depending on the type of pump used, the system can also be used for cooling. (Seuna, Poistoilmalämpöpumppu, 2018)

An exhaust air heat pump is not sufficient to heat a house throughout the entire year. A complimentary heating system is required, especially during the winter season when demand for heat is higher than during the rest of the year. Also, additional electrical resistors can be used to boost the heating ability of the pump, especially when heating the domestic water supply. (ibid)



PICTURE 13. An exhaust air pump of a single-family house. (Sulpu ry)

3.2.6 Fireplaces

The use of fireplaces has been common in Finland for centuries. Over time, the use of wood fuels has developed from open camp fires to modern heat storing fireplaces. The use of fireplaces for heating decreased in the 1930’s due to trends in urbanisation and the development of central heating furnaces. Due to the development of district heating the use of wood fuels decreased further in the 1960’s. As electric heating became more common in the 1980’s the share of wood fuels in heating decreased again. Even though the use of wood fuels has decreased, the role as a supplimentary and/or complimentary heating method has remained. During the 21st century, the need to curb the effects of global warming and reduce the use of fossil fuels has increased the popularity of wood fuels. Today, when considering heating methods for a home, wood burning fireplaces are often installed as a complimentary heating method. (Motiva Oy. Kodin tulisijat, 2017)

The main structure of a fireplace consists of a fire grate, an ash pan, a firebox (consisting of a fire and smoke chamber), a smoke duct (consisting of flues and an air chimney), a flue damper, a thoat, the frame and the shell. The fire grate of a fireplace is a type of grid where the fuel (e.g. wood) sits. Air flows throught the grid to ensure the burning process. Beneath the grate is the ash pan which is used to store the ash created by the fire. The ash must be removed regularly to ensure an sufficient airflow when using the fireplace. The firebox is often closed with hatches, however it can also be open on one or more sides. A narrowing called a throat in between the firebox and smoke chamber ensures that the flow velocity of the combustion gases increases and that the gases are sucked from the firebox and are removed. The combustion gases flow through the flues inside the fireplace releasing heat into the frame of the fireplace. The frame and shell of the fireplace is made of a material which can withstand the effects of heat expansion. The materials used and thickness of the shell determines the rate and efficiency of heat release. (ibid)

The flow of heat from the combustion gases and the cooler indoor air is known as the counterflow principle. As the heat from the combustion gases flows down the side of the fireplace in flues and releases its heat into the shell, the cooler indoor air flows up against the fireplace wall and heats up. (Museovirasto, 2000)

Fireplaces can be reviewed as a heat source accoring to their heat capacity. Some fireplaces release the combustion heat they produce quickly into the surrounding environment, whereas for example heat storing fireplaces release heat slowly. The following table indicates the efficiency of the burning and heat-transfer process of various fireplaces. As can be seen from the table, pellet burning fireplaces have the highest efficiency and open fireplaces (often used as a decorative element) has the lowest efficiency.

TABLE 2. The efficiency of various fireplaces.

FIREPLACE	**EFFICIENCY %**
Open fireplace	< 30%
Heat-storing fireplace	80-85%
Baking oven	80-85%
Stove, sauna stove	50-70%
Pellet burning fireplace	75-90%

*If the heat stored is strored from only the baking process, the efficiency is then 5-10 %.

(Motiva Oy. Kodin tulisijat, 2017)

4 CASE EXAMPLE

4.1 Basic information on the property

The case example used for this thesis is a single-family home built in 1958. The property is located in a suburb of a city located in Päijänne Tavastia. The house is 107 square meters large. The living area makes up 79 square meters and is situated on two floors. The house is situated on a 1666 square meter plot. The total roof area is 118 square meters. The house is occupied by three people.

PICTURE 15. The street view of the property. (Photo: Owner, 1.4.2018)

PICTURE 16. The house photographed from the side of the garden. (Photo: Owner, 1.4.2018)

During the years of 2002 to 2004, the property has undergone renovation work. All electrical work and the main distribution board were renewed, as was the water supply network of the property. Underfloor heating was added in the wetrooms and passageway on the lower floor. The kitchen was renovated as were all surfaces in the house. Outside, the house was painted, the drainage system and thermal insulation was installed, and the plinth was resurfaced. Also, thermal insulation was added in the roof of the house. The oil tanks were also renewed during 2002 to 2004. The windows of the house were renewed in 1992. The water supply network was renewed in 2000 and the water main to the house was renewed in 1990.

4.1.1 Location

In the component master plan of the city in question seen below in Picture 4, it can be seen that the house is located in a residential area. According to the definitions of the markings in the map, the light brown areas marked with the letter A indicate residential areas, the green areas marked with the letters VL or VU indicate recreational and sports areas and the dark red areas marked with the letter C indicate areas allocated for central services, such as the service industry, administration services and workplaces and living areas with little or no environmental impact. The blue areas marked with the letter T indicate industrial areas allocated for businesses. (Lahden läntisten osien osayleiskaava, 2016)

PICTURE 17. Component master plan of the city. The location of the house is in an area marked A-7.

4.1.2 Heating

The house is heated using light fuel oil. A Jämä Nova oil boiler, an Oilon Junior oil burner and two 1500 litre oil tanks are all situated on the bottom floor of the house in a boiler room. The oil boiler was renewed in 2000 and the oil burner was changed in 2010. The oil is used for heating the hot water radiators, which are situated throughout the house. The underfloor heating installed in the wet rooms and hallway on the lower floor also use oil. The underfloor heating installed in the smaller bathroom on the upper floor uses electricity. The sauna has two stoves, one which uses wood as a fuel and one which uses electricity.

PICTURE 18. The boiler and burner in the boiler room. (Photo: Owner, 1.4.2018)

PICTURE 19. Two 1500 litre oil tanks in the boiler room. (Photo: Owner, 1.4.2018)

The house does not have a fireplace, however a chimney still exists in the structure of the wall in between the kitchen and living room. The chimney was used for an old wood burning stove, which used to be in the kitchen. It was closed up after the wood burning stove was removed. This existing structure would make installing a fireplace fairly easy.

4.1.3 Ventilation

The air in the house is ventilated using a natural ventilation system. In a house where the air is ventilated naturally, the supply air is supplied and removed from an indoor space without the use of mechanical systems.

The windows of the house were renewed in 1992. The old windows were changed to triplicate windows, which can be seen in PICTURE 9.

PICTURE 20. The triplicate windows renewed in 1992. (Photo: Owner, 1.4.2018)

4.2 Energy, Electricity and Domestic Water Consumption

To be able to study the data of energy, electricity and water consumption the years 2015 to 2017 were chosen as a time frame.

4.2.1 Energy and Electricity Consumption

During the 14 years the residents have lived in the house, the total amount of oil consumed was 31 887 litres. During the year 2015, 2234 litres of oil was utilised. The amount of oil consumed in 2016 was 2411 litres and 2017 2444 litres. The consumption of fuel has stayed fairly consistent with a slight incline during the past years.

The heating value of light fuel oil is 10,02 kWh/litre. (Motiva Oy, Energiatehokkuus-sopimukset, 2010) To calculate the amount of energy produced and consumed the amount of oil consumed must be multiplied with the heating value. Thus, the amount of 31 887 litres of light fuel oil produces approximately 319 507 kWh of energy, equivalent to 320 MWh of energy. Furthermore, in 2015 the amount of energy produced with 2234 litres of light fuel oil was approximately 22,4 MWh. In 2016, the amount of energy produced was approximately 24,2 MWh and in 2017 approximately 24,5 MWh. These values are considered the theoretical amount of energy used, losses due to for example boiler efficiency have not been considered in this calculation. The amount of energy used was consumed mostly by the heating of spaces and domestic water.

In 2015, 6132 kWh of electricity was consumed. The amount of electricity consumed in 2016 was 6021 kWh and 2017 5038 kWh. This information was confirmed from Lahti Energia on 22.3.2018. The electricity is consumed by the electric appliances, underfloor heating in the upstairs bathroom and occasionally the sauna.

4.2.2 Domestic Water Consumption

Domestic water consumption in the year 2015 was 130 cubic meters. During the year 2016 the water consumption was 119 cubic meters and in 2017 114 cubic meters. Oil is used to heat the domestic water and the energy required for this is included in the total energy consumed indicated in chapter 5.2.1.

4.3 CO_2 Emissions

The fuels used today are light fuel oil and electricity. According to the CO_2 emission calculations shown in chapter 2.2.1, the CO_2 emissions of 2015-2017 are as follows:

The CO_2 emissions of light fuel oil and electricity in 2015 were:
Oil: $22{,}384\ \mathrm{MWh/a} \cdot 261\mathrm{kgCO_2/MWh} = 5842{,}2\ \mathrm{kgCO_2/a}$
Electricity: $6{,}132\ \mathrm{MWh/a} \cdot 181\mathrm{kgCO_2/MWh} = 1109{,}9\ \mathrm{kgCO_2/a}$
Total: $5842{,}2\ \mathrm{kgCO_2/a} + 1109{,}9\ \mathrm{kgCO_2/a} = 6952\ \mathrm{kgCO_2/a}$

The CO_2 emissions of light fuel oil and electricity in 2016 were:

Oil: $24{,}158\ \mathrm{MWh/a} \cdot 261\mathrm{kgCO_2/MWh} = 6305{,}3\ \mathrm{kgCO_2/a}$

Electricity: $6{,}021\ \mathrm{MWh/a} \cdot 181\mathrm{kgCO_2/MWh} = 1089{,}8\ \mathrm{kgCO_2/a}$

Total: $6305{,}3\ \mathrm{kgCO_2/a} + 1089{,}8\ \mathrm{kgCO_2/a} = 7395{,}1\ \mathrm{kgCO_2/a}$

The CO_2 emissions of light fuel oil and electricity in 2017 were:

Oil: $24{,}48\ \mathrm{MWh/a} \cdot 261\mathrm{kgCO_2/MWh} = 6391{,}6\ \mathrm{kgCO_2/a}$

Electricity: $5{,}038\ \mathrm{MWh/a} \cdot 181\mathrm{kgCO_2/MWh} = 911{,}9\ \mathrm{kgCO_2/a}$

Total: $6391{,}6\ \mathrm{kgCO_2/a} + 911{,}9\ \mathrm{kgCO_2/a} = 7303{,}5\ \mathrm{kgCO_2/a}$

Average total CO_2 emissions for the three years: $7216{,}9\ \mathrm{kgCO_2/a}$

The total CO_2 emissions caused by the oil heating system: $18539{,}1\ \mathrm{kgCO_2/a}$

The total CO_2 emissions caused by electricity consumption: $3111{,}6\ \mathrm{kgCO_2/a}$

Total CO_2 emissions: $21650{,}7\ \mathrm{kgCO_2/a}$

5 CHOOSING THE MOST SUITABLE HEATING METHOD

A single-family house requires heating for its living areas, wet rooms, supply air and water supply. A suitable heating method depends on the need and requirements of the house and the owner it is designed for. Initial factors effecting the choice of heating method are, for example the size of the house, the energy demand, the location of the property, local legislation and the budget set aside for the system. The size of the house effects whether it is more profitable to invest in a more expensive heating system which uses affordable energy or on a more affordable system which uses a possibly more expensive energy source. The location of the property can rule out certain heating systems. For example, district heating is not available in some areas. Also, the type of ground of the property can determine the possibility of geothermal borehole installation. (Motiva Oy, Lämmitys, 2018)

The energy demand of a property is a key factor when evaluating the size and type of a suitable heating system. Therefore, before choosing a heating method it is beneficial to evaluate if the energy demand of a property can be decreased by, for example improving the insulation of the roof, walls, windows and base floor of a house. Also, for example, the expense of the system, the price of the fuel now and in the future, manageability, space requirement, and environmental issues need to be evaluated. The expense of the system includes expenses during the construction stage, annual energy costs, fixed annual charges, and maintenance charges. Environmental issues are, for example, CO_2 and particulate matter emissions caused by the system. (Motivan hankintapalvelu. 2016)

When considering the environment, the most suited option would be to choose a heating system which utilises renewable energy as an energy source. Renewable energy is for example, wood, pellets, geothermal energy, solar power and wind energy. Also, district heating can be considered renewable if it is produced using renewable energy sources. (ibid)

When renovating an existing house and its heating system, it is beneficial to consider whether the primary heating system should be completely renewed or if the installation of a complementary heating system is a more valuable option. Whether renovating an existing house or building a new one, it is profitable to consider if the amount of purchased energy can be decreased with a complementary heating system. Complementary heating systems can be, for example heat storing fireplaces, solar heating systems, and air source heat pumps. These systems are discussed further in chapter three. (Motiva Oy, Tukilämmitysjärjestelmät, 2016)

5.1 Choosing a Heating Method for the Case Property

In this chapter the beforementioned heating systems are compared from the aspect of cost, emissions and use. When considering the cost of the system, the cost of the fuel source, initial investment of the system and possible maintenance costs are evaluated. When discussing CO_2 emissions, only the emissions of the heating system are evaluated. The CO_2 emissions of the electricity consumed for, for example the household appliances and the underfloor heating of the upper floor bathroom are not taken into account. A lifespan of 20 years is used when comparing costs and emissions of the different systems. Data from a calculator, which compares various heating systems (Motivan Pientalon lämmitystapojen vertailulaskuri) is used for some aspects of the comparison. The values given by the calculator are estimations. If there is a variation in costs of systems or products, the most expensive option is taken into account when calculating the costs of the systems to ensure that the, so called, worst case scenario is considered.

The comparison of heating systems is done taking into consideration the limitations of the case property of this study. Whether or not the primary heating system, light fuel oil heating, should be changed is considered and the option of installing a complementary heating system is reviewed.

5.1.1 Geothermal Heat Pumps

From the point of view of the consumer, geothermal heating systems are fairly easy to use as the system is low maintenance. The lifetime expectancy of a geothermal heat pump is approximately 15 to 30 years and the expectancy of the compressor of the system approximately 10 to 15 years. (Energiatehokas koti-hanke, 2016.) A geothermal heating system uses a water circulating heating network to distribute the heat it produces. The property is equipped with said network (renewed in 2000) and thus no major changes need to be done to the heating network. However, the oil boiler, burner and oil tanks situated in a boiler room would need to be removed. The space is suitable for the geothermal heating system equipment.

Horizontal installation of geothermal pipes requires a lot of space and involves digging up a lot of earth, thus vertical borehole installation is better suited for the case property. The borehole can then also be used for cooling. Geothermal borehole drilling and installation requires a permit from the city. The property is not situated in a groundwater area, which is one of the preventive factors considered when applying for a permit.

A risk when drilling a borehole geothermal well is sizing the depth of the well poorly. A limited amount of heat energy can be attained from a geothermal well, thus assuring the well is deep enough is important: if a well is undersized the system must compensate with using more electricity to supply enough heat and thus decreasing the efficiency of the system and increasing the size of the electricity bill. In a worst-case scenario, a well can dry out. To minimize risks, sizing of geothermal wells and systems should always be done by professionals with the correct equipment. Single-family house cases are sized using specific programs, which calculate a theoretical depth of a geothermal well. 10 to 20 meters is usually added to this value to ensure the depth of the well is sufficient. (Ministry of Environment, 2013.) A well, which is sized generously can withstand the demand load more efficiently, which in turn leads to a better coefficient of performance. (Seuna, Lämpöpumput, UKK)

The initial investment of a geothermal heating system is high; however, the operation costs are minimal due to low energy costs and low maintenance. The profitability of a geothermal heat pump is higher the bigger the house is. According Motiva, if a house is 150 square feet or larger, a geothermal heating system is a viable option when choosing a heating system. When changing heating systems of a house, a geothermal heat pump for a 150 square meter house is estimated to cost 15 000 to 20 000 euros. (Seuna, Maalämpöpumppu, MLP, 2018) In Finland, it is possible to receive tax credit for the work done, for example, on the installation of a geothermal heat pump, thus decreasing the initial cost of the system. This can be a maximum of 2400 euros annually with an excess of 100 euros. Receiving tax credit is personal, so it is possible for a couple to both receive tax credit, totalling 4800 euros. (Verohallinto, 2018)

According to a calculator provided by Motiva used to compare heating systems, the initial evaluated investment of a geothermal heating system (coefficient of performance 3) for the case property of this study would be 15 000 euros. A new compressor at approximately 10 years would cost approximately 2500 euros. (Energiatehokas koti-hanke, 2016) The cost of the fuel used by the geothermal heating system and the cost of the system for the case property over a 20-year period can be seen in the following table. 1/3 of the energy produced by a system is generating with electricity and thus the cost of fuel can be considered 1/3 that of direct electrical heating. Calculations regarding the table can be seen in Appendix 4.

TABLE 3. The cost of a geothermal heating system over a period of 20 years.

Geothermal Heating		
Year	**Cost of fuel/ €**	**Cost of system/ €**
1	974.71	15974.71
2	1019.55	1019.55
3	1066.45	1066.45
4	1115.50	1115.50
5	1166.82	1166.82
6	1220.49	1220.49
7	1276.63	1276.63
8	1335.36	1335.36
9	1396.78	1396.78
10	1461.03	1461.03
11	1528.24	1528.24
12	1598.54	1598.54
13	1672.07	1672.07
14	1748.99	1748.99
15	1829.44	4329.44
16	1913.60	1913.60
17	2001.62	2001.62
18	2093.70	2093.70
19	2190.01	2190.01
20	2290.75	2290.75
Total €	**30900.28**	**48400.28**

The cost of fuel, in this case electricity, over a matter of 20 years totals approximately 30 900 euros. The cost of the entire system, including the initial investment, new compressor and cost of fuel, over a matter of 20 years totals approximately 48 400 euros. The cost of a new compressor, 2500 euros, is added at the 15-year mark. Possible maintenance fees are disregarded in this calculation. According to the heating system calculator provided by Motiva, the price of electricity has changed on average 4,6 percent over the last 10 years. This data is provided by Statistics Finland. This trend is taken into consideration when calculating the future cost of electricity.

The CO_2 emissions of a geothermal heating system are low due to the energy source being renewable. However, 1/3 of the energy produced by a system is generated with electricity. Thus, the CO_2 emissions of geothermal heating can be considered 1/3 of that of electrical heating. By using the energy consumption values (used for heating and produced by light fuel oil) of the case property introduced in chapter 4.3 and the emission factor of electricity introduced in chapter 2.2.1, the CO_2 emissions a geothermal heating system over a matter of 20 years can be seen in the following table. Calculations regarding the table can be seen in Appendix 4.

TABLE 4. The CO_2 emissions caused by geothermal heating over 20 years.

Geothermal Heating	
Year	**Emissions/ kgCO2**
1	1428.53
2	1428.53
3	1428.53
4	1428.53
5	1428.53
6	1428.53
7	1428.53
8	1428.53
9	1428.53
10	1428.53
11	1428.53
12	1428.53
13	1428.53
14	1428.53
15	1428.53
16	1428.53
17	1428.53
18	1428.53
19	1428.53
20	1428.53
Total kgCO2	**28570.60**

The total amount of CO_2 emissions caused over 20 years is approximately 28 570 $kgCO_2$.

5.1.2 Pellet Heating

Pellet heating is fairly easy to use from the point of view of the consumer. Most systems are automated; however, systems require more work than for example oil heating does. The system requires careful maintenance work to ensure it is used safely. For example, the soot needs to be removed regularly (when the temperature of the flue gas reaches $20 - 30°C$) to minimise a fire hazard and ensure a clean burning process. Also, pellets produce ash, which needs to be removed. Most systems include an automated ash removal unit, which decreases the need for cleaning by hand. Pellet heating also requires some manual labour: the fuel is delivered in large bags, which needs to be transferred into the storage unit. Proper equipment to move said heavy bags is needed. The storage unit should be cleaned every second year. (Motiva Oy, 2012)

Risks related to automated pellet heating systems mostly relate to the fuel feeding system. Also, when using pellet boilers, there is a risk of back fire. This can happen due to multiple reasons. For example, a small spark from the furnace can create a fire, which slowly moves through the fuel distribution line to the fuel storage unit. A fire can also erupt if excess pressure builds in the burner. These malfunctions can be averted by ensuring the system is designed efficiently and equipped with the correct safety equipment. Also, performing careful maintenance work and necessary repairs and removing soot is important to ensure the system works as it should. (Turvallisuus- ja kemikaalivirasto, 2017)

The cost of a pellet heating system depends on how much of the existing system needs to be changed. Changing from oil heating to pellet heating can be fairly easy as both systems use the same equipment; oftentimes it is enough to change the burner of an oil heating system to a pellet burner. However, better efficiency of the system is achieved by also using a boiler specifically meant for pellet heating. (ibid) According to a calculator used to compare heating systems provided by Motiva, the initial investment of a pellet heating system (coefficient of performance 3) for our case property would be 12 000 euros.

The cost of the fuel used by the pellet heating system and the cost of the system for the case property over a matter of 20 years can be seen in the following table. Calculations regarding the system can be seen in Appendix 4.

TABLE 5. The cost of the fuel and system over a matter of 20 years.

Pellet Heating		
Year	**Cost of fuel/ €**	**Cost of system/ €**
1	1349.60	13349.60
2	1422.48	1422.48
3	1499.29	1499.29
4	1580.25	1580.25
5	1665.59	1665.59
6	1755.53	1755.53
7	1850.33	1850.33
8	1950.25	1950.25
9	2055.56	2055.56
10	2166.56	2166.56
11	2283.55	2283.55
12	2406.87	2406.87
13	2536.84	2536.84
14	2673.83	2673.83
15	2818.21	2818.21
16	2970.40	2970.40
17	3130.80	3130.80
18	3299.86	3299.86
19	3478.05	3478.05
20	3665.87	3665.87
Total €	**46559.70**	**58559.70**

The cost of fuel over a matter of 20 years totals approximately 46 600 euros. The cost of the entire system, including the initial investment and cost of fuel, over a matter of 20 years totals approximately 58 600 euros. The cost of the pellet storage unit and possible maintenance costs are disregarded in this calculation. According to the heating system calculator provided by Motiva, the price of pellets has changed on average 5,4 percent over the past 10 years. The data is provided by Statistics Finland. This trend is taken into consideration when calculating the future cost of fuel.

Pellets are a locally produced renewable fuel as they are made from side-products of the wood industry. The environmental impact of pellet heating is low as they are considered a carbon-neutral fuel source. The CO_2 created during the burning process is directly proportional to the CO_2 trees bind to themselves as they grow. Particle emissions of pellet heating are also low due to the fuel being homogenous, the low moisture content of the pellets and the even burning process of the system. (Bioenergia ry, Pellettienergia)

The case property uses an average of 2500 litres (2,5 m^3) of light fuel oil annually. 1000 litres of oil is equivalent to approximately 2100 kilograms of pellets. In cubic meters, one cubic meter of oil is equivalent to 3,3 cubic meters of pellets. (Bioenergian Pikkujättiläinen) Thus, approximately 5300 kilograms and 8,3 cubic meters of pellets is needed to meet the annual energy demand of the case property.

According to the CO_2 calculations introduced in chapter 2.2.1, the CO_2 emissions of burning pellets are $0\,\mathrm{kgCO_2/a}$ due to the emission factor of wood-based fuels being $0\,\mathrm{kgCO_2/MWh}$ (TABLE 1). However, when including production and transportation emissions, the average CO_2 emission factor of pellets in the Nordic Countries is $30\,\mathrm{kgCO_2/a}$. (Bioenergia ry) The evaluated CO_2 emissions of pellet heating over a matter of 20 years can be seen in the following table. Calculations regarding the table can be seen in Appendix 4.

TABLE 6. The CO_2 emissions caused by a pellet heating system over 20 years.

Pellet Heating	
Year	**Emissions/ kgCO2**
1	710.32
2	710.32
3	710.32
4	710.32
5	710.32
6	710.32
7	710.32
8	710.32
9	710.32
10	710.32
11	710.32
12	710.32
13	710.32
14	710.32
15	710.32
16	710.32
17	710.32
18	710.32
19	710.32
20	710.32
Total kgCO2	**14206.36**

The total amount of CO_2 produced by a pellet heating system are approximately 14 200 $kgCO_2$.

5.1.3 Oil Heating and Complementary Heating Systems

The option of keeping the existing oil heating system in place must also be considered. The oil boiler was renewed in 2000 and the burner in 2010 and are thus still in good condition.

The use of an oil heating system is easy from the point of view of the consumer. The system is automated and requires little maintenance work. Oil burners should be serviced approximately every two years, or when 5000 litres has been consumed by the system. The first inspection of oil tanks should be done after the first ten years, after which the inspector sets the date for future inspections. Boilers can also be inspected; however, it is not mandatory. The aim of a boiler inspection is to ensure heat is produced efficiently and economically. (Motiva, Pientalon lämmitysjärjestelmät)

It is difficult to foresee the development of oil prices as they tend to vary greatly due to multiple factors, such as world politics. According to Kauppalehti, the current trend (4/2018) indicates that crude oil prices are increasing and the production of oil by OPEC countries (the Organisation of the Petroleum Exporting Countries) is dropping. In April of 2018, oil production of OPEC countries was 32,12 million barrels a day, which is 70 000 barrels less than the month before. (Sjöström, M. 2018)

The cost of fuel used by the oil heating system of the case property over a matter of 20 years can be seen in the following table. The expected lifespan of an oil boiler is approximately 20 to 30 years and the lifespan of a burner is approximately 10 to 15 years. (Energiatehokas koti-hanke) According to these evaluations, the oil boiler of the existing system will need to be renewed in 2-12 years and the boiler in 2-7 years. Thus, the expected cost of the system is approximately 1000 euros for a new burner and approximately 2600-3800 euros, depending on the model, for a new Jäspi-boiler (similar to the existing unit). The calculations are done using the most expensive option. Calculations regarding the table are seen in Appendix 4.

TABLE 7. The cost of fuel and the system over a matter of 20 years.

Oil Heating		
Year	**Cost of fuel/ €**	**Cost of system/ €**
1	2084.17	2084.17
2	2196.71	2196.71
3	2315.33	2315.33
4	2440.36	2440.36
5	2572.14	2572.14
6	2711.04	2711.04
7	2857.43	3857.43 1)
8	3011.73	3011.73
9	3174.37	3174.37
10	3345.78	3345.78
11	3526.46	3526.46
12	3716.88	7516.88 2)
13	3917.60	3917.60
14	4129.15	4129.15
15	4352.12	4352.12
16	4587.13	4587.13
17	4834.84	4834.84
18	5095.92	5095.92
19	5371.10	5371.10
20	5661.14	5661.14
Total €	**71901.40**	**76701.40**

1) The cost of a new burner, 1000€ is added

2) The cost of a new boiler, 3800€ is added

The total cost of fuel over a matter of 20 years is approximately 71 900 euros. The cost of the entire system over a matter of 20 years totals approximately 76 700 euros. The cost of a new burner, 1000 euros, is added at the 7-year mark and the cost of a new boiler, 3800 euros, is added at the 12-year mark. According to the heating system calculator provided by Motiva, the price of oil has changed on average 5,4 percent during the past 10 years. This data is provided by Statistics Finland. This trend is taken into consideration when calculating the future cost of fuel.

An oil heating system has the most negative impact on the environment in comparison to the other heating systems discussed. Based on the calculations done in chapter 4.3, the average CO_2 emissions of the oil heating system in place today were approximately 6180 $kgCO_2/a$ and the total CO_2 emissions were 18 539,1 $kgCO_2/a$ during 2015-2017.

The evaluated CO_2 emissions of oil heating over a matter of 20 years can be seen in the following table. Calculations regarding the table can be seen in Appendix 4.

TABLE 8. The CO_2 emissions caused by an oil heating system over a 20-year period.

Oil Heating	
Year	**Emissions/ kgCO2**
1	6179.76
2	6179.76
3	6179.76
4	6179.76
5	6179.76
6	6179.76
7	6179.76
8	6179.76
9	6179.76
10	6179.76
11	6179.76
12	6179.76
13	6179.76
14	6179.76
15	6179.76
16	6179.76
17	6179.76
18	6179.76
19	6179.76
20	6179.76
Total kgCO2	**123595.30**

The total CO_2 emissions caused by an oil heating system over 20 years are approximately 123 600 $kgCO_2$. To decrease the emissions caused by the system, a complementary heating system can be installed to decrease the demand of oil.

Solar Energy as a Complementary System

Due to, for example, the irregular irradiation in Finland, solar energy systems are best considered as complementary heating systems. Both solar power and solar heating systems are easy to use from the consumer point of view. Both systems are low maintenance and easy to combine with other heating systems. The energy used is renewable and thus reduces the energy costs of the existing heating system. The lifetime expectancy of solar panels is 30 to 40 years and of the inverter 15 years. (Finsolar, 2016)

According to Sun Energia, the total roof area of the case property is $118\ \mathrm{m}^2$, of which $39\mathrm{m}^2$ is suitable for solar panel installation. The map calculation takes into consideration the annual irradiation on every square meter of the roof of the house and the surrounding shading elements on the property. (Sun Energia, 2018) According to Helen Ltd, a system suited for the case property would be a 5 kW system consisting of 20 270 W solar panels covering $33\ \mathrm{m}^2$. The maximum estimated production of this system would only be approximately 4860 kWh annually. Installation costs including the solar panels would be 9785 euros. (Helen Ltd)

A more beneficial option for the case property is the use of a solar heating system. For the case property to be able to use said system, an additional energy storage unit (e.g. boiler) needs to be installed in addition to the existing oil boiler. As mentioned in chapter 3.2.4, the greatest benefit of the system (highest efficiency) is achieved by using solar heating to heat both the domestic water and the water of the heat distribution network. Solar energy can be used to heat approximately 50 percent of the domestic water demand. If the system is also used to produce heat energy for the water of the heat distribution network, approximately 25 to 35 percent of the total annual heat energy demand of the property can be covered by a solar heating system. (Motiva Oy, Pientalon lämmitysjärjestelmät)

To heat the domestic water of the case property, 4-8 square meters of thermal collector panels are needed. To heat the domestic water, 1-1,5 square meters of panels are required per consumer, in this case 3 people. According to Motiva, the consumption of water per resident in a household is approximately 35-50 litres per day, depending on consumption habits. Approximately 1000 kWh of energy is required to heat said water per resident. (Motiva Oy, Pientalojen lämmitysjärjestelmät) To heat both the domestic water and the water of the heat distribution network, 8-12 square meters of panels are required. (Motiva, Aurinkolämpöjärjestelmän mitoitus; Motiva Lämmitysjärjestelmien vertailulaskuri)

According to Finsolar, the price of a small thermal collector system $(4 - 20\mathrm{m}^2)$ is 500 to 1000 euros per square meter. Maintenance costs of a system this size during its lifetime are approximately 10 percent from initial costs, equivalent to 50 to 100 euros per square meter. A hot water boiler is estimated to cost 1500 to 2000 euros. (Finsolar, 2016) In Finland, it is possible to receive tax credit for the labour costs of solar heating system installation. As mentioned in chapter 5.1.1 when discussion geothermal heat pump installation, the maximum tax credit amount is 2400 euros annually with an excess of 100 euros. Receiving tax credit is personal, so it is possible for a couple to both receive tax credit, totalling 4800 euros. (Verohallinto, 2018)

According to the heating system comparison calculator, 5 square meters of panels are required to heat the domestic water supply of the case property. A system of this size would cost approximately 4500 euros. According to Motiva, heating the domestic water supply of a house consumes approximately 10 percent of total energy consumption annually. Thus, using a solar heating system to heat the domestic water supply, a saving of 5 percent can be achieved in the energy consumption and thus also of the emissions produced. The cost of the fuel used by the oil and solar heating system and the cost of the system over a period of 20 years can be seen in the following table. Calculations regarding this table can be found in Appendix 4.

TABLE 9. The cost of fuel and the system over a matter of 20 years.

Oil and Solar		
Year	**Cost of fuel/ €**	**Cost of system/ €**
1	1979.96	8479.96
2	2086.88	2086.88
3	2199.57	2199.57
4	2318.34	2318.34
5	2443.53	2443.53
6	2575.48	2575.48
7	2714.56	3714.56 [1)]
8	2861.15	2861.15
9	3015.65	3015.65
10	3178.49	3178.49
11	3350.13	3350.13
12	3531.04	7331.04 [2)]
13	3721.72	3721.72
14	3922.69	3922.69
15	4134.51	4134.51
16	4357.78	4357.78
17	4593.10	4593.10
18	4841.13	4841.13
19	5102.55	5102.55
20	5378.08	5378.08
Total €	**68306.33**	**79606.33**

[1)] The cost of a new burner, 1000€ is added

[2)] The cost of a new boiler, 3800€ is added

Over the period of 20 years, the investment costs of both the oil and solar heating systems need to be taken into consideration, including the thermal collectors, and the burner (cost added at 7-year mark) and boiler (cost added at 12-year mark) of the oil heating system. According to the heating system calculator provided by Motiva, the price of oil has changed on average 5,4 percent during the past 10 years. This data is provided by Statistics Finland. This trend is taken into consideration when calculating the future cost of fuel.

The CO_2 emissions caused by a solar heating/oil heating system over 20 years can be seen in the following table. The emission factors introduced in TABLE 1 are used to calculate the emissions of the system. Calculations regarding the table can be seen in Appendix 4.

TABLE 10. The CO_2 emissions caused by an oil/solar heating system over 20 years.

Oil and Solar	
Year	**Emissions/ kgCO2**
1	5870.78
2	5870.78
3	5870.78
4	5870.78
5	5870.78
6	5870.78
7	5870.78
8	5870.78
9	5870.78
10	5870.78
11	5870.78
12	5870.78
13	5870.78
14	5870.78
15	5870.78
16	5870.78
17	5870.78
18	5870.78
19	5870.78
20	5870.78
Total kgCO2	**117415.53**

The total CO_2 emissions caused by an oil/solar heating system are approximately 117 400 $kgCO_2$.

Air Heat pumps as Complementary Systems

According to Motiva, the air heat pumps suitable to be installed as a complementary heating system of an oil heating system are air-air heat pumps and air-water heat pumps. (Motiva Oy, Lämpöä ilmassa) As an exhaust air heat pump requires a mechanical exhaust ventilation system, it is not suitable for the case property of this study.

The efficiency of the heat pump effects the amount of energy the system can produce. As the efficiency depends highly on the temperature of the outdoor air, the amount of energy savings produced by the system vary. According to Motiva, an air-air heat pump with a coefficient of performance value of around 2 can produce approximately 30 to 40 percent of the annual energy demand needed to heat spaces. It is important to remember, that using the cooling function of a heat pump requires electricity. Cooling a 150 square meter house requires approximately 200-300 kWh of electricity annually. (Motiva Oy, Lämpöä ilmassa)

An air-air heat pump can be used to heat (or cool) the indoor air of the case property. Using the system requires little or no maintenance work and is thus easy to use. The filters of the system should be vacuumed monthly and the outdoor unit should be kept clean from leaves and other debris. The locations of the indoor and outdoor units need to be considered carefully, as the air needs to be distributed evenly throughout the house. The outdoor unit can be noisy and thus installation should be done away from, for example the bedroom. The lifetime expectancy of an air-air heat pump is approximately 10 to 20 years. According to the heating system comparison calculator, the initial investment of an air-air heat pump system for the case property would be 2000 euros.

The cost of fuel used by an oil/air-air heat pump system and the cost of the system over a period of 20 years can be seen in the following table. Calculations regarding the table can be seen in Appendix 4.

TABLE 11. Cost of an oil and air-air heat pump system over 20 years.

Oil and air-air heat pump		
Year	**Cost of fuel/ €**	**Cost of system/ €**
1	1306.70	3306.70
2	1377.26	1377.26
3	1451.63	1451.63
4	1530.02	1530.02
5	1612.64	1612.64
6	1699.73	1699.73
7	1791.51	2791.51 [1)]
8	1888.25	1888.25
9	1990.22	1990.22
10	2097.69	2097.69
11	2210.97	2210.97
12	2330.36	6130.36 [2)]
13	2456.20	2456.20
14	2588.83	2588.83
15	2728.63	2728.63
16	2875.98	2875.98
17	3031.28	3031.28
18	3194.97	3194.97
19	3367.50	3367.50
20	3549.34	3549.34
Total €	**45079.72**	**51879.72**

[1)] The cost of a new burner, 1000€ is added

[2)] The cost of a new boiler, 3800€ is added

Over the period of 20 years, the investment costs of both the oil and solar heating systems need to be taken into consideration, including the heat pump, and the burner (cost added at 7-year mark) and boiler (cost added at 12-year mark) of the oil heating system. According to the heating system calculator provided by Motiva, the price of oil has changed on average 5,4 percent during the past 10 years. This data is provided by Statistics Finland. This trend is taken into consideration when calculating the future cost of fuel.

The emissions of an oil and air-air heat pump heating system can be seen in the following table. As the cooling function requires electricity, annual emissions of 300 kWh of electricity are added to the emissions of light fuel oil. The emission factors introduced in TABLE 1 are used to calculate the emissions of the system. Calculations regarding the table can be seen in Appendix 4.

TABLE 12. The CO_2 emissions caused by an oil/air-air heat pump system over 20 years.

Oil and air-air heat pump	
Year	**Emissions/ kgCO2**
1	3947.55
2	3947.55
3	3947.55
4	3947.55
5	3947.55
6	3947.55
7	3947.55
8	3947.55
9	3947.55
10	3947.55
11	3947.55
12	3947.55
13	3947.55
14	3947.55
15	3947.55
16	3947.55
17	3947.55
18	3947.55
19	3947.55
20	3947.55
Total kgCO2	**78951.04**

The total CO_2 emissions caused by an oil and air-air heat pump system are 79 000 $kgCO_2$.

An air-air heat pump does not work as well with a water circulating radiator system as with a direct electrical heating network. (Motiva, Lämpöä ilmassa) Thus, of the two options, an air-water heat pump system is better suited for our case property.

Installing an air-water heat pump is beneficial for cases where, for example the installation of geothermal heating is not possible. The existing oil heating system of the case property works well alongside an air-water heat pump as it can be used to supply energy during the periods where demand is highest, for example the cold winter season. This system can only be used for heating. The indoor unit of the system can be installed in the boiler room alongside the existing oil heating equipment. The outdoor unit of the system produces a large amount of water, approximately 10 litres daily. This needs to be taken into consideration when choosing a location for the unit. (Motiva Oy, Lämpöä ilmassa)

The expected lifespan of an air-water heat pump 10-20 years. A new compressor for a heat pump system costs approximately 1000-2000 euros. According to the heating system comparison calculator, the initial investment of an air-water heat pump system for the case property would be 15 000 euros. The calculator also indicates that the air-water heat pump system can cover 80 percent of the energy demand.

The cost of fuel used by an air-water heat pump and oil heating system and the cost of the system over a period of 20 years can be seen in the following table. Calculations regarding the table can be seen in Appendix 4.

TABLE 13. The cost of an air-water heat pump and oil heating system over 20 years.

Oil and air-water heat pump		
Year	**Cost of fuel/ €**	**Cost of system/ €**
1	414.83	15414.83
2	437.23	437.23
3	460.84	460.84
4	485.72	485.72
5	511.95	511.95
6	539.60	539.60
7	568.73	1568.73 1)
8	599.45	599.45
9	631.82	631.82
10	665.93	665.93
11	701.89	701.89
12	739.80	4539.80 2)
13	779.75	779.75
14	821.85	821.85
15	866.23	866.23
16	913.01	913.01
17	962.31	962.31
18	1014.28	1014.28
19	1069.05	1069.04
20	1126.77	1126.77
Total €	**14311.02**	**34111.02**

1) The cost of a new burner, 1000€ is added

2) The cost of a new boiler, 3800€ is added

Over the period of 20 years, the investment costs of both the oil and solar heating systems need to be taken into consideration, including the heat pump, and the burner (cost added at 7-year mark) and boiler (cost added at 12-year mark) of the oil heating system. According to the heating system calculator provided by Motiva, the price of oil has changed on average 5,4 percent during the past 10 years. This data is provided by Statistics Finland. This trend is taken into consideration when calculating the future cost of fuel.

The CO_2 emissions of an air-water heat pump and oil heating system can be seen in the table below. The emission factors introduced in TABLE 1 are used to calculate the emissions of the system.

TABLE 14. The CO_2 emissions caused by an oil/air-water heat pump system.

Oil and air-water heat pump	
Year	**Emissions/ kgCO2**
1	1235.95
2	1235.95
3	1235.95
4	1235.95
5	1235.95
6	1235.95
7	1235.95
8	1235.95
9	1235.95
10	1235.95
11	1235.95
12	1235.95
13	1235.95
14	1235.95
15	1235.95
16	1235.95
17	1235.95
18	1235.95
19	1235.95
20	1235.95
Total kgCO2	**24719.06**

The total CO_2 emissions caused by an oil and air-air heat pump system are 24 700 $kgCO_2$.

5.1.4 Summary

The following figure compares the total cost of the fuel used by each system and the total cost of each heating system over a period of 20 years.

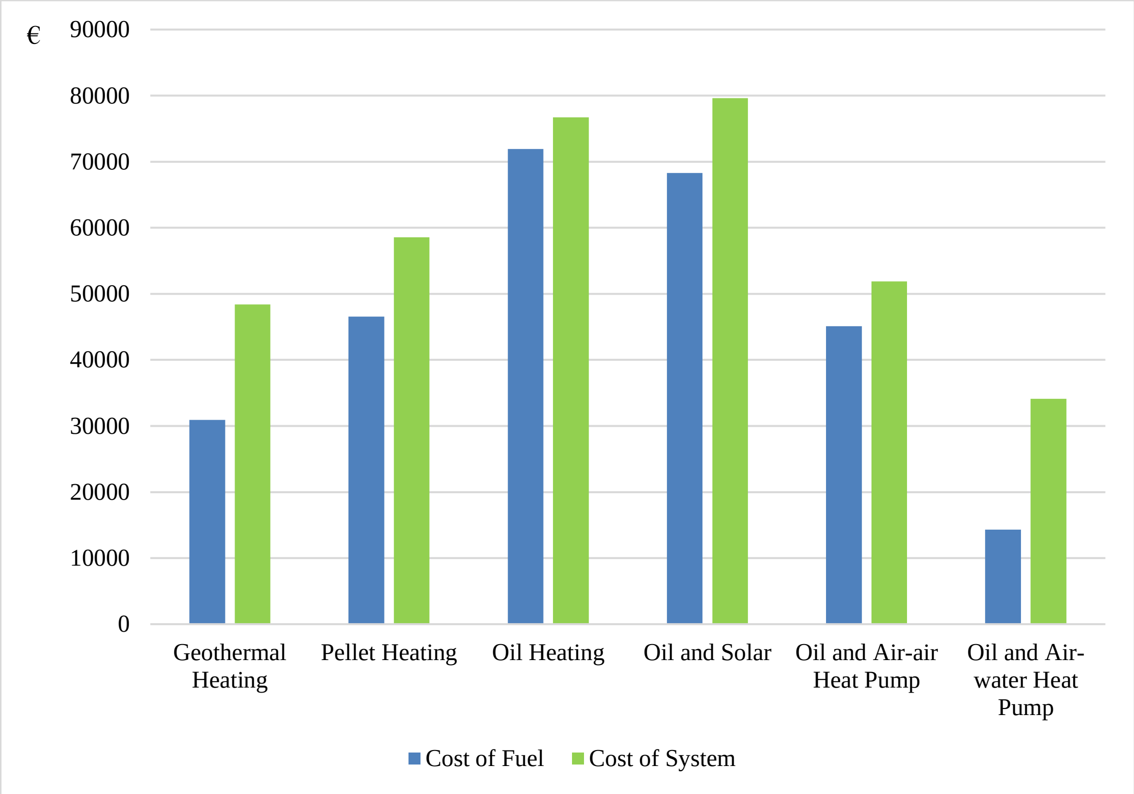


FIGURE 15. Comparison of the total cost of fuel and the total cost of each system over 20 years.

As can be seen from the figure, the oil and air-water heat pump system have the lowest cost of fuel and lowest system cost over a matter of 20 years. The second cheapest option is the geothermal heating system, after which the oil and air-air heat pump system. The oil and solar heating heating system is the most expensive option over a 20 year period. The largest fuel expense over 20 years is caused by the oil heating system.

The following figure compares the total CO_2 emissions in kilograms of CO_2 caused by each system over a period of 20 years.

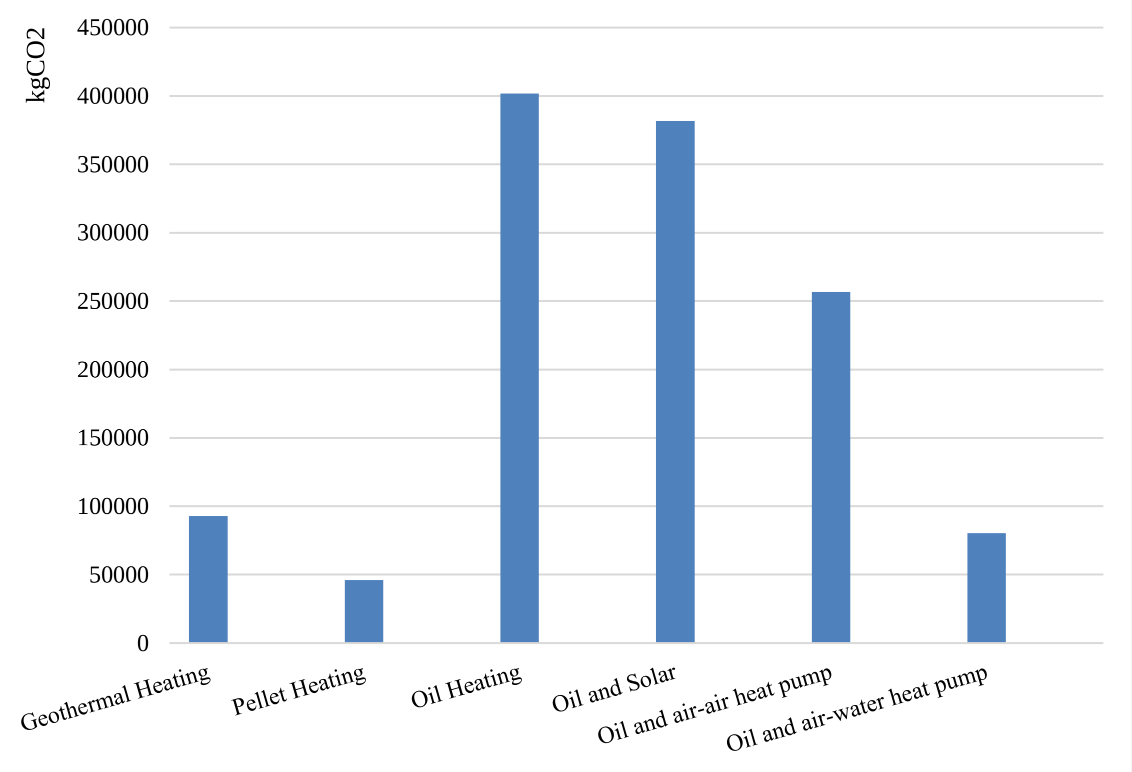


FIGURE 16. The CO_2 emissions comparison of heating systems over 20 years.

As can be seen from the figure, pellet heating causes the lowest CO_2 emissions over a period of 20 years. The second lowest emissions are caused by the oil and air-water heat pump system. This is due to the fact that an air-water heat pump can cover up to 80 percent of the energy demand required by the case property. It is important to remember, however, that an air-water heat pump does not work well in cold weather and can thus switch off. The system requires a fully sized heating system along side it, in this case the existing oil heating system, to ensure the production of energy. CO_2 emissions will increase as the consumption of oil increases. The third lowest emissions are caused by the electricity used by a geothermal heating system. The highest CO_2 emissions over 20 years are caused by oil heating.

6 CONCLUSION

The heating systems studied in this thesis were compared taking into consideration the use, cost and CO_2 emissions of each system over a period of 20 years. The case property of this study was used as an example and the limitations of the property were taken into account when performing the comparison. The compared heating systems were primary heating systems: geothermal heating, pellet heating and the existing oil heating. Complementary heating systems to be added on to the existing oil heating system were solar energy systems, air-air heat pumps and air-water heat pumps.

From the point of view of cost, the oil heating and air-water heat pump system was the most inexpensive option over a period of 20 years. CO_2 emissions of this system were also low as they were second lowest of all systems compared. The highest cost of both fuel and cost of fuel over 20 years was caused by the oil heating and oil and solar heating systems. Similarly, the highest emissions were caused by oil heating and oil and solar heating systems. The lowest CO_2 emissions were caused by the pellet heating system.

As oil heating causes high CO_2 emissions and the price of fuel varies greatly, as per wishes of the owner, systems which use an alternative fuel to light fuel oil were considered more seriously. Geothermal and pellet heating systems both have low CO_2 emissions and are easy to use from the point of view of the consumer. However, it was found that pellet heating is slightly more burdensome as it requires more maintenance work and the construction of a separate fuel storage system. Generally, geothermal heating systems are also more automated and carry less risks and is thus a more suitable option for the case property. Geothermal heating also has the lowest cost of fuel and system cost over a 20-year period after the oil consuming oil and air-water heat pump heating system.

The pros and cons of the studied heating systems have been gathered into the following table.

TABLE 15. The pros and cons of the heating systems studied in this thesis.

	Pros	Cons
Primary heating systems:		
Geothermal Heating	+ Renewable energy + Cost of energy low + System is low maintenance + Can use existing heat distribution network + Tax credit + CO_2 emissions low	- High initial investment - Requires a planning permit - Uses 1/3 electricity
Pellet Heating	+ Renewable energy + Cost of energy low + Can use existing heat distribution network and heat production equipment with minimal changes + No CO_2 emissions of the fuel + Lowest CO_2 emissions	- Requires a separate storage unit - Requires regular maintenance e.g. ash removal (unless the system is automated) - Risk of back fire - Requires more manual labour than other systems
Oil Heating	+ Oil heating system has a good efficiency + Fuel has excellent heat value + Existing system allows for easy addition of complementary systems	- Uses fossil fuel - Cost of energy varies greatly - Highest CO_2 emissions - Both the boiler and burner need to be replaced within 12 years

Complementary heating system with oil heating:		
Solar heating + oil	+ Oil has excellent heat value and the oil heating system has good efficiency + Solar energy is a renewable fuel + Solar energy decreases the amount of CO_2 emissions caused by oil slightly	- Most expensive option - Oil has highest CO_2 emissions
Air-air Heat Pump + oil	+ Low maintenance + Air-air heat pump is inexpensive	- Can be noisy - Efficiency depends on the outdoor air temperature: efficiency is low during cold weather when heating demand is highest
Air-water Heat Pumps + oil	+ Low maintenance + Pump works well with the existing oil heating system + Can theoretically cover 80% of energy production	- Can be noisy - Efficiency depends on the outdoor air temperature: efficiency is low during cold weather when heating demand is highest - System shuts down during cold weather, consumption of oil increases

As a conclusion, the most inexpensive option regarding the cost of fuel and cost of the system over a period of 20 years is the combination of the oil heating and air water heat pump systems. The least CO_2 emissions is caused by the pellet heating system. The geothermal heating system is considered the most user-friendly system as it, for example requires little maintenance work.

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APPENDICES

Appendix 1. Price data of direct electrical heating in 2017

TABLE 16. Price indicated in cents/kWh. Prices include transfer costs and taxes.

Kuluttajatyyppi	Vuosi	Kuukausi	Hinta snt/kWh	Vuosimuutos %
L2 (Pientalo, osittain varaava sähkölämmitys, pääsulake 3x25 A, sähkön käyttö 20 000 kWh/vuosi)	2017	Tammikuu	12,33	5
L2 (Pientalo, osittain varaava sähkölämmitys, pääsulake 3x25 A, sähkön käyttö 20 000 kWh/vuosi)	2017	Helmikuu	12,34	5
L2 (Pientalo, osittain varaava sähkölämmitys, pääsulake 3x25 A, sähkön käyttö 20 000 kWh/vuosi)	2017	Maaliskuu	12,42	4
L2 (Pientalo, osittain varaava sähkölämmitys, pääsulake 3x25 A, sähkön käyttö 20 000 kWh/vuosi)	2017	Huhtikuu	12,43	7
L2 (Pientalo, osittain varaava sähkölämmitys, pääsulake 3x25 A, sähkön käyttö 20 000 kWh/vuosi)	2017	Toukokuu	12,22	5
L2 (Pientalo, osittain varaava sähkölämmitys, pääsulake 3x25 A, sähkön käyttö 20 000 kWh/vuosi)	2017	Kesäkuu	12,19	5
L2 (Pientalo, osittain varaava sähkölämmitys, pääsulake 3x25 A, sähkön käyttö 20 000 kWh/vuosi)	2017	Heinäkuu	12,19	5
L2 (Pientalo, osittain varaava sähkölämmitys, pääsulake 3x25 A, sähkön käyttö 20 000 kWh/vuosi)	2017	Elokuu	12,18	4
L2 (Pientalo, osittain varaava sähkölämmitys, pääsulake 3x25 A, sähkön käyttö 20 000 kWh/vuosi)	2017	Syyskuu	12,17	4
L2 (Pientalo, osittain varaava sähkölämmitys, pääsulake 3x25 A, sähkön käyttö 20 000 kWh/vuosi)	2017	Lokakuu	12,34	3
L2 (Pientalo, osittain varaava sähkölämmitys, pääsulake 3x25 A, sähkön käyttö 20 000 kWh/vuosi)	2017	Marraskuu	12,35	3
L2 (Pientalo, osittain varaava sähkölämmitys, pääsulake 3x25 A, sähkön käyttö 20 000 kWh/vuosi)	2017	Joulukuu	12,35	3

(Statistics Finland, 2017)

Appendix 2. Price data of pellets in 2017

TABLE 17. Data of pellet prices was documented quarterly by Statistics Finland. Prices are in cent/kWh.

Tuote	Vuosi	Jakso	Hinta, indeksi	Vuosimuutos %
Puupelletti, Kuluttajahinta, snt/kWh	2017	Tammikuu	.	.
Puupelletti, Kuluttajahinta, snt/kWh	2017	Helmikuu	5,7	.
Puupelletti, Kuluttajahinta, snt/kWh	2017	Maaliskuu	.	.
Puupelletti, Kuluttajahinta, snt/kWh	2017	Huhtikuu	.	.
Puupelletti, Kuluttajahinta, snt/kWh	2017	Toukokuu	5,6	.
Puupelletti, Kuluttajahinta, snt/kWh	2017	Kesäkuu	.	.
Puupelletti, Kuluttajahinta, snt/kWh	2017	Heinäkuu	.	.
Puupelletti, Kuluttajahinta, snt/kWh	2017	Elokuu	5,7	.
Puupelletti, Kuluttajahinta, snt/kWh	2017	Syyskuu	.	.
Puupelletti, Kuluttajahinta, snt/kWh	2017	Lokakuu	.	.
Puupelletti, Kuluttajahinta, snt/kWh	2017	Marraskuu	5,7	.
Puupelletti, Kuluttajahinta, snt/kWh	2017	Joulukuu	.	.

(Statistics Finland, 2017)

Appendix 3. Price data of light fuel oil in 2017

TABLE 18. Prices are indicated in €/MWh.

Polttoaine	Vuosi	Kuukausi	Hinta	Vuosimuutos %
Kevyt polttoöljy, €/MWh	2017	Tammikuu	89,7	38,0
Kevyt polttoöljy, €/MWh	2017	Helmikuu	89,8	40,1
Kevyt polttoöljy, €/MWh	2017	Maaliskuu	87,0	19,6
Kevyt polttoöljy, €/MWh	2017	Huhtikuu	90,7	24,5
Kevyt polttoöljy, €/MWh	2017	Toukokuu	84,9	11,8
Kevyt polttoöljy, €/MWh	2017	Kesäkuu	81,9	0,9
Kevyt polttoöljy, €/MWh	2017	Heinäkuu	82,1	7,4
Kevyt polttoöljy, €/MWh	2017	Elokuu	84,5	11,3
Kevyt polttoöljy, €/MWh	2017	Syyskuu	87,6	13,1
Kevyt polttoöljy, €/MWh	2017	Lokakuu	88,6	6,6
Kevyt polttoöljy, €/MWh	2017	Marraskuu	92,8	17,8
Kevyt polttoöljy, €/MWh	2017	Joulukuu	91,8	4,3
Kevyt polttoöljy, €/MWh	2017	Vuosi yhteensä	87,6	15,2

TABLE 19. Prices are indicated in cent/litre.

Polttoaine	Vuosi	Kuukausi	Hinta	Vuosimuutos %
Kevyt polttoöljy, snt/l	2017	Tammikuu	90,0	38,0
Kevyt polttoöljy, snt/l	2017	Helmikuu	90,1	40,1
Kevyt polttoöljy, snt/l	2017	Maaliskuu	87,3	19,6
Kevyt polttoöljy, snt/l	2017	Huhtikuu	91,0	24,5
Kevyt polttoöljy, snt/l	2017	Toukokuu	85,2	11,8
Kevyt polttoöljy, snt/l	2017	Kesäkuu	82,2	0,9
Kevyt polttoöljy, snt/l	2017	Heinäkuu	82,4	7,4
Kevyt polttoöljy, snt/l	2017	Elokuu	84,8	11,3
Kevyt polttoöljy, snt/l	2017	Syyskuu	87,9	13,1
Kevyt polttoöljy, snt/l	2017	Lokakuu	88,9	6,6
Kevyt polttoöljy, snt/l	2017	Marraskuu	93,1	17,8
Kevyt polttoöljy, snt/l	2017	Joulukuu	92,1	4,3
Kevyt polttoöljy, snt/l	2017	Vuosi yhteensä	88,2	15,6

(Statistics Finland, 2017)

Appendix 4. Calculations for 20-year evaluations of cost and emissions

The consumption of light fuel oil of case property:

2015: 2234 L

2016: 2411 L

2017: 2444 L

Average (2015-2017): 2363 L

The amount of energy produced with light fuel oil:

2015: $2234\ \text{L} * 10{,}02\ \text{kWh/L} = 22384{,}68\ \text{kWh}$

2016: $2411\ \text{L} * 10{,}02\ \text{kWh/L} = 24158{,}22\ \text{kWh}$

2017: $2444\ \text{L} * 10{,}02\ \text{kWh/L} = 24488{,}88\ \text{kWh}$

Average (2015-2017): 23677,26 kWh

Geothermal Heating

Cost of fuel (year 1)

1/3 electricity of average total energy:

$\frac{23677{,}26\text{kWh}}{3} = 7892{,}42\ \text{kWh}$

Cost of 1/3 electricity based on December 2017 price 12,35 cents/kWh:

$$\frac{7892{,}42\ kWh * 12{,}35\,\frac{cents}{kWh}}{100} = 974{,}71€$$

The development of price is based on the annual percentage change average of the fuel price of the past ten years: 4,6%

Cost of system (year 1)

$$974{,}71€ + 15000€ = 15974{,}72€$$

Emissions (year 1)

Emission factor of electricity: $181\text{kgCO}_2/\text{MWh}$

$$7{,}89242\ \text{MWh} * 181\ \text{kgCO}_2/\text{MWh} = 1428{,}53\ \text{kgCO}_2$$

Pellet Heating

Cost (year 1)

Based on November 2017 price 5,7 cents/kWh:

$$\frac{23677{,}26\ kWh * 5{,}7\,\frac{cents}{kWh}}{100} = 1349{,}60€$$

The development of price is based on the annual percentage change average of the fuel price of the past ten years: 5,4%

Cost of system (year 1)

$$1349{,}60€ + 12000€ = 13349{,}60€$$

Emissions (year 1)

Emission factor of pellet heating caused by production and transportation: $30\ \mathrm{kgCO_2/MWh}$

$$23{,}67726\ MWh * 30\ \mathrm{kgCO_2/MWh} = 710{,}3178\ \mathrm{kgCO_2}$$

Oil Heating

Cost (year 1)

Based on 2017 average price 88,2 cents/L:

$$\frac{2363\ L * 88{,}2\,\frac{cents}{L}}{100} = 2084{,}166€$$

The development of price is based on the annual percentage change average of the fuel price of the past ten years: 5,4%.

Emissions (year 1)

Emission factor of light fuel oil: $261\ \mathrm{kgCO_2/MWh}$

$$23{,}67726\ \mathrm{MWh} * 261\ \mathrm{kgCO_2/MWh} = 6176{,}764\ \mathrm{kgCO_2}$$

Oil heating with solar heating energy as a complementary system:

Cost (year 1)

Solar heating saves 5%:

$$2084{,}166€ * 0.95 = 1979{,}96€$$

Cost of system (year 1)

Initial cost of solar heating system (4500 € + boiler 2000 €):

$$1979{,}96€ + 4500€ + 2000€ = 8479{,}96€$$

In addition, Burner 1000 € + boiler 3800 € (at year 7 and 12)

Emissions (year 1)

Emissions are 5% less than that of oil heating:

$$6176{,}764\ \mathrm{kgCO_2} * 0.95 = 5870{,}78\ \mathrm{kgCO_2}$$

Oil Heating with an air-air heat pump as a complementary system:

Cost (year 1)

10% of energy consumption consumed by heating the domestic water supply, 90% on the heating network.

$$23677{,}26\ kWh * 0.90 = 21309{,}534kWh$$

30% savings of energy consumption consumed by heating spaces created by air-air heat pump.

$$21309{,}534kWh * 0{,}3 = 6392{,}86\ kWh$$

Energy consumed to heat spaces (by oil when using heat pump):

$$21309{,}534kWh - 6392{,}8602kWh = 14916{,}6738\ kWh$$

Cost of fuel based on 2017 average price 87,6 €/MWh:

$$14{,}9166738\ MWh * 87{,}6\ €/MWh = 1306{,}700€$$

Cost of system (year 1), pump 2000€:

$$1306{,}700€ + 2000€ = 3306{,}70€$$

Emissions (year 1)

Emission factor of light fuel oil: $261\ \mathrm{kgCO_2/MWh}$

$$14{,}9166738\ \mathrm{MWh} * 261\ \mathrm{kgCO_2/MWh} = 3893{,}25\ \mathrm{kgCO_2}$$

CO2 produced by electricity (300kWh):

$$0{,}3\ \mathrm{MWh} * 181\ \mathrm{kgCO_2/MWh} = 54{,}3\ \mathrm{kgCO_2}$$

Total

$$3893{,}25\ \mathrm{kgCO2} + 54{,}3\ \mathrm{kgCO2} = 3947{,}55\ \mathrm{kgCO_2}$$

Oil Heating with an air-water heat pump as a complementary system:

Cost (year 1)

Air-water heat pump creates an approximate 80 % saving of energy consumption. The amount of energy still covered by light fuel oil:

$$23677{,}26\ kWh * 0{,}2 = 4735{,}452\ kWh$$

$$4{,}735452\ MWh * 87{,}6€/MWh = 414{,}83€$$

Cost of system (year 1):

Cost of air-water heat pump 15 000€

$$414{,}83€ + 15000€ = 15414{,}83€$$

Emissions (year 1)

$$4{,}735452\ \mathrm{MWh} * 261\ \mathrm{kgCO2/MWh} = 1235{,}95\ \mathrm{kgCO2}$$