LECo - Feasibility study

– Replacing oil heating with renewable energy

Eskola Village Service Ltd

Centria TKI

1. Introduction

This feasibility study reviews alternative heating solutions for a large property owned by Eskola Village Service Ltd located in Central Ostrobothnia, Finland. The focus of this research report is to assess the suitability of heat pumps or wood-chip heating as a primary heat source for heating the Eskola property. The goal is to replace the current oil-based system with a more cost-effective and environmentally friendly heating system.

2. About the LECo-project

The LECo project supports small communities in becoming self-sufficient regarding energy. The project aims at raising awareness about energy efficiency and the possibilities to use locally available renewable energy, such as wind, solar and hydropower, as well as side streams from industry, households and agricultural origin. The project gathers test groups from Finland, Sweden, Norway and Ireland. The goal is that the test group will become self-sufficient regarding energy making the most of locally available energy source and new technologies.

3. Village Service Ltd

Eskola is a village in Central Ostrobothnia, Finland. The nearest towns are Kannus, Toholampi and Sievi. One of the main developers of Eskola are the 400 villagers, who have founded Eskola Village Service Ltd to represent them.

IMAGE 1. Eskola Village Service Ltd logo

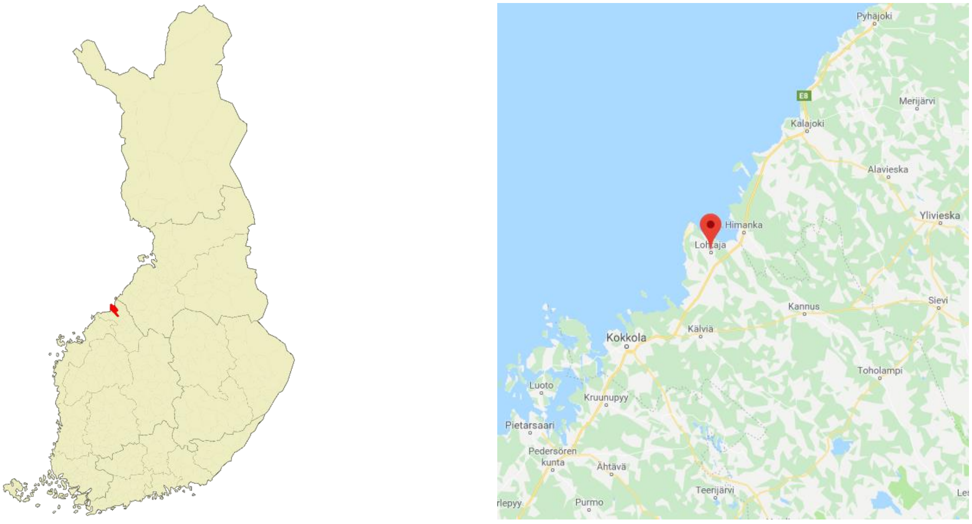


IMAGE 2. Location of Eskola

Eskola Village Service Ltd is a multi-service company owned by over 130 shareholders that consists of current and former villagers and other supporters.

There are around 400 inhabitants in Eskola, and although it is a rural village, there is very little agriculture. There are three major industrial workplaces in Eskola: a window and door factory, a sawmill and a concrete foundry. Eskola Village Service Ltd provides most of the basic services in the village: a kindergarten, a restaurant, domestic services and rental apartments.

4. The property in question

The property in question (the so-called Eskola House) is one of largest and the one with the highest maintenance cost of all the properties owned by Eskola Village Service Ltd. The Eskola House provides vacancy for the association’s own offices, village info office, kindergarten, library and a school. Eskola has been an example in various case studies concerning local and inhabitant-based development. It is also one of the example villages in EU's Smart Village initiative. Eskola is constantly trying to develop and better itself, and to take care of itself with all the diminishing public services.

4.1 Technical details

The property is a two-story full-stone house built in 1959 and has a floor area of 643 m^2 and a volume of approximately 1850 m^3. No significant energy efficiency measures have been taken in recent years.

IMAGE 3. Eskola House

Floor area 643 m2 (1800 m3)

Ventilation The property has a frequency converter controlled exhaust fan and fresh air valves in the windows. The ventilation is not equipped with a heat recovery unit.

Heating The property is heated with light fuel oil and the building's heat distribution is carried out via a water-circulating radiator network.

The oil boiler was installed in the early 1980's and the oil burner was renewed in 1990. The oil burner model is OILON KP-26 H, a two-power Monoblock-type, fully automatic light oil burner with a power range of 95-350 kW. The heating system also consist of a second much older oil boiler, which is utilized when the outside temperature drops below -15 °C.

4.4 Energy consumption

The total oil consumption in 2017 was 16.5 m^3, which corresponds to approximately 165 MWh in heating energy and 257 kWh/m^2. The annual gross cost of heating the property in 2017 was 16 500 €. The estimated efficiency of the boiler is 0.8, therefore the real heating energy consumption is approximately 132 MWh/a, and the net cost 125 €/MWh.

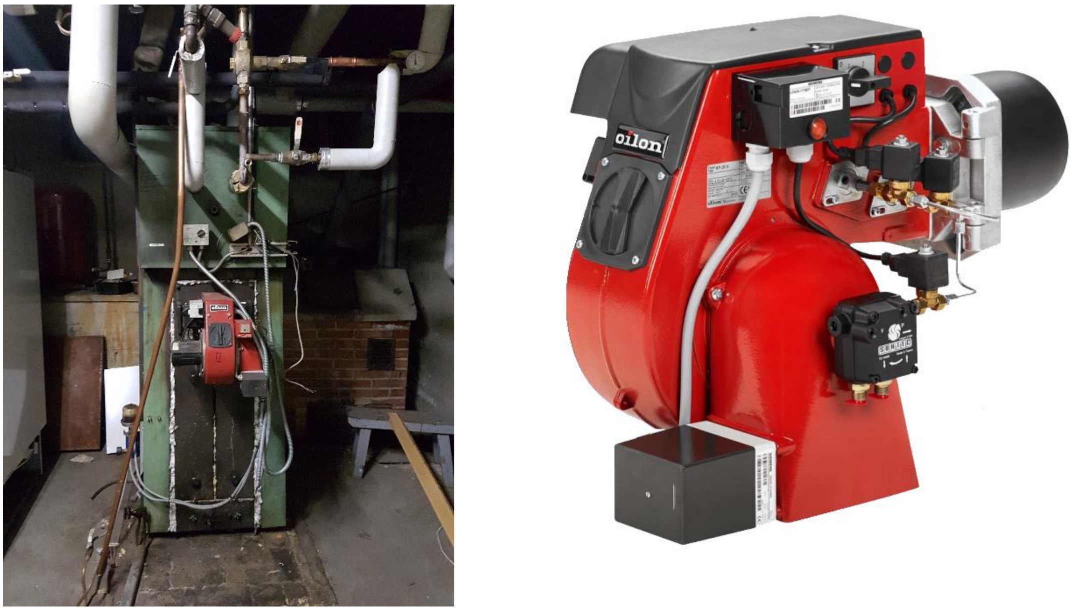


IMAGE 4. The current oil burner

In addition to the annual energy consumption, the peak power of the heating system is another important factor. Peak power refers to the energy power demand of a certain property at peak consumption time, for example during winter. The peak power consumption factor is needed when the new heating system is dimensioned.

The peak power demand for the Eskola property was unknown to the owners, but it can be approximated by dividing the annual oil consumption by 250. This gives an estimate of the peak demand in (kW). When calculated with this equation, the peak power for the property amounts to 65 - 70 kW.

The actual power requirement is probably lower than 65 kW. Considering the system efficiency, the real peak heat requirement is approximately 50 - 55 kW.

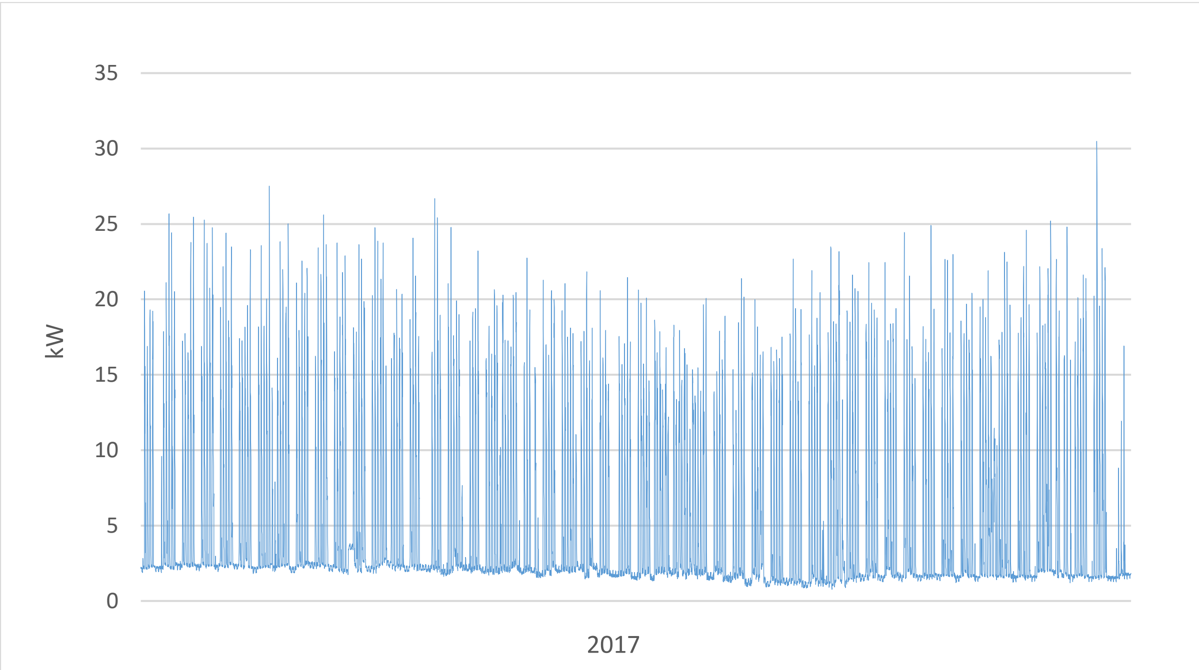
Hot water for the residents and operatives is partly heated by the oil burner, and partly with a separate electric water heater installed in 2018. The community has also installed an 8 kW solar panel system that produces domestic hot water when surplus electricity is available. Production information for the solar system is not yet available. The gross amount of energy required to produce domestic hot water with the oil-burner is approximately 25 MWh/a, which corresponds to around 15 % of the total energy consumption.

The annual net energy required merely for heating the property is 112 MWh, and the required specific energy per square meters of space is 174 kWh/m2/a witch is high above average when comparing to similar properties (Motiva 2019).

4.3 Electricity consumption profile

The electrical-energy consumption in 2017 was 43 MWh, with a peak power consumption of 30 kW and base load of 1.5 kW. There are no electrical heating elements in the property.

CHART 1. Electricity consumption profile for the Eskola House



5. Potential heating systems

Because the energy demand of the property is rather significant and the intent is to utilize the existing water circulation radiator network, the most potential replacement heating systems are:

- District heating
- Heat pump-based system
    - Ground source heat pump (GSHP)
    - Air-water heat pump (AWHP)
- Wood-chip heating

5.1 Ground source heat pump

The soil maintains in average the annual outside temperature, and is a considerably warmer heat source in winter times than the outdoor air. With a geothermal energy system like a ground source heat pump, the stored thermal energy can be utilized in the heating of buildings and domestic hot water. Geothermal systems are suitable for all types of buildings, and the energy production costs are almost without exception lower then with oil heating.

A ground source heat pump system includes a heat pump, a piping system and a collection circuit. The collecting circuit can be installed in the soil, a well or in water areas.

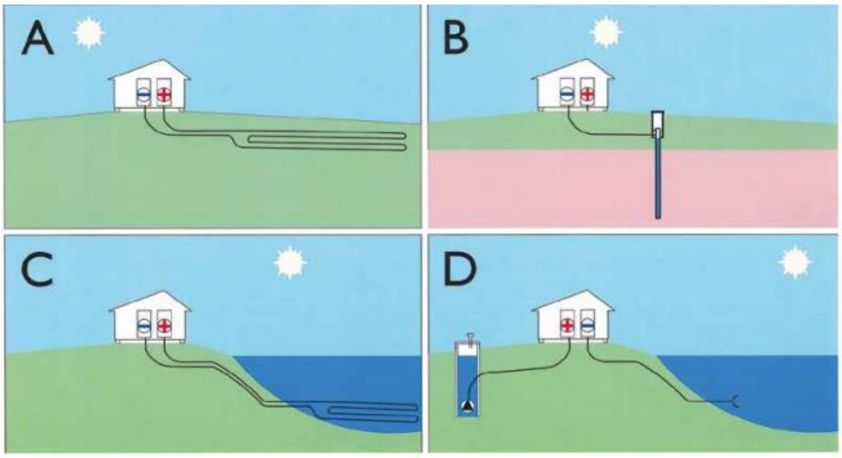


IMAGE 5. Different types of collector circuits

The use of geothermal heat in Finland has been boosted both by rising energy prices and by pressure to switch to renewable energy sources. The higher the energy consumption of the property is, the more profitable it is to invest in geothermal energy. A ground source heat pump also consumes some electricity but it produces 2-5 times more heat energy then for example direct electrical heating systems. To determine the energy balance of a heat pump system, a COP (Coefficient Of Performance) value is often calculated:

$$COP = \frac{Q}{W} = \frac{kWh_{heat\ supplied}}{kWh_{electricity\ consumed}}$$

- Q represents the heat energy supplied by the system
- W represents the work required by the system

The COP-value of a heat pump-system is a measure of how efficiently consumed electrical energy can be converted into thermal energy. For example, the designation COP 3 means that 1 kW of the input power produces 3 kW of thermal power.

Another heat pump system performance indicator is the SCOP (Seasonal Coefficient of Performance) which is calculated according to the same principle as COP, but reflects the heat factor for the specific heating season.

A typical GSHP has a COP average of 2.5 – 5, but the real COP and profitability of a heat pump system is affected by many factors. However, the profitability is generally highly improved in particular when:

- Changing from an oil heated system
- The property's energy consumption is high
- Changing from an system already equipped with a water circulated heat distribution network

5.1.1 Permits required

In Finland, the construction of a ground collector based heating system requires a permit in accordance with the Land Use and Building Act and a permit in accordance with the Water Act. When considering the licensing of a geothermal system, the municipality considers the following: Is there a Class I or II groundwater area within the municipality, a protected ancient monument area or any underground constructions that limits the drilling of energy wells. Connecting the system to the electrical network may also require authorization from your utility company.

5.1.2 Other things to consider

When changing the heating system from oil to a heat pump-based system the heat capacity of the radiator network should be checked. Old radiator networks are designed to operate at a design point within a specific climate range (in Finland -26 - 38 degrees °C), typically at flow and return temperatures of 60/40, 70/50 or even 80/60. Heat pump systems usually work at slightly lower temperatures and therefore the size or number of radiators may need to be increased.

Replacement of water radiators should be considered if they have been in use for more than 40 years, have significantly insufficient heating power or are otherwise in poor condition. Deposits accumulate in old pipes and radiators, which reduces water flow and also reduces heating capacity.

However, in many cases even over 100 years old radiators will still be usable, provided the conditions are good, and there has historically been little need to add water to the network.

5.2 Air to water heat pump

Air to Water Heat Pumps (AWHP) are technically the same as ground source heat pumps but they draw heat from the outside air instead of the ground. AWHP:s are usually installed in areas that are not suitable for ground heat.

An AWHP is potentially a good solution when the horizontal pipeline or the thermal well required for geothermal heat cannot be constructed because of groundwater restrictions. The investment costs are usually cheaper than with ground source heating but the overall economy depends on many factors.

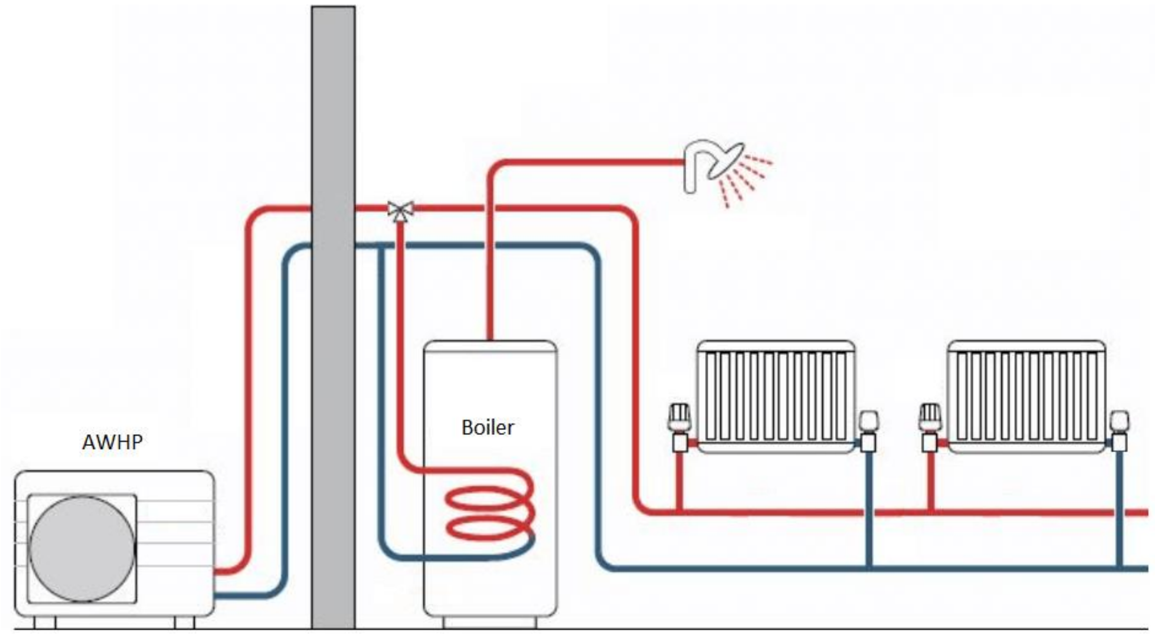


IMAGE 6. The principal of an Air to Water heat pump system

The efficiency of an AWHP depend on the outside air temperature and the annual efficiency is therefore not as good as a GSHP. AWHP is in many cases utilized in so-called hybrid mode. For example, retrofitted in addition to an older heating system, for example adjacent to an oil heating system.

In hybrid mode, the AWHP produces most of the required heat energy but the oil boiler is still utilized to cover the peak power requirements. This lowers the heat pump-systems investment costs, as the property owner does not need to cover the whole peak power requirements with the heat pump.

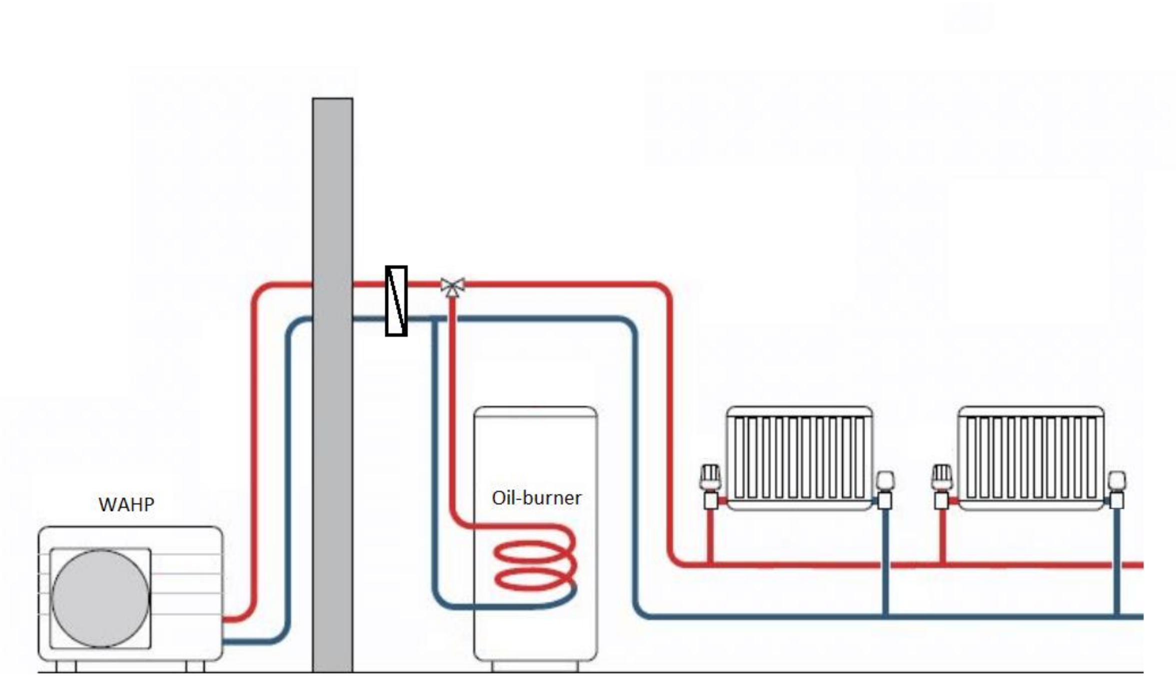


IMAGE 7. The principal of an Air to Water/Oil-burner hybrid system

A hybrid solution consists of an AWHP unit installed outside the building, an indoor heat exchanger and a control unit. From the heat exchanger, the thermal energy is transferred to the existing water circulation heat distribution. Installing and commissioning an AWHP alongside your existing heating system is a simple operation.

For most of the season, the property can be heated with a high efficiency water to air heat pump-system. When the outdoor temperature drops to around -5 °C and below, the existing oil heating system works alongside the heat pump. The operating range of the water-air heat pump reaches to about -25 °C, after which heating is done merely with oil. However, this is a relatively short part of the season.

5.3 Wood-chip heating

Wood is renewable energy source and it is abundantly available in Finland. Wood-chips are mechanically chipped from raw materials harvested from the forests. Wood-chips are produced mainly from non-pruned solid wood, pruned stems or logging residues. Wood-chips has an energy content of 4-5 kWh/kg when the moisture content is less than 30 %. For small heaters, the wood-chip size is usually 1-3 cm, and one loose cubic meter of wood-ships contains about 0,8 MWh of heat energy. This corresponds to 80 liters of oil and 180 kg of pellets.

IMAGE 8. Wood-chip storage

Wood-chip heating can be fully automated, and there are several container solutions on the market that includes both the boiler room and the storage in a pre-fabricated container. A heating container is a convenient option as the construction work is minimal compared to a separate heating plant.

IMAGE 9. Wood-chip heating container 60-500 kW (http://www.biofire.fi)

6. Investment calculations

Preliminary studies revealed that it is not possible to construct a drill well on the Eskola site needed for the GSHP due to groundwater restrictions. Therefor the heating systems included in the investment calculations are:

- Air-water heat pump/oil hybrid
- Wood-chip heating

Approximation of the annual net energy consumption:

Total energy consumption	132 000 kWh
Domestic hot water	20 000 kWh
Peak power requirement	50 kW

System conditions:

Average outdoor temperature	2 °C
System design temperature	-32 °C
Indoor temperature	20 °C
Heating stops at (outdoor temperature)	17 °C
System flow temperature	60 °C (Heat pump) 80 °C (Wood-chip)
Flow return temperature	45 °C (Heat pump) 60 °C (Wood-chip)

6.1 System costs

The system investment costs that are used in the investment calculations are based on budget tenders or average information from suppliers. Prices includes all system components, mounting accessories, shipment and the installation of the system.

Air to water heat pump/oil hybrid:

System initial investment	17 000 € (VAT 0 %)
Electricity cost	85 €/MWh
Estimated annually electricity price increase	0,2 %
Annual maintenance costs	0,2 % of initial investment
Finance rate	3,0 %
System life cycle	15 years

Wood-chip heating:

System initial investment (heat container)	55 000 € (VAT 0 %)
Wood-chip cost	30 €/m^3
Wood-chip cost (MWh)	24 €/MWh
Annual maintenance and shipping costs	5 % of operating costs
Finance rate	3,0 %
System life cycle	15 years

The wood-chip heating system includes a 60 kW integrated heat container, which contains a boiler room and a fuel storage. The storage compartment has a hydraulically opening roof. The annual efficiency of the wood-chip heating container is approximately 80 %. The current oil heating system would serve as a backup heat source as well as for summertime hot water production. About 1-3 % of the energy production is orginated from oil. The annual maintenance costs (5 % of operating costs) consist of wood-chip chipping costs, insurance premiums and other maintenance costs.

The wood-chip heating solution would virtually replace the use of oil as a main source of energy, but the AWHP-system would still utilize oil for peak performance. To estimate the levelized production costs of an AWHP/oil-hybrid system a more detailed energy simulation is required.

The AWHP-simulation takes into account the structural properties and consumption profile of the property as well as historical weather data from the area. To simulate the energy consumption of a hybrid system, the heat pump needs to be dimensioned.

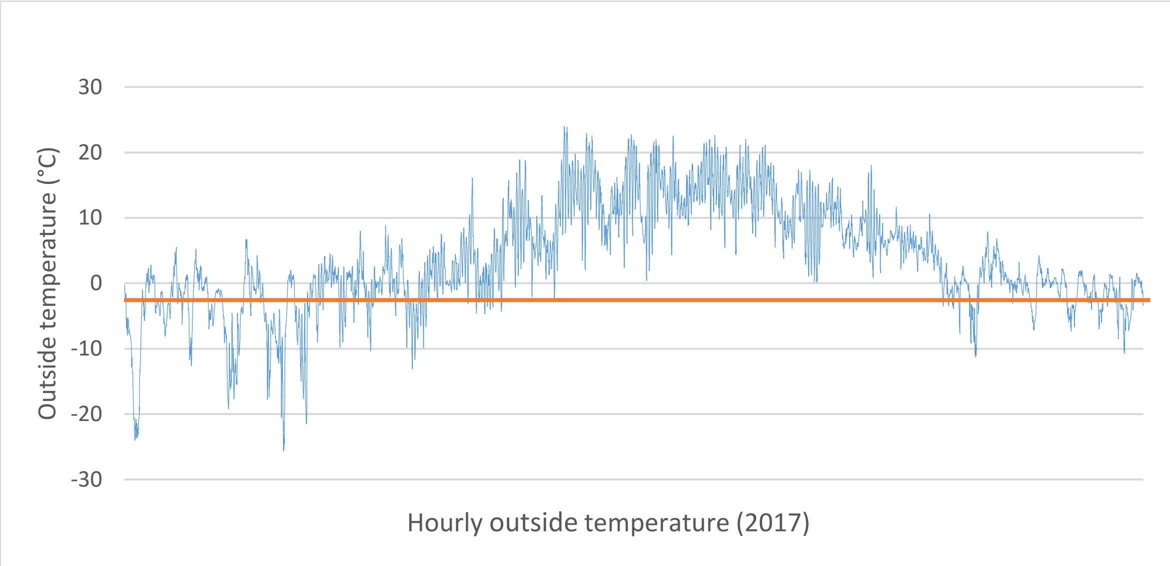
The correct dimensioning of the heat pump ensures a comfortable yet cost effective operation. The advantage of a hybrid system is that the heat pump does not need to be dimensioned according to peak load, since the oil heating takes care of the intermittent peaks. This reduces total investment costs of the heating system.

In a hybrid system, the AWHP is typically dimensioned to cover approximately 50% of the calculated peak power demand. With this type of dimensioning, the AWHP will cover in average over 90 % of the annual heat demand.

An AWHP capable of a max output of 28 kW_{TH} was selected for the simulation:

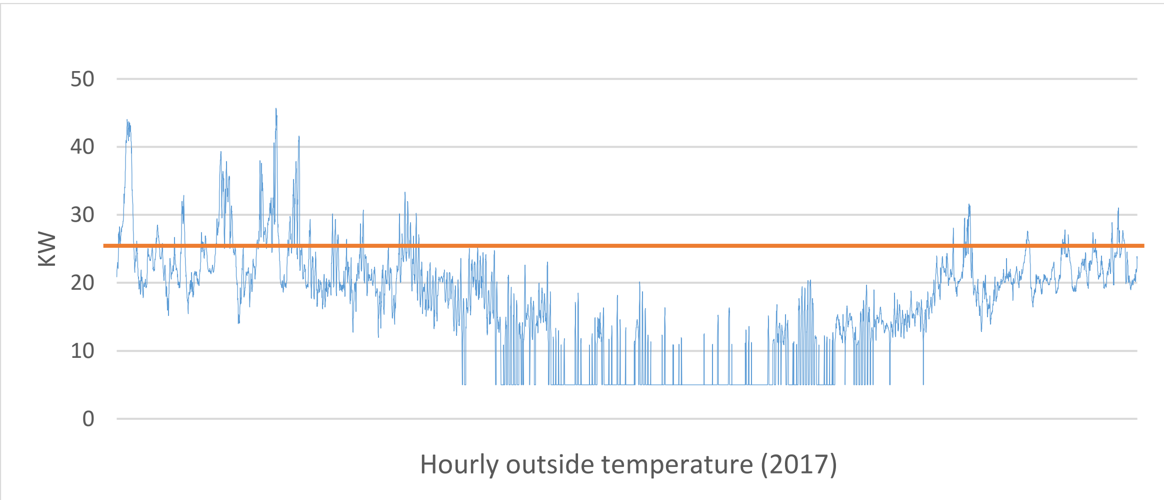
Feature:	**Value:**
Heating power (kW)	11.4-27.9
COP	3.65
Operating range	-25 ° C
Compressor Type	Scroll
Refrigerant type and level	R410A 7,1 kg

CHART 2. Temperature stability scale and heat pump coverage



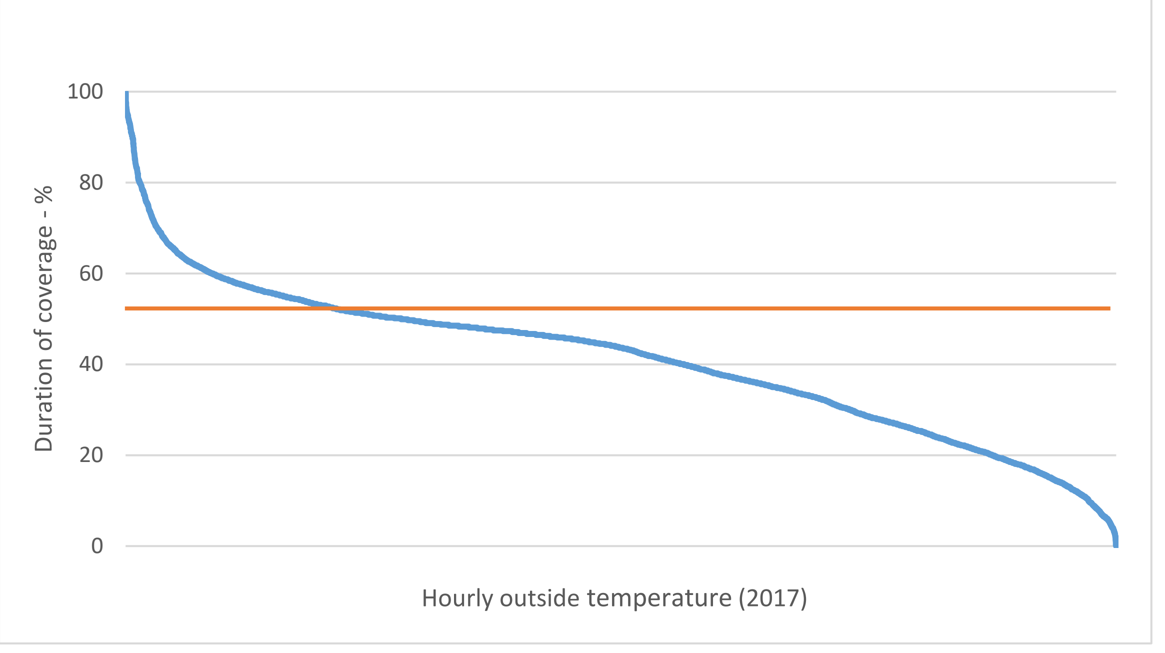
The blue chart represent the hourly outside temperature measurements in Eskola, and the orange line represents the typical point where the oil-boiler begins to gradually support the AWHP system. In practice, the AWHP is the only source of heat more than 80 % of the time, and produced a large part of the required heat in the remaining 20 %.

CHART 3. Power stability scale and heat pump coverage



The blue chart represent the required power from the heating system based on hourly outside temperature measurements. The orange line represents the power coverage of the AWHP, and the point where the oil-boiler begins to gradually support the AWHP system.

CHART 4. Temperature duration curve



The orange line represents the typical annual coverage of the AWHP.

The energy balance is divided into production and consumption to better visualize the efficiency of the system.

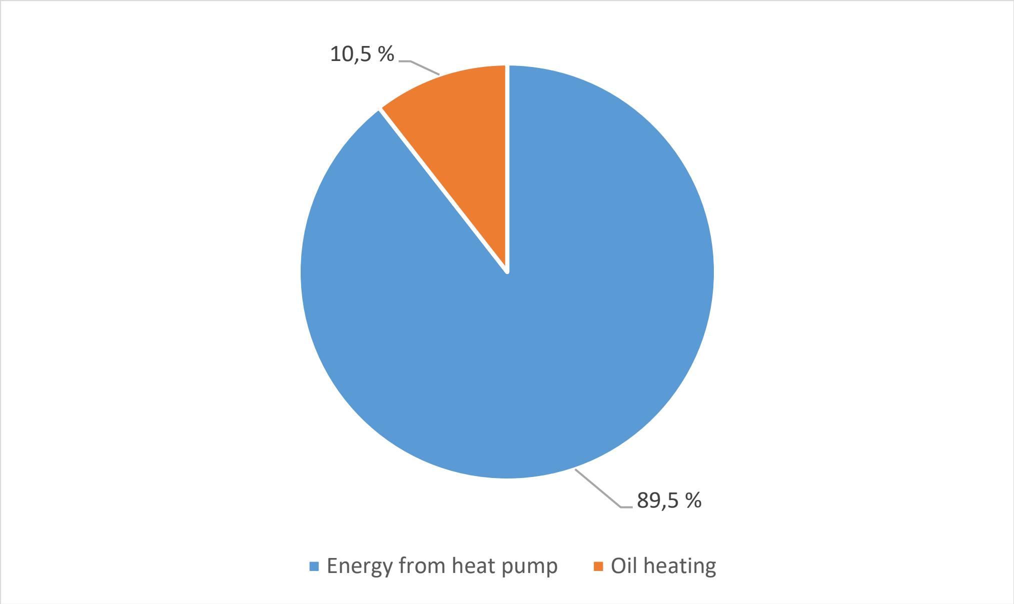
Annual energy production:

Energy from heat pump	100 411 kWh
Energy from oil-burner	13 812 kWh
Energy from the heat pump (domestic hot water)	17 678 kWh
Oil heating (domestic hot water)	2799 kWh
Total production:	134 700 kWh

Annual energy consumption:

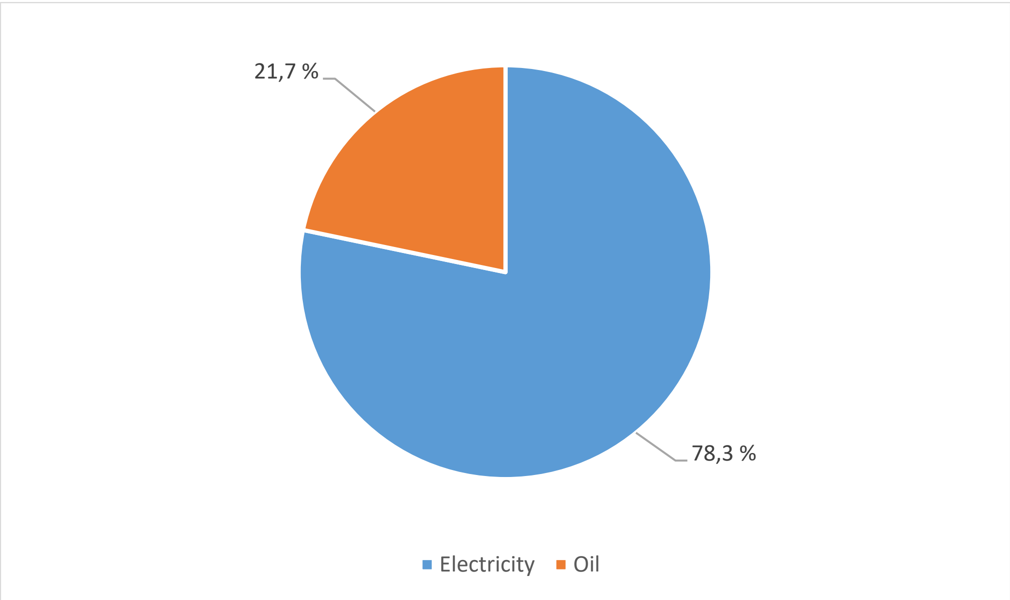
Electrical energy for heat pump (heating)	42 372 kWh
Oil-based energy (heating)	17 265 kWh
Electrical energy for heat pump (hot water)	7 732 kWh
Oil-based energy (hot water)	3499 kWh
Total consumption:	70 868 kWh

CHART 5. Annual heat production between different sources



The heat pump produced about 90 % of the utilized heat energy and 10 % was originated from oil.

CHART 6. Energy sources for heat production



The heat energy produced with the heat pump utilized around 80 % of the total energy consumed and 20 % was from the burning of oil.

7. Results and conclusions

	LCC:	LCOE:	Net asset value:	Payback years:
AWHP-hybrid	142 937 €	68 €/MWh	121 062 €	<4 years
Wood-chip	189 880 €	72 €/MWh	50 120 €	>8 years

The Levelized cost of energy are calculated by dividing lifecycle costs with the total energy production, and allows the comparison of different technologies.

7.1 Carbon footprint

Wood-chip heating systems are in Finland considered carbon neutral. The impact of transferring to a hybrid AWHP-system is:

Current carbon footprint	43 ton CO_2/a
New carbon footprint (oil)	4 ton CO_2/a
New carbon footprint (electricity)	7 ton CO_2/a
Reduced emissions	-32 ton CO_2/a

8. Conclusions

The simulations shows that the payback period of the AWHP system is rather short and the investment profitable during its life cycle. Although the wood-chip system has lower fuel costs, it is a more capital-intensive alternative and therefore the LCOE is higher and payback period double of the AWHP.

The existing oil boiler would in the hybrid scenario work as a support heat source alongside the AWHP. However, the oil-boiler is beginning to reach the end of its life cycle and needs to be fully replaced in 5-10 years. When the oil-boiler is finally fully decommissioned, the system will require a permanent heat source for peak periods. This could be done by adding a boiler equipped with electrical heating elements that would be utilized only under these peak hours.