Guide report 1:

Heat supply in Leirvík - case study

Nordic Energy Research
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Peter Bode Nielsen, Morten Hørmann, Jakob Nymann Rud and Frederik Møller Lauge

COWI A/S

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1 Introduction and scope

This case study is part of the project 'Sustainable energy and energy storage in sparsely populated areas'. The project was initiated by Nordic Energy Research in 2016 and involves this case study project along with a guide for energy planners and decision makers in sparsely populated areas.

This case study has been developed in co-operation with the Faroese energy department Umhvørvisstovan (US) and in close dialogue with Nordic Energy Research. The project has also been followed by a reference group with participants from the Nordic Countries.

The purpose of the case study is to convert the heat supply system in the city of Leirvík from fossil fuels to a more sustainable energy system, as near to 100 % renewable as possible. The future should involve smart energy solutions such as energy storage and electricity based heat production systems.

The wind turbines are a central element of the Faroese transition to an energy production, which is 100% based on renewable energy. Within the heating sector, electric heating (heat pumps and electric boilers) is essential because of the lack of local biomasses. If implementing electric heating the share of renewables in the heat production will follow the renewable part of the electricity production. When having a 100% renewable electricity system the heat production will be 100% renewable as well.

A 100 % renewable energy system needs smart meters in households/production facilities to ensure that production and consumption of energy is optimised.

The three project scenarios in this case study involve both individual solutions along with common heating systems.

The case study should show how to put together a heat supply system for a sparsely populated area such as Leirvík.

1.1 Report structure

The case study main report is divided into following three main areas:

- Introduction and frames for the case study
- Scenario analyses with sensitivity analyses and environment
- Next steps and conclusion

After the main report, a number of appendices follows. The main report can be read without the appendices. If there is a need to go into technical details within a certain area this will be possible. There is references in the main report to the specific appendices.

1.2 List of abbreviations

COP: Coefficient of Performance. The ratio between used electricity and produced heat.

DDK: Danish currency 'kroner'.

DH: District heating

GWh: Giga Watt hour, 1 GWh = 1.000 MWh = 1.000.000 kWh

GWP: Global Warming Potential

M: Million. Used before DKK with more.

O&M: Operation and maintenance.

SEV: Main energy supplier at the Faroe Islands.

US: Umhvørvisstovan. The Faroe Islands energy department.

2 Summary

In the project, four scenarios have been analysed for heating in Leirvík. One of these are the reference scenario, which today is based on oil boilers. The three other scenarios all involve heating based on electric heat pumps. The three project scenarios are:

- Scenario 1: Individual heat pumps, individual brine
- Scenario 2: Individual heat pumps, shared brine
- Scenario 3: Seawater heat pump, district heating.

The three project scenarios have much higher investment costs compared with the reference scenario. However, the energy cost is much higher in the reference scenario. The annual project costs of the four project scenarios are shown in Figure 2.1.

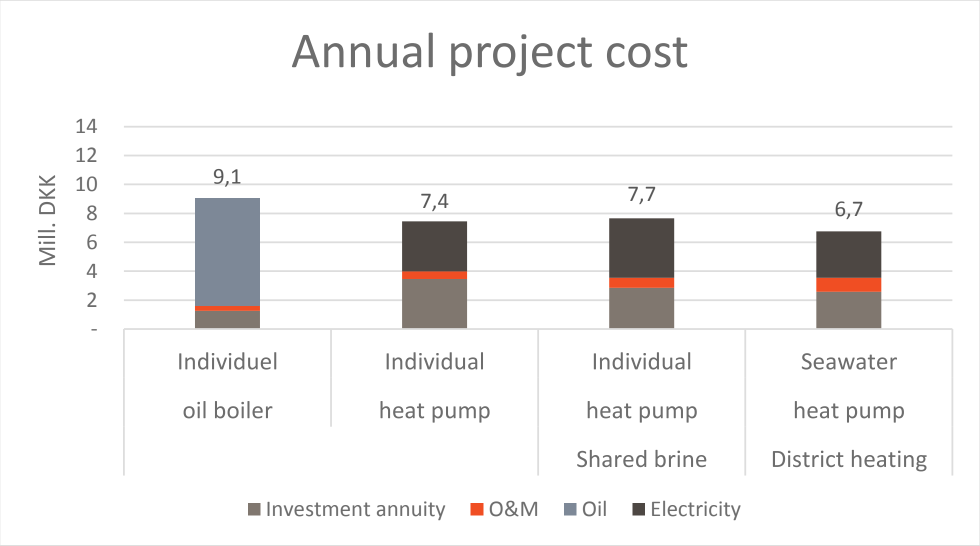

Figure 2.1 *The annual project costs in the four scenarios. The electricity prices are different during day and night but the same for small and large consumers.*

The reference scenario has the highest annual costs and the district heating scenario has the lowest annual costs. The two other scenarios are almost equal in the annual costs. The scenarios have been evaluated by the annual cost in the sensitivity analyses in chapter 12. These analyses show that the project scenarios are quite robust.

3 Faroe Islands energy system

The Faroe Islands have a population of approx. 50.000 and an area of approx. 1.400 km². 25 % of the population are residing in the capital of Tórshavn. 30-35 % is residing in the eight towns with more than 1.000 inhabitants (excluding Tórshavn). Another 30-35 % is residing in 46 town villages with 100-1.000 inhabitants.

The climate of The Faroe Islands is subpolar oceanic. The temperatures varies typically between 0-15 °C. Frost is not very common.

The energy production in the Faroe Islands is currently very dependent on oil. While only approx. a third of the electricity production in 2015 was based on oil, almost all the heat is produced by oil.

Figure 3.1 shows the electricity production in 2015 in the Faroe Islands divided by energy sources. Hydro power is essential for the electricity system producing almost half of the annual electricity. The total electricity production in 2015 was approx. 280.000 MWh.

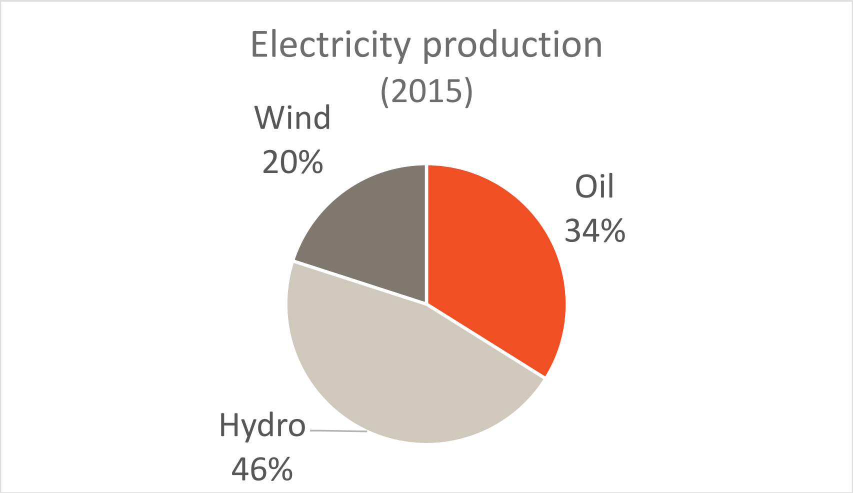

Figure 3.1 Electricity production by production type.

No commercially viable funds of oil have been made yet at The Faroe Islands today, but expectations of financial gain from oil extraction are still high.

The installed wind power capacity in the Faroe Islands is approx. 20 MW distributed on 21 wind turbines in three wind farms. It is possible to integrate more wind in the electricity system but the wind turbines will have trouble utilizing the potential in some periods. When the wind power production is high compared with the energy consumption the electric grid becomes unstable. On the production side there is the fluctuating production from wind turbines. A gust of wind can close down a wind turbine. On the consumption side, there can be a sudden change if e.g. a larger industry shuts down production.

Today some (3-5 %) of the potential electricity production cannot be utilized. If wind turbines should cover a larger part of the electricity production system there is a need for stabilising capacity and long term energy storage. Stabilising capacity can be electric batteries or electric boilers with controlling abilities. The advantage of batteries is that the electricity produced can be used later. The electric boiler converts the electricity to heat and can therefore only even out the electricity consumption. The disadvantage of the battery is both that it is many times more expensive than an electric boiler and that the efficiency is poor. If several cities in the Faroe Islands are supplied with heat from heat pumps and electric boilers the electricity demand during the day can be evened out by heat pumps and heat storages and when the wind power production approaches the electricity demand the electric boilers can be started up stabilising the network.

4 Leirvík

Leirvík is a small city of approx. 850 people and 340 buildings. The geographical conditions are very common for the Faroese cities. It is near the sea and the elevation is high. Leirvík is one of the largest Faroese village towns[1] but approx. 40 cities have more than 200 inhabitants.

Figure 4.1 Map of the Faroe Islands with Leirvík pointed out and map of Leirvík (from www.kortal.fo)

There are 320 households in Leirvík. Of these five households have individual heat pumps and are therefore not included in the project. The sports arena is not included in the project because of an inappropriate location far from the nearest building and higher than the rest of the buildings. There are 19 large buildings. Two industrial buildings (Tavan and Norðfra) are not included because it is assumed that they can use excess heat from the cooling process.

The ground area of Leirvík is approx. 0.5 km² which leads to a population density of approx. 1.700 people/km². This is quite high for a town but not necessary unusual for a Faroese town village.

Leirvík is a relatively densely populated town village. However, the town of Leirvík is located in a sparsely populated area - along with most of the other towns in The Faroe Islands – being relative small and located multiple kilometres away from neighbouring towns.

The heat demand and heat density of towns do have some influence of the feasibility of shared energy systems such as district heating. A low heat demand can result in the loss of economy of scale when investing in the project. The major impact is from the heat density. If the buildings are more scattered the investment costs will increase with the same number of consumers paying. In the sensitivity analyses (section 12.5) the influence of the number of connected buildings is analysed.

4.1 Electricity

Leirvík is a part of the central electricity network in the Faroe Islands. The local electric grids in and through Leirvík are shown in Figure 4.2. The high voltage system going through Leirvík is at 20 kV.

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[1] 12th largest according to wikipedia.

Figure 4.2 Electric grids in and through Leirvík. The orange line is 20 kV (from www.kortal.fo)

The electricity price is stated by US to be 1.51 DKK/kWh for electricity to small consumers and 1.39 DKK/kWh to larger consumers. Prices are for 2016. The electricity production costs are lower during the night when the consumption is low. The electricity company has therefore talked about reducing the electricity price in some periods to an increased incentive to move the electricity consumption from daytime with high demand and therefore high production cost to night-time with low demand and low production cost.

In this project, the electricity prices are assumed to be decreased by 0.5 DKK/kWh during the nights from 11 PM to 7 AM. In this way, the electricity prices will be reduced to 1.01 and 0.89 for small and large consumers respectively during night-time.

4.2 Weather conditions

US has forwarded degree days for the last approx. 60 years. The degree days are found from the temperature and is a way of determining how the heat demand for room heating is distributed over the years. In Figure 4.3 the degree days of 2015 are compared with the average degree days of 1952-2014 and 2005-2014 respectively. As shown, the trend is very similar for the three curves. The main difference is that the average degree days do not have the high fluctuations which will occur during one year. These fluctuations are important when estimating the necessary capacities of heat generation and storage technologies.

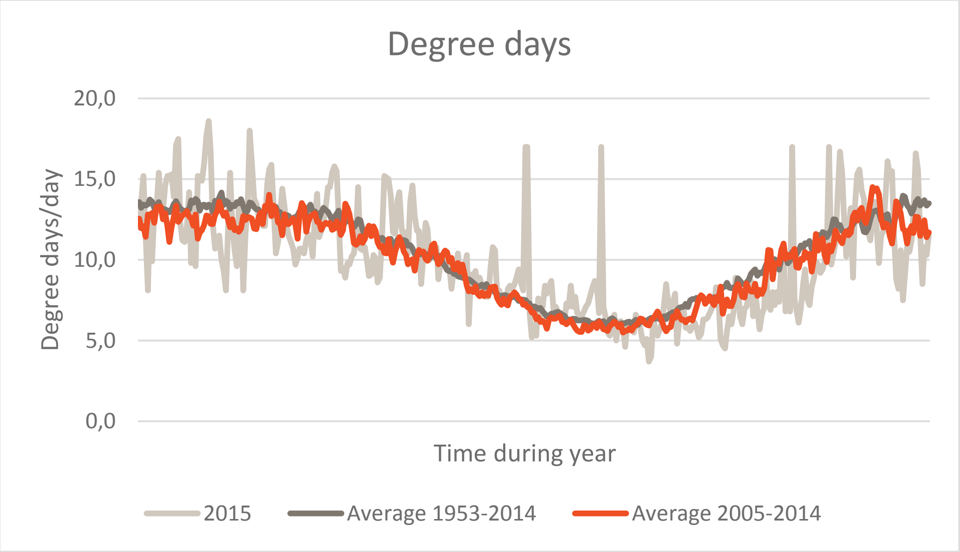


Figure 4.3 *Degree days in three periods.*

The stated degree days are on daily basis. Since the temperature can vary a lot during a day, hourly degree days have been developed. Hourly temperatures have been founded from the climate forecast system CFSR2. To compare with the stated daily degree days for 2015 from US the forecast data has been converted into average daily degree days.

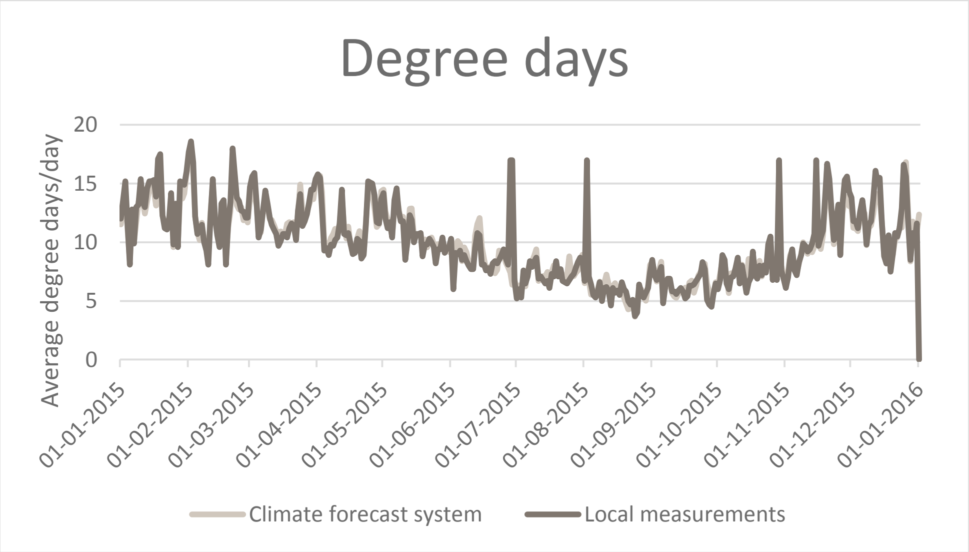


Figure 4.4 *Degree days from both climate forecast and local measurements.*

The two temperature overviews are shown in Figure 4.4. As shown, the two sets of data are very much aligned. Because of this, the forecast temperature has been used.

The hourly temperatures from the forecast is shown in Figure 4.5. The temperature rarely decreases to less than 0 °C and does not increase to more than 15 °C. The temperature is mainly 5-10 °C.

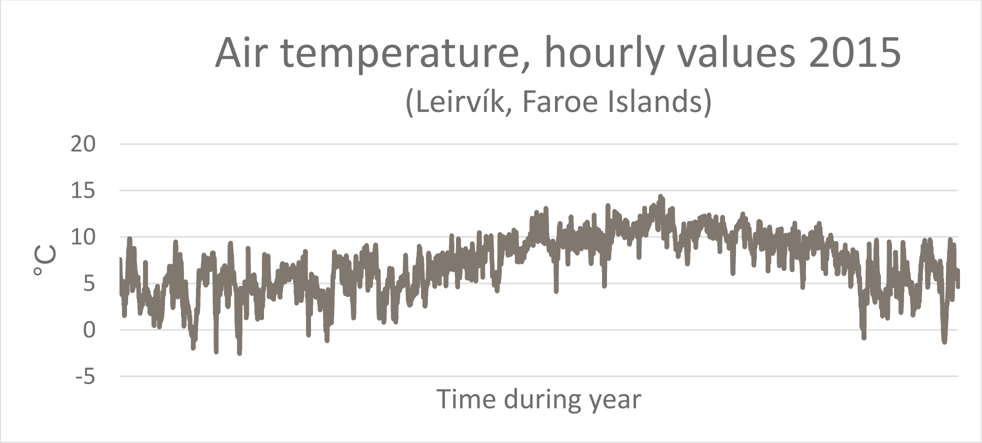


Figure 4.5 *Air temperature in Leirvík in 2015.*

A duration curve of the temperature shown in Figure 4.6.

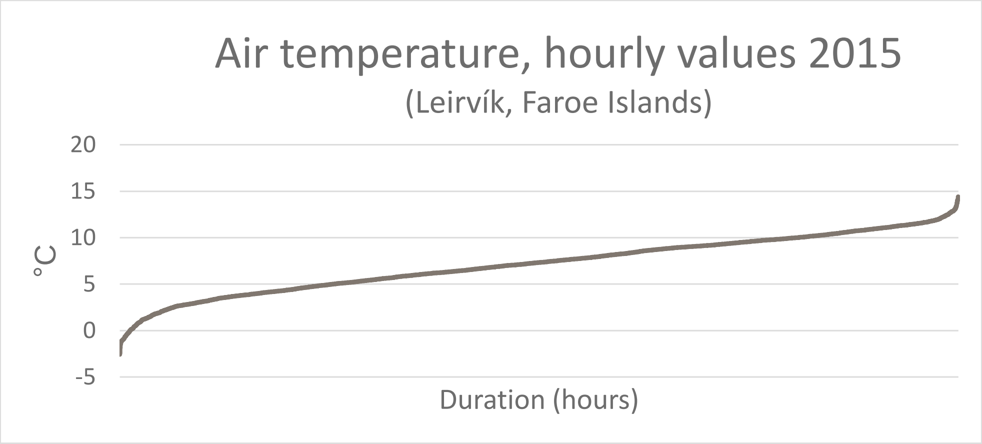


Figure 4.6 *Air temperature duration curve for Leirvík for 2015 (lowest temperature first).*

5 Main scenarios

The current heat demand in the project is 100% based on oil boilers. In this project three alternative scenarios are developed. In all three scenarios, the heat demand is covered by electric heat pumps. The three alternative scenarios are:

- Scenario 1: Individual heat pumps, individual brine
- Scenario 2: Individual heat pumps, shared brine
- Scenario 3: Seawater heat pump, district heating.

Other scenarios could be relevant in general in the Nordic countries such as biomass combustion but biomass resources are very limited in the Faroe Islands (and other areas).

The purpose of the project is to develop a 100 % renewable heat supply. The three chosen scenarios all use heat pumps as the heat supply technologies using only electricity. When converting the electricity production in the Faroe Islands to 100 % renewable the heating supply in the scenarios will also become 100 % renewable. The heat pump systems can also accelerate the transition to 100 % renewable electricity production.

5.1 Heat pumps

The electric heat pump uses electricity to produce heat. The heat is subtracted from a source of heat, which could be the ground or the sea. Electricity is used to power a compressor, which increases the temperature of a media (e.g. etanol/water solution) by pressuring it. The now high temperature media can deliver the heat through a heat exchanger e.g. in a building or in a district heating network. The media is cooled down in the heat exchanger and is afterwards expanded through a valve or likewise. The purpose is to reduce the pressure, which also reduces the temperature of the media. The media – now with a very low temperature – is led out to the external source of heat. Here it will obtain a higher temperature before it will be compressed and discharged back into the building/district heating network again. To use a heat pump the temperature of the low temperature heat source must be higher than the temperature of the media after expansion. In addition, the temperature of the media must be higher than the demanded temperature. Only with these criteria met, can a heat pump function. Examples of a heat source can be the ground with a temperature of approx. 10 °C and the demanded high temperature can be 55 °C as a supply temperature in an internal water borne distribution network in a building.

The heat pump can have a very high efficiency. The efficiency is called Coefficient of Performance (COP) and can typically be in the area of 3-4 (corresponding to 3-400% of efficiency) in a heat pump.

5.2 Heat storage

In this project, heat is assumed stored in traditional hot water tanks (small or large). The cost of this type of storage is relatively small (compared with the total heating systems), the tanks can be placed suitable relative to the place of use (district heating network or building), the efficiency if relatively high and the technology is very common.

Other kind of thermal heating could be in rocks. Here water can be stored at temperatures high enough to be used in electricity generation units. High temperature heat storage is not relevant in this case study since heat is only produced at relatively low temperatures. The storage can still be used as a low temperature storage.

Rock heat is usually a combination of the rock heat storage and a heat pump using the stored heat. If only used as a heat storage for district heating water the rock heat storage is not suitable.

5.3 Estimating heat demand variation

The heat demand in Leirvík is divided in two or three types of heat demand. In the buildings, there is a demand for room temperature and supply of hot water. In a district heating system there will also be a heat loss which should be added to the heat demand of the buildings.

The heat demand for room heating is both dependant of the outside temperature and the time of the day. In the project, it is assumed that the heat demand is highest in the morning when people get up and lowest at night with no doors and no windows open.

The heat demand for the hot water supply is the same every day. The heat demand for hot water supply is assumed to be high during the day time and almost nothing during the night.

The heat loss from the distribution pipe is mainly dependent of the surrounding temperatures. Since the pipes is in the soil and the soil temperature is quite stable the heat loss is assumed to be independent of air temperature The heat loss is also independent of the heat demand. Because of the constant heat loss (in absolute terms) the heat loss is relative low during winter and relative high during summer.

5.4 Operation and maintenance

Operation and maintenance (O&M) cover the running cost for the technologies. Operation cost cover man hour costs for operational staff, electricity consumption for small devices etc. for the daily use of the technology. Maintenance cost cover replacement of parts and man hour costs of fixing issues. O&M costs are typical by either fixed annual costs or variable. The fixed costs are independent of the use of the technology. This can be cost of being connected to the electric grid. The variable costs are dependent of the use of the technology. This could be the electricity consumption for pumps, valves etc. In this project electricity consumption for the distribution pumps are included in the 'fuel cost' instead of the O&M cost.

6 Reference scenario – Individual oil boilers

Today almost all buildings in Leirvík are heated up with oil boilers. The boilers are placed in each building making the consumers independent of other consumers. Along with the boiler, it is necessary to have an oil tank to store oil. The tank can usually contain oil for one third of the demand of a year.

6.1 Energy

The heat demand is estimated from stated oil consumptions from Leirvík. The oil consumption from households is approx. 3,000 litres pr. year. The oil consumption of four of the larger buildings is stated at approx. 12,000 litres pr. year. For the school the oil consumption is stated at 60,000 litres pr. year. For the 12 buildings where the oil consumption is not stated the oil consumption is assumed to be 4,000 litres pr. year. The oil consumption is described more thorough in Appendix A.

This results in a total oil consumption of approx. 1.1 mill. litres of oil pr. year. Based on a heat efficiency assumed to be 85% (stated to be 80-85 %) for the oil boilers, the oil consumption converts to an annual heat demand of approx. 9,000 MWh. The influence of the heat efficiency is described further in the sensitivity analyses (section 12.2).

6.2 Economy

The current heating system with individual oil boilers is a relatively simple heating system compared with the heat pump solutions. For the consumer there is a cost of establishment/ reestablishment of the boiler. Variable costs include fuel and operation and maintenance (O&M). The O&M cost represents a smaller part of the cost. This is mainly an annual maintenance visit perhaps including some new parts to the boiler. The cost of oil is by far the largest part of the total costs of being heated with an oil boiler. The economic data for the project is described in the following sections.

6.2.1 Investment

The investment costs for oil boilers in the project is shown in the table below.

Table 6.1 Investments in the reference scenario.

Technology	Number of units	Specific investment cost, DKK/unit	Investment cost, MDKK
Oil boilers, houses	315	55,000	17
Oil boilers, large buildings	17	65,000	1.1
Oil boilers, school	1	200,000	0.2
Total	333	-	18.3

The specific investment cost for oil boilers for the houses is stated by US. Investment costs for oil boilers in large buildings and in the school are estimated.

The total investment cost in the reference scenario is approx. 18.3 MDKK

The oil boilers have an expected lifetime of 20 years. With an interest of 3% the investment can be converted to an annually investment annuity of 1.25 MDKK.

The influence of the investment cost is described further in the sensitivity analysis (section 12.7).

6.2.2 O&M costs

The cost of O&M for the oil boilers is shown in the table below.

Table 6.2 O&M costs in the reference scenario.

Technology	Number of units	Specific O&M costs, DKK/unit pr. year	Total O&M costs, DKK pr. year
Oil boilers, houses	315	1,000	315,000
Oil boilers, large buildings	17	1,500	26,000
Oil boilers, school	1	10,000	10,000
Total	333	-	351,000

The specific costs of O&M are estimated.

6.2.3 Fuel costs

The oil price fluctuates due to various technical and geopolitical circumstances. These fluctuations leads to some insecurities in the consumers' private economy. In 2009, the price of oil reached a low of 4.5 DKK/litres. In 2012-2013, the price was 8-8.5 DKK/litres and in 2016, the price is approx. 5-6 DKK/litres. Because of these fluctuations, a price of 7 DKK/litres (average over the past three years) is chosen for the project. This price corresponds to approx. 0.7 DKK/kWh oil. The influence of the oil price is described further in the sensitivity analyses (section 12.1).

The fuel costs are shown in the table below.

Table 6.3 Fuel costs in the reference scenario.

Technology	Oil consumption, MWh	Specific oil costs, DKK/MWh	Total oil costs, MDKK
Oil boilers, houses	9,400	700	6.6
Oil boilers, large buildings	600	700	0.4
Oil boilers, school	600	700	0.4
Total	10,600	-	7.4

The total oil costs for the project is approx. 7.4 MDKK/year.

6.3 Project costs

The current cost of heat incl. investment costs for the project are calculated to approx. 9 MDKK annually. The cost is shown in the table below.

Table 6.4 Project costs for the reference scenario.

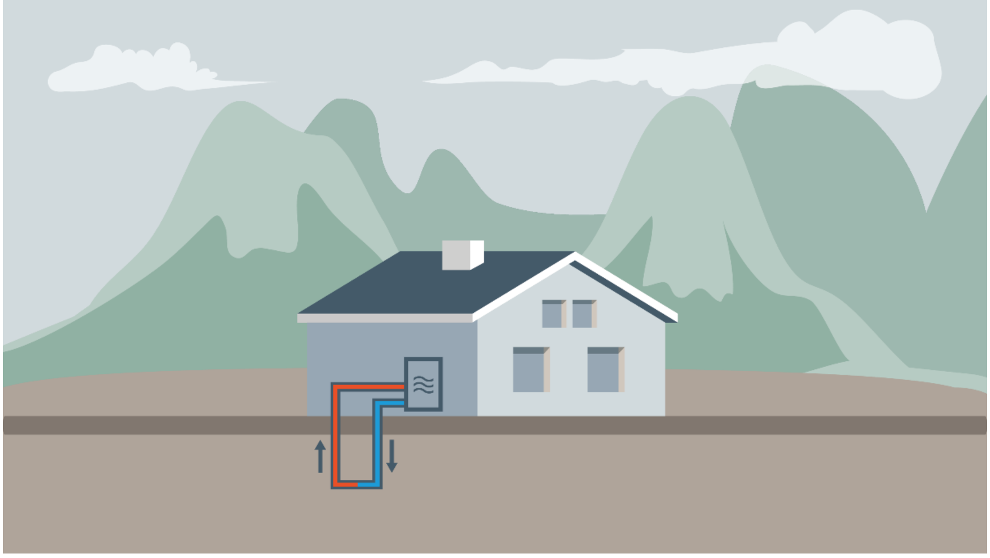
	Cost, MDKK/year
Investment annuity	1.25
O&M	0.35
Oil	7.43
Total	9.06

For the reference scenario, oil cost represents more than 80% of the annual costs.

7 Individual heat pumps

In the first project scenario the heat is produced by an individual heat pump with individual brine. The individual brine pipe is a vertical system with borehole of appr. 200 m where the heat pumps utilizes the soil. The brine is an antifreeze fluid (often ethanol) which is circulated in pipes in the pipe system. Another type of individual heat pump is the air to water heat pump. This uses air instead of heat from the soil. The air to water heat pumps can have noise issues. The air to water heat pumps are usually cheaper than the heat pumps with a brine but the COP is expected to be lower. If using air to water heat pumps they should be high quality units, designed to work under the specific climate conditions. In the old buildings the COP is approx. 2.5. In new buildings with floor heating and low supply temperature the COP can be approx. 3. According to US, the air to water heat pumps does not seem to be a relevant solution. The is due to both the low COP and due some noise issues.

The buildings are still not dependent of each other in terms of a heating system but the heat pumps are connected to the central electricity grid.



With the heat pump comes an electric boiler, which can be used for peak load/ back up. In addition to this a hot water tank with a volume of 300 litres. The typical size of the hot water tank is 160 litres but if the system in any way should support the integration of wind power the storage needs to be higher.

The supply temperature to the buildings from the heat pumps is set to 55 °C and the return temperature to the pipes at 45 °C. The storage can therefore only contain approx. 3.5 kWh of heat corresponding to approx. 1 hour of average heat consumption and 0.5 hours of peak load consumption.

The electric boilers can to some extend be used by SEV to balance the electricity production from the wind turbines. In these cases, it can be necessary to increase the electric connection to the individual households. Each house has a 35 A fuse in the connection point. According to SEV, the buildings should be able to deliver power to the heat pump/electric boiler. If the fuses cannot handle the added power demand, it can be necessary to increase the level of receivable power. This cost is not included in this project.

7.1 Energy

The COP for the individual heat pumps are estimated by a Danish heat pump manufacturer to be approx. 3.5. With a heat demand in the buildings at approx. 9,000 MWh this causes the electricity consumption to be approx. 2,600 MWh. The influence of the COP is described further in the sensitivity analyses (section 12.4).

The demand of heat during the night-time (11 PM to 7 AM) is approx. 27%. Because of the heat tank in the buildings a simulation of the system shows that approx. 33% of the heat can be produced during night-time.

7.2 Economy

The costs in this scenario is mostly at a private level. Costs are for the heat pump, O&M and electricity costs along with costs for controlling and perhaps increase of the fuses in the buildings. All of this is private costs.

7.2.1 Investment

The investment costs for this scenario is shown in the table below.

Table 7.1 Investment costs in the individual heat pump scenario.

Technology	Number of units	Specific investment cost, DKK/unit	Investment cost, MDKK
Heat pumps, houses	315	150,000	47.3
Heat pumps, large buildings	17	200,000	3.4
Heat pump, school	1	500,000	0.5
Controlling	-	-	0.5
Total	-	-	51.7

The specific investment cost for individual heat pump for the houses are stated by US. Investment costs for individual heat pumps in large buildings and in the school are estimated.

The total investment cost in this scenario is approx. 52 MDKK.

The individual heat pumps along with the controlling have an expected lifetime of 20 years. With an interest of 3% the investment can be converted to an annually investment annuity of 3.47 MDKK.

The influence of the investment cost is described further in the sensitivity analysis (section 12.7).

7.2.2 O&M costs

The cost of O&M for the individual heat pumps is shown in the table below.

Table 7.2 O&M costs in the individual heat pump scenario.

Technology	Number of units	Specific O&M costs, DKK/unit pr. year	Total O&M costs, DKK pr. year
Heat pumps, houses	315	1,500	473,000
Heat pumps, large buildings	17	2,000	34,000
Heat pump, school	1	4,500	4,500
Total	333	-	511,500

The specific costs of O&M are estimated. It is assumed that SEV will cover O&M of the substations.

7.2.3 Fuel costs

The total electricity consumption is approx. 2,600 MWh annually with 1,700 MWh used in day-time and 900 MWh in night-time. In this case, the price of electricity is assumed to be 1.51 DKK/kWh for consumption in day time and 1.01 DKK/kWh for consumption in night-time.

The total electricity costs add up to 3.47 MDKK annually. The influence of the electricity price is described further in the sensitivity analyses (section 12.3).

7.3 Project costs

The cost of heat incl. investment costs for this scenario is calculated to app 7.6 MDKK annually. The cost is shown in the table below.

Table 7.3 Project costs for the individual heat pump scenario.

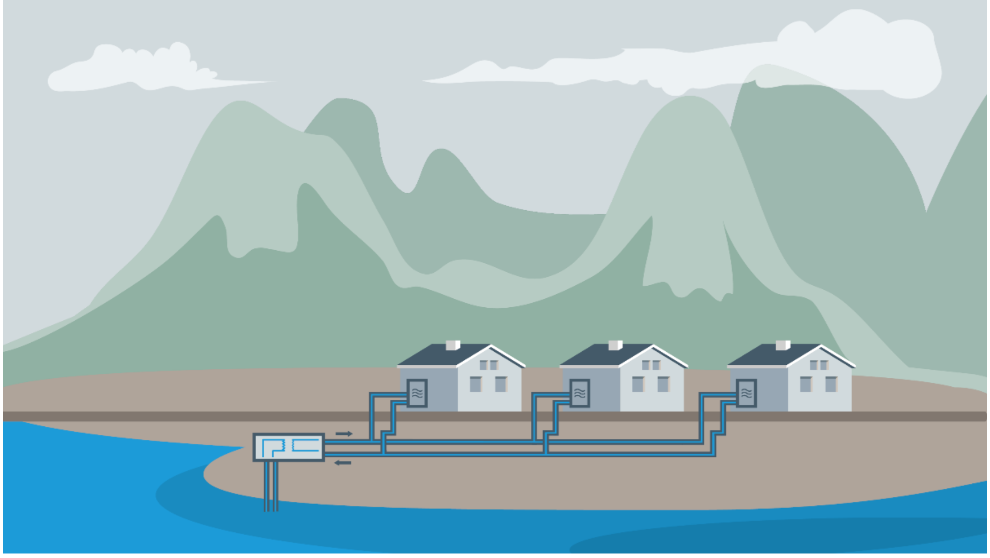
	Cost, MDKK/year
Investment annuity	3.47
O&M	0.51
Electricity	3.47
Total	7.45

If, however, the electricity price is fixed at the current level – 1.51 DKK/kWh – the annual costs increases to approx. 7.9 MDKK. In both cases, the heat costs are lower than for the reference scenario.

8 Individual heat pumps, shared brine

The second project scenario is in some ways similar to the first project scenario. The heat production units are still individual heat pumps in every building but in this scenario instead of have individual brine pipe systems one large shared brine network is established.

By the seashore, a seawater intake is established. The intake and the shared brine network is connected through a heat station containing a heat exchanger and a supply and return pump.



The individual heat pumps come with an electric boiler for peak load/back-up and a 300 litres heat tank.

The seawater intake in the shared brine scenario is placed as shown in the figure below.

Figure 8.1 Overview of the brine network and the placement of the seawater intake.

The shared brine scenario could be improved by adding an electric heating unit and a heat storage. The electric heating unit could use surplus wind power production at very low cost increasing either directly or indirectly (through the heat storage) to the brine network. If increasing the brine temperature the COP of the individual heat pumps can be increased.

This is an interesting but also risky approach. The risk is mainly that the amount and the price of low cost electricity is unknown. The saving is the reduction in electricity consumption in the individual heat pumps. The saving should be large enough to cover the cost of both the electric heating unit and the heat storage along with the (low cost) electricity consumption for the electric heating unit.

The brine network pipes are not insulated which means that some of the heat added to the brine system is lost to the surrounding soil. This heat loss could be quite significant but is not known.

This approach could be analysed further but because of the essential unknowns this scenario should be feasible without this supporting technologies.

8.1 Energy

The seawater temperature varies through the year from 6 to 11 °C. The weighted average temperature of the seawater is approx. 8 °C. The COP is estimated to be 3.75. The influence of the COP is described further in the sensitivity analyses (section 12.4).

The electricity demand for the system is partly for heat production and partly for the pumps circulating the brine in the network. The hydraulics for the project is described in Appendix B.

The electricity consumption for the pumps is 680 MWh and for the heat pumps 2,400 MWh. Of these approx. 70% is used during daytime and approx. 30% is used during night-time.

8.2 Economy

The economy is more comprehensive than for the previous scenarios. In this scenario there is a local heat pump installed in every building in Leirvík. In addition to this, there is a large shared brine network, a heat station with a heat exchanger and pumps and a seawater intake. Furthermore, there will be a connection fee to SEV for new substations to the electric grid along with control systems.

8.2.1 Investment

The investment costs for this scenario is shown in the table below.

Table 8.1 Investment costs for the shared brine scenario.

Technology	Number of units	Specific investment cost, DKK/unit	Investment cost, MDKK
Heat pumps, houses	315	90,000	28.0
Heat pumps, large buildings	17	100,000	1.7
Heat pump, school	1	300,000	0.3
Branch pipes, all buildings	333	5,000	1.7
Controlling	-	-	0.5
Substations	-	-	1.0
Brine network	-	-	7.5
Pumps	-	-	1.4
Seawater intake	-	-	0.5
Other	-	-	2.1
Total	-	-	45.1

The specific investment cost for individual heat pumps for the houses is stated by US. Investment costs for individual heat pumps in large buildings and in the school are estimated.

The costs of the brine network and pumps are described in Appendix E.

The branch pipes from the brine network to the individual heat pumps are estimated at 5,000 DKK pr. building.

The cost of the seawater intake is estimated to be 0.5 MDKK. This is the same price as seawater intake for the seawater heat pump.

Other costs include planning, projecting and unforeseen expenses. These are assumed to be 5% of the total investment cost of the project.

The total investment cost in this scenario is approx. 45.1 MDKK.

The individual heat pumps, branch pipes, distribution pumps and the seawater intake along with the controlling and substations have an expected lifetime of 20 years. The brine network has an expected lifetime of 40 years. With an interest of 3% the investment can be converted to an annually investment annuity of 2.9 MDKK.

The influence of the investment cost is described further in the sensitivity analysis (section 12.7).

8.2.2 O&M costs

The cost of O&M for the individual heat pumps with shared brine network is shown in the table below.

Table 8.2 O&M costs for the shared brine scenario.

Technology	Number of units	Specific O&M costs, DKK/unit pr. year	Total O&M costs, DKK pr. year
Heat pumps, houses	315	1,000	315,000
Heat pumps, large buildings	17	1,500	26,000
Heat pump, school	1	3,000	3,000
Brine network	-	-	50,000
Pumps	-	-	50,000
Seawater intake	-	-	50,000
Operation staff	-	-	200,000
Total	-	-	694,000

The specific costs of O&M of the heat pumps are estimated. It is assumed that SEV will cover O&M of the substations. The remaining costs of O&M are estimated.

8.2.3 Fuel costs

The electricity consumption for the heat pumps is approx. 2,400 MWh annually with 1,700 MWh used in daytime and 700 MWh in night-time. The price of electricity is in this case assumed to be 1.51 DKK/kWh for consumption in daytime and 1.01 DKK/kWh for consumption in night-time.

The electricity consumption for the distribution pumps is approx. 680 MWh (see Appendix C) with 480 MWh used in daytime and 200 MWh used in night-time. It is assumed that the pumps for the shared brine network is a large consumer and therefore pays a lower electricity price. The price of electricity is therefore 1.39 DKK/kWh for consumption in daytime and 0.89 DKK/kWh for consumption in night-time.

The total electricity costs add up to 4.1 MDKK annually. The influence of the electricity price is described further in the sensitivity analyses (section 12.3).

8.3 Project costs

The cost of heat incl. investment costs for this scenario is calculated to app 7.7 MDKK annually. The cost is shown in the table below.

Table 8.3 Project costs for the shared brine scenario.

	Cost, MDKK/year
Investment annuity	2.85
O&M	0.69
Electricity	4.11
Total	7.65

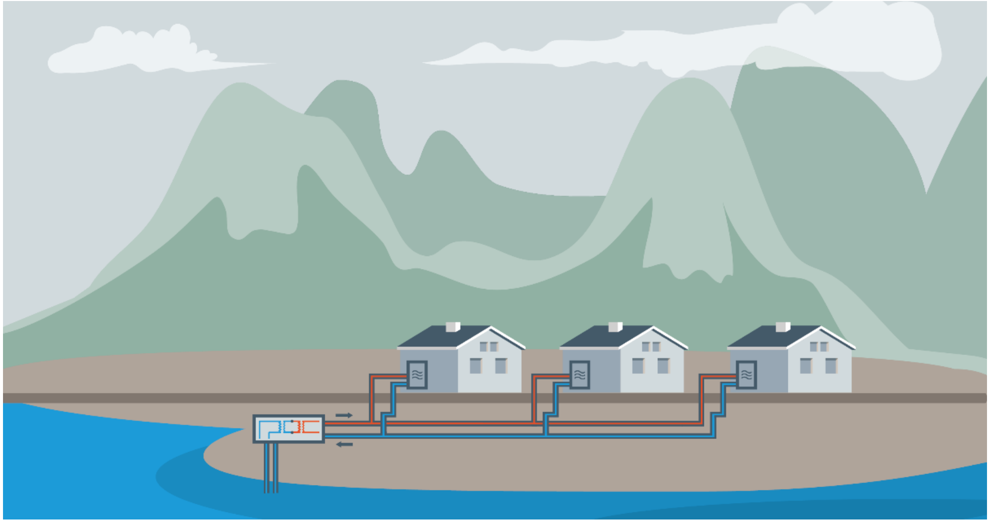
If, however, the electricity price is fixed at the current level – 1.51 DKK/kWh and 1.39 DKK/kWh – the annual costs increases to approx. 8.1 MDKK. In both cases, the heat costs are lower than for the reference scenario.

9 Seawater heat pump, district heating

The third project scenario is a district heating system. Like the shared brine scenario, the district heating scenario also includes a shared pipe network. Instead of distributed brine at low temperature, the district heating system distributes hot water to the buildings. This means that instead of having decentralised heat production as in the other scenarios (oil boiler/individual heat pumps in buildings) the heat is produced by a large heating plant.

One of the advantages of district heating is that is does not matter for the district heating system what produces the heat as long as some temperature criteria are met. Thermal power boilers (e.g. oil or waste), heat pumps, electric boilers or another production facility can therefore produce the heat. It is also possible to combine production units. This gives a very high level of flexibility.

In this scenario, a few large heat pump units are established to produce the heat for the city of Leirvík. The electrically driven heat pump units utilize seawater as heat source and heats up the return water temperature in the district heating system.



In addition to the heat pump units the electric boilers and a heat storage is established. The electric boilers will be used for back up and are not expected to produce heat under normal circumstances.

The electric boilers can be used by SEV to balance the electric grid when wind power production is high. In these cases some heat production can be produced from the boilers.

The heat storage can be used to level out the heat production with the purpose of limiting the required heating capacity of the heat pump. A heat storage can also be used to move some of the heat production from daytime to night-time. This can decrease the cost of electricity production and therefore be beneficial for both SEV and to the heat consumers in Leirvík.

In the district heating scenario the heat pump units, electric boilers and heat storage are placed as shown in the figure below (red circle).

The figure also shows the distribution network (blue lines).

Figure 9.1 *Overview of the district heating network and the placement of the heat pump system.*

9.1 Technology

9.1.1 Heat pumps

Since the heat pump utilizes an external low temperature heat source the COP is very high, typically between 3 and 4. This means that when using 1 MWh of electricity the heat pump can produce approx. 3-4 MWh heat. The COP is very dependent on the heat source (seawater; see Appendix I), the temperatures of the district heating network and the type of working fluid in the heat pump.

There are many different working fluids with different advantages and disadvantages. The working fluids are described in Appendix I. In this project, the working fluid is assumed to be either HFO1234ze or ammonia (R717).

The temperature of the hot water produced in the heat pump should be as low as possible to attain a high COP. However, there is a lower limit of the production temperature, which is the lower limit of the supply temperature in the district heating network. The supply temperature in the project is assumed to be 60 °C delivering at approx. 55 °C hot water to the buildings. The 55 °C inlet temperature to the house is the same as the expected inlet temperature of the individual heat pumps. The return temperature at design conditions is expected to be approx. 35 °C.

The temperature of the seawater is stated by US. The temperature fluctuates within 6-11 °C during the year. Based on this COP's has been calculated for several types of heat pumps. Further described in Appendix K.

The main difference in the heat pump types are weather they has one or two stages. The two stage heat pumps are more expensive but also have a much higher COP than single stage heat pumps (Appendix K). Considering these two parameters (price and COP) the HP3 (Appendix K) heat pump is the more feasible choice.

Seawater as heat source and the seawater heat source systems are further described in Appendix H and Appendix J respectively.

9.1.2 Electric boilers

Electric boilers use electricity to produce heat. The efficiency is approx. 100% producing 1 MWh of heat from 1 MWh of electricity. Compared to the heat pump the electric boiler is very inefficient. However, as a back-up unit is has the advantage of being very cheap. The investment cost of a heat pump can be 25 times more expensive pr. MW heat installed than an electric boiler. The low investment cost and high production costs make the electric boilers a good choice as back-up units.

In this project, the heat is assumed to be provided by heat pumps only. If SEV wishes to use the electric boilers, the heat price should be significantly lower than the current expected prices. The price of electricity needs to be low enough to make heat produced by electric boilers cheaper than heat produced by high efficient heat pumps at normal electricity prices. Since it is not known how low this price would be and how often this could be relevant this is not included in the project. The project will need to be feasible without this possibility.

Electric boilers does not typically come with the control ability, which would be necessary for SEV to use the electric boilers to support the electricity production system. A Danish manufacturer of electric boilers estimates that a 600 kW electric boiler is an investment of approx. 140,000 DKK. This price is without control ability. To include control ability the total cost will be approx. 200,000 DKK.

9.1.3 Heat storage

Instead of installing a heat pump with a capacity high enough to cover the peak demand at every hour, a heat storage could be established. The heat storage has multiple purposes. First, it decreases the need for heat capacity reducing investment costs of the heat pump. The heat can be produced evenly during 24 hours. Secondly, the storage can be used as a back-up and thirdly it can be used to move electricity consumption from daytime to night-time and thereby support the integration of wind power. In this project, the focus is on reducing the required production capacity while still producing all heat by heat pumps and when possible also move electricity consumption from daytime to night-time.

The heat loss of the thermal heat storage is assumed insignificant.

9.2 Energy

The heat demand in the buildings is approx. 9.000 MWh. When distributing high temperature water in pipes there will be some heat loss. The heat loss is estimated to 850 MWh (8.3% of total heat production) due to heat loss in the distribution network and 340 MWh (3.3% of total heat production) due to heat loss in the branch pipes. The heat loss calculation is specified in Appendix G. The influence of the heat loss is described further in the sensitivity analyses (section 12.6).

The total demand of heat production is therefore approx. 10,200 MWh. The chosen heat pump has an estimated COP of 3.85 when producing heat at 60 °C. The COP will decrease when producing part load. The COP will also decrease if there is a need – during cold days – to deliver heat at a higher temperature than 60 °C. Though neither part load nor higher supply temperatures are expected, the COP used in this project is 3.80. The influence of the COP is described further in the sensitivity analyses (section 12.4).

The heat demand of 10,200 MWh can be covered by using approx. 2,700 MWh of electricity.

In addition to the electricity consumption for the heat production some electricity is needed for district heating pumps to distribute the water in the district heating network. The electricity consumption is estimated to approx. 86 MWh pr. year. This is further described in Appendix D.

9.3 Heat supply and storage system

The heat demand in this scenario is a combination of room heating, hot water and heat loss. The demand of room heating is dependent of the outdoor weather conditions and therefore changing during the year. The hot water demand is changing during the day but not much from day to day during the year. The heat loss is almost constant during the year losing similar heat pr. day in the winter and the summer.

When these three heat demands are summed up at hourly values, the development in the hourly heat demand in the district heating system in Leirvík during a year is as shown in Figure 9.2.

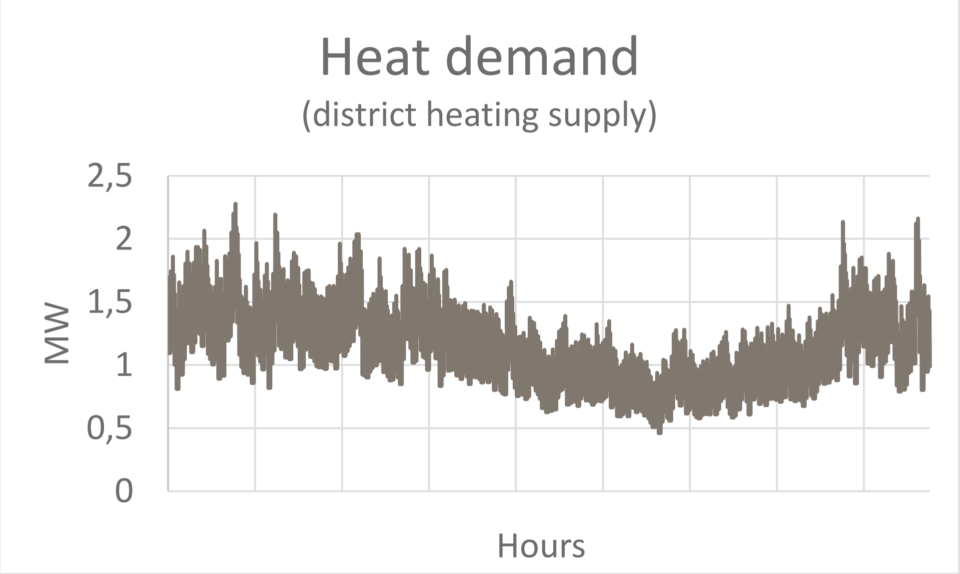


Figure 9.2 *Heat demand by hour during a year (estimated).*

As the figure shows the heat demand gets as high as approx. 2.3 MW and as low as approx. 0.5 MW. Heat loss included.

The heat demand curve for a year shows the great fluctuations of the heat demand system. The curve is – for simplicity – converted into a duration curve in Figure 9.3. This curve shows the heat demand pr. hour with the highest heat demand first and the lowest heat demand last. When buildings are energy renovated the heat demand will become less dependent on the air temperature (see also section 14.3).

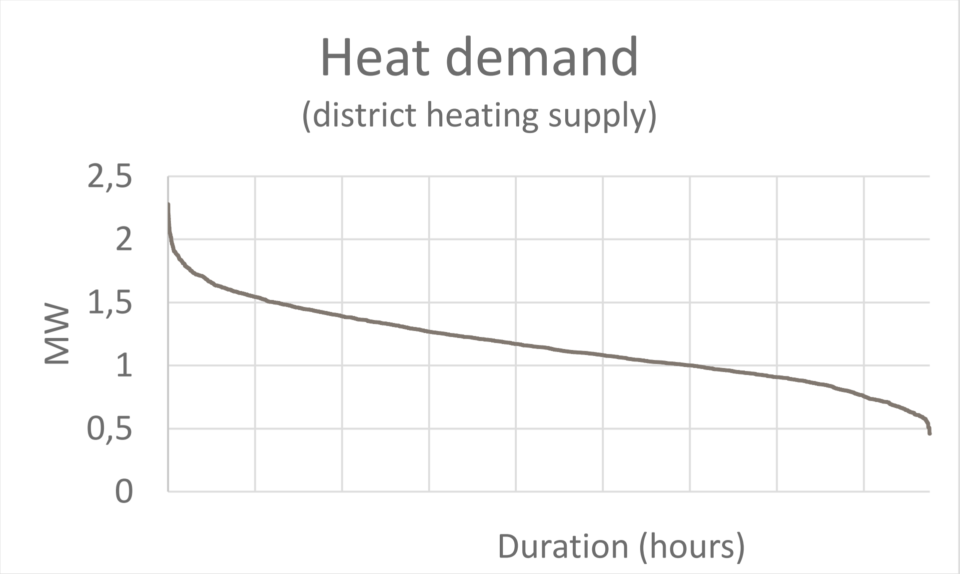


Figure 9.3 *Heat demand duration curve. Highest heat demand first (estimated).*

To find a suited size of the heat pump and heat storage a model of the system has been made. The optimal sizes of the units depend on the electricity pricing system. A high price difference between electricity pricing during daytime and night-time will increase the demand for larger heat pumps and heat storage capacity. In this main scenario, it has been assumed that the capacity of the units should not be higher than needed. If SEV introduces a tariff scheme, which can increase the incentive to produce the heat at night, then another combination of capacities can be argued. Further description in the sensibility analysis (chapter 12.8).

When simulating the system a 1.6 MW heat pump capacity in combination with 500 m³ of thermal heat storage is needed to cover 100% of the heat demand with heat from the heat pumps. As back-up three 600 kW of electric boilers are established.

The electric boilers have the controlling ability and should only be used when SEV can deliver an electricity price, which makes the heat production from the electric boilers cheaper than the heat produced by the heat pumps. With a heat price of 0.89-1.39 DKK/kWh and a COP of the heat pumps at approx. 3.8 the electricity price should be as low as approx. 0.2-0.4 DKK/kWh before it will be feasible for Leirvík to change the heat production from the heat pumps to the electric boilers.

The heat will be storage in a 500 m³ hot water cylinder tank with 7 m in diameter and 14 m in height. With a supply temperature of 60 °C and a return temperature of 35 °C the heat storage capacity of the thermal storage is approx. 15 MWh. With an average demand during the year at approx. 1.2 MW the storage contains heat for approx. 13 hours in average. During winter, this will be less and during summer, this will be more. The heat storage is further described in Appendix L.

With the chosen capacities for heat pumps and heat storage the production at a cold day is as shown in Figure 9.4. Here the heat pump will produce heat at peak load all day and the heat storage will store the excess production from the night to be used in daytime. In cold periods the storage should be loaded when possible.

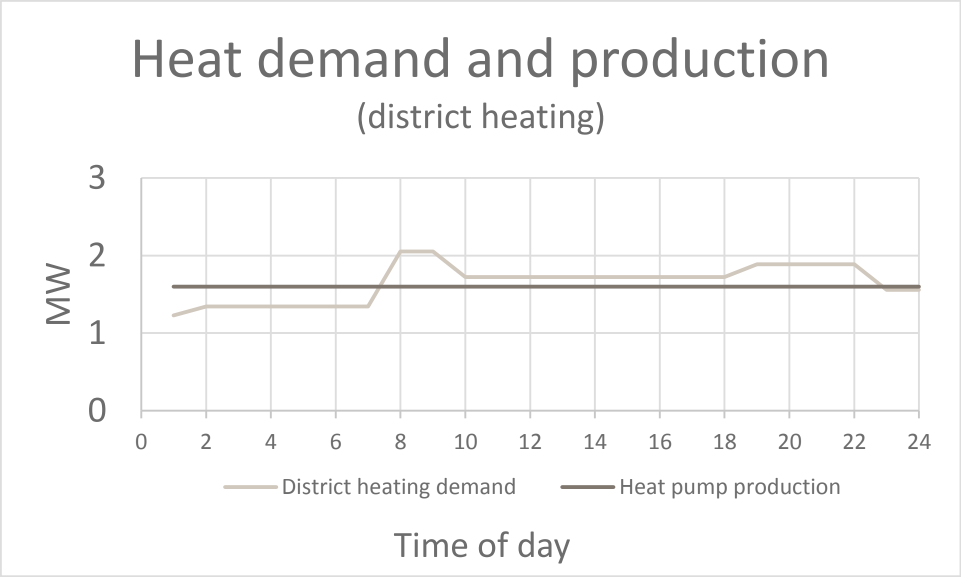


Figure 9.4 Heat demand and heat pump production by hours on a cold day in Leirvík.

During cold periods, there are no room for the heat pumps to produce more heat during the night and therefore, a larger heat storage will not be relevant with this heat pump capacity.

With the chosen capacities for the heat pumps and heat storage, the heat production during a warm day is as shown in Figure 9.5. Because of the low district heating demand, it will now be possible to produce more heat during the night.

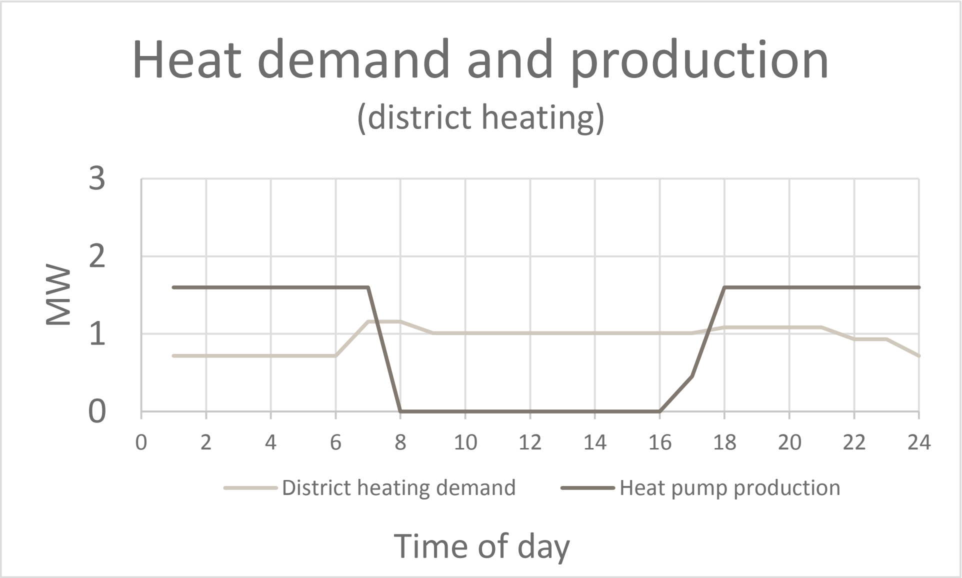


Figure 9.5 Heat demand and heat pump production by hours on a warm day in Leirvík.

As shown in the figure above the heat pump will produce at full load during night until 7.00 in the morning. Because of the higher electricity price during the day compared to the night prices the heat pumps will stop producing at 7.00 in the morning and switch to using from the storage. In this example, the storage is empty at approx. 4-5 in the afternoon. There is no need for a larger heat storage since the heat pumps produce at full load during the night with low electricity prices.

If the heat pump capacity is increased, it will be relevant to increase the heat storage capacity as it then will be possible to produce a larger part of the daily heat production during the night. This will be discussed in the sensitivity analysis (section 12.8).

9.4 Economy

In this scenario, the heat is produced central at the sea and distributed in a district heating network. In the buildings the district heating units are placed to make the connection from the district heating branch pipes to the internal water borne distribution systems. In addition to this there is a heat station with a heat exchanger and pumps, a seawater intake, two heat pumps and back-up electric boilers. Furthermore, there will be a connection fee to SEV for new substations to the electric grid along with the control systems.

9.4.1 Investment

The investment costs for this scenario is shown in the table below.

Table 9.1 Investment costs in the district heating scenario.

Technology	Number of units	Specific investment cost, DKK/unit	Investment cost, MDKK
DH units, houses	315	22,500	7.1
DH units, large buildings	17	25,000	0.4
DH units, school	1	100,000	0.1
Controlling	-	-	0.5
Distribution network	-	-	13.1
Pumps	-	-	1.4
Heat storage	-	-	2.6
Heat pump	-	-	9.6
Heat pump building	-	-	3.1
Seawater intake	-	-	0.5
Electric boilers	3	200,000	0.6
Substations	-	-	2.0
Other	-	-	2.0
Total	-	-	43.0

The specific investment cost for the district heating units incl. branch pipes for households is based on similar project at the Faroe Islands. The investment costs are estimated for district heating units incl. branch pipes in large buildings and in the school.

The costs of the district heating network and the pumps are described in Appendix F.

The cost of the seawater intake, heat pump building and heat pumps are based on experience from project in Norway. This is described further in Appendix K.

The cost for a heat storage is based on Danish prices and described further in Appendix L.

DKK 500,000 are allocated for controlling systems.

The cost for electric boilers are stated by a Danish manufacturer.

Other costs include planning, projecting and unforeseen expenses. These costs are assumed to be 5% of the total investment cost of the project.

The total investment cost in this scenario is approx. 43 MDKK.

The district heating network has an expected lifetime of 40 years. The heat pumps have an expected lifetime of 25 years but in this scenario, the lifetime is fixed at 20 years. The rest of the components have an expected lifetime of 20 years. With an interest of 3% the investment can be converted to an annually investment annuity of 2.6 MDKK.

The influence of the investment cost is described further in the sensitivity analysis (section 12.7).

9.4.2 O&M costs

The cost of O&M for the individual heat pumps with shared brine network is shown in the table below.

Table 9.2 Investment costs in the district heating scenario.

Technology	Number of units	Specific O&M costs, DKK/unit pr. year	Total O&M costs, DKK pr. year
DH units, houses	315	800	252,000
DH units, large buildings	17	1,200	20,000
DH units, school	1	2,500	2,500
Distribution network	-	-	68,000
Heat storage	-	-	50,000
Heat pump	-	-	288,000
Heat pump building	-	-	92,000
Seawater intake	-	-	2,000
Electric boilers	3	-	5,000
Operation staff	-	-	200,000
Total	-	-	981,000

The O&M cost of the distribution network is estimated at 6.75 DKK/MWh heat distributed and is based on technology data catalogue from the Danish Energy Agency.

The O&M cost of the heat pumps, heat pump building and seawater intake are estimated at 3%, 3% and 0.5% of the investments respectively.

It is assumed, that SEV will cover O&M of the substations. The remaining costs of O&M are estimated.

9.4.3 Electricity costs

The electricity consumption for the heat pumps is approx. 2,700 MWh annually with 1,440 MWh used in daytime and 1,220 MWh during the night. In this case, the price of electricity is assumed to be 1.39 DKK/kWh for consumption during the day and 0.89 DKK/kWh for consumption during the night.

The electricity consumption for the distribution pumps is approx. 86 MWh with 60 MWh used in day and 26 MWh used in night.

The total electricity costs add up to 3.2 MDKK annually. The influence of the electricity price is described further in the sensitivity analyses (section 12.3).

9.5 Project costs

The cost of heat incl. investment costs for this scenario is calculated to approx. 6.75 MDKK annually. The cost is shown in the table below.

Table 9.3 Project costs in the district heating scenario.

	Cost, MDKK/year
Investment annuity	2.58
O&M	0.98
Electricity	3.19
Total	6.75

If, however, the electricity price is fixed at the current level – 1.39 DKK/kWh – the annual costs increases to approx. 7.4 MDKK. In both cases, the heat costs are lower than for the other scenarios.

10 Overall results

This chapter compares the results of the reference scenario and three project scenarios.

10.1 Investments

The estimated investment costs are shown in Figure 10.1 for the four scenarios. The total investment costs are considerable higher for the three project scenarios than the reference. In the reference scenario, the only investment needed is for the oil boilers, which is relatively cheap compared to the heat pumps in the other scenarios.

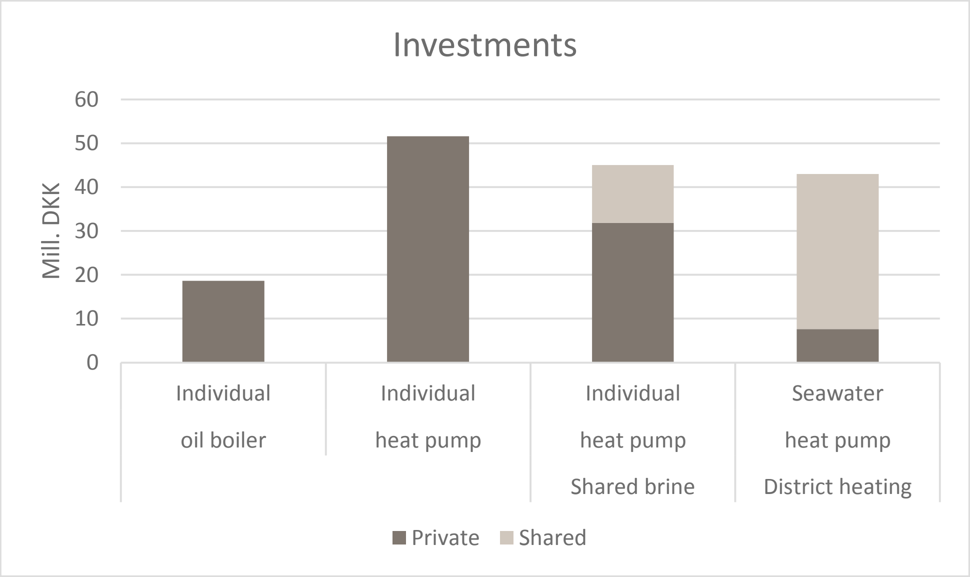


Figure 10.1 Investment costs in the four scenarios by private and shared costs respectively.

The investment costs in the figure are grouped in private and shared investments respectively. The reason for this is to show how a larger part of the investment costs in the district heating scenario is shared investments moving some of the risk from the individual consumer to the city of Leirvík. In addition, the interest rate for the financing could possibly be lower if taken by a heating company instead of individual households.

If possible, an energy company could be created renting heat pumps to the individual households. This could perhaps function in the same manner as a district heating company.

Some of the technologies has different lifetime. Figure 10.2 shows the annuity of the investments.

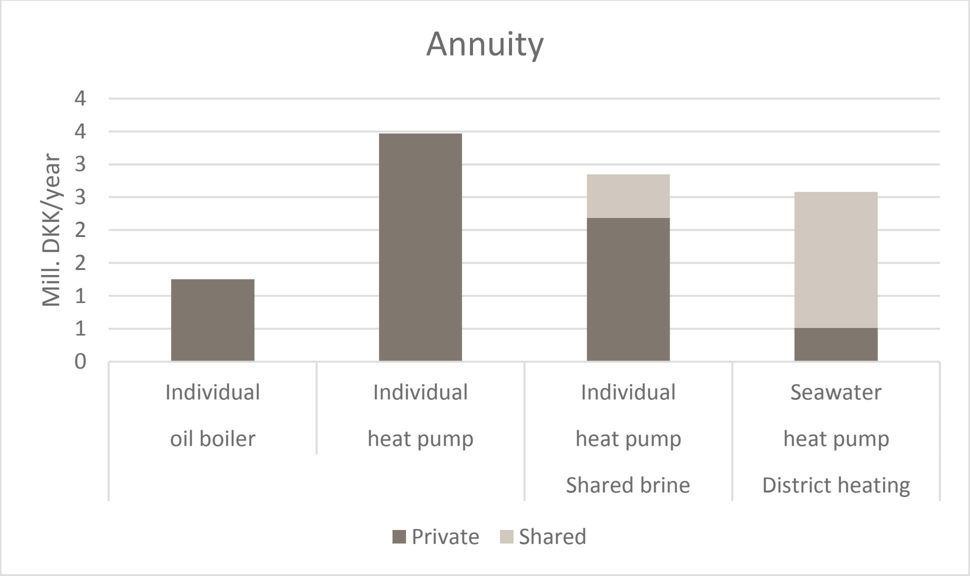


Figure 10.2 Investment annuity in the four scenarios by private and shared costs respectively.

10.2 Energy

In the reference scenario, the energy consumption is oil. In the three project scenarios, the energy consumption is electricity. The electricity is combined by oil, wind and hydro plants. In the energy consumption it is not taken into account that the fuel consumption for electricity generation is high for the oil generators. The energy consumption in Leirvík, in the four scenarios, is shown in Figure 10.3.

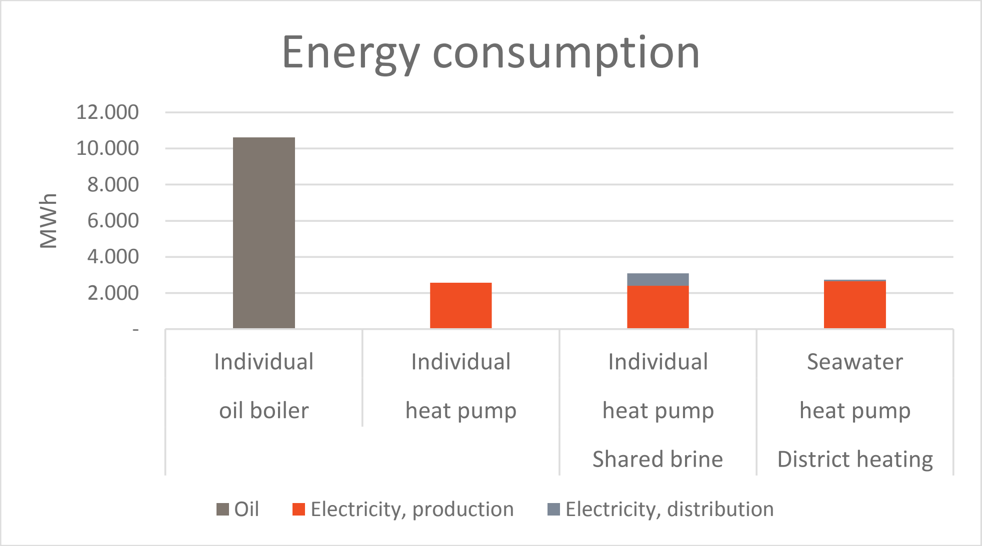


Figure 10.3 Energy consumption in the four scenarios by consumption type.

As shown in the figure, the oil consumption in the reference scenario is approx. four times higher than the electricity consumptions in the three project scenarios.

10.3 Annual costs

In addition to investment costs and energy costs is the cost of O&M. When adding the costs in annual project costs the four scenarios become comparable. Figure 10.4 shows the annual project costs when using a lower electricity price during the night and different cost for small and large consumers.

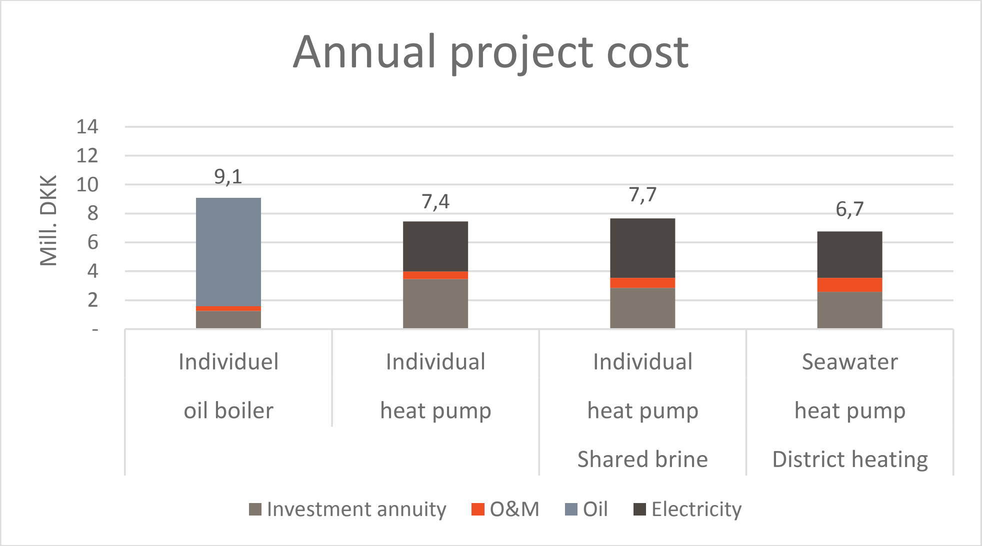


Figure 10.4 *Annual project costs in the four scenarios divided by cost type. Electricity price is different day and night and different for small and large consumer.*

As it appears in Figure 10.4, the three project scenarios are associated with considerable lower costs than the reference scenario with oil boilers. The two scenarios with individual heat pumps (individual and shared brine solutions respectively) are at the same level. The district heating scenario has the lowest annual costs approx. 12% lower than the two other project scenarios.

If maintaining the current electricity prices of 1.51 DKK/kWh for electricity consumed by small consumers and 1.39 DKK/kWh for electricity consumed by large consumers and no nightly price reduction the results are as shown in Figure 10.5. The higher cost of electricity causes the annual costs of the three project scenarios to increase. However, not so much that they become more expensive compared with the reference scenario.

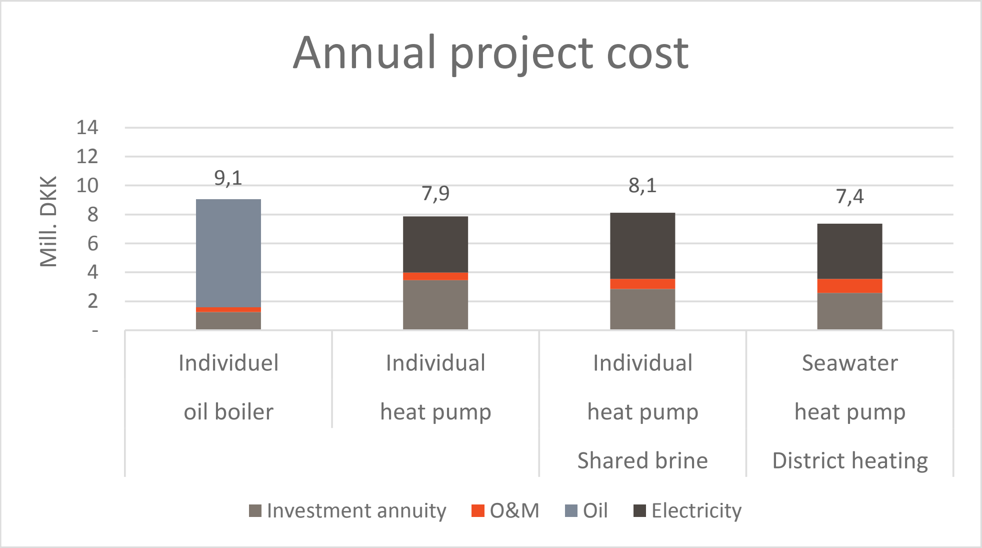


Figure 10.5 *Annual project costs in the four scenarios divided by cost type. The electricity price is the same day and night but different for small and large consumers.*

The two project scenarios with individual heat pumps are still at the same level and the district heating scenario still has the lowest costs.

11 Smart grid

Smart grid is a way of optimising the electricity system by using data and control systems (meters) to make the electricity system more flexible. In this project the smart grid solutions is to use the surplus electricity production from existing wind turbines but also to implement new wind turbines. The wind turbines are a central element of the Faroese transition to an energy production, which is 100% based on renewable energy. Within the heating sector, electric heating (heat pumps and electric boilers) is essential because of the lack of local biomasses. If implementing electric heating the share of renewables in the heat production will follow the renewable part of the electricity production. When having a 100% renewable electricity system the heat production will be 100% renewable as well.

The use of the electric heating systems can both support short-term control of wind power production when having a large part of wind power in the electricity system, and on longer-term control when moving the electricity demand from hours with a high demand to hours with a low electricity demand.

The first part – the short term – can be supported by both electrical batteries and with electric boilers. The electric boilers have a much lower efficiency compared with heat pumps but the investment price is very low making them ideal for back-up capacity. If the heat pump systems are developed in many towns in the Faroe Islands the total electric heating capacity can be rather large and some battery capacity can be saved.

The second part – the longer term (hours) – can be supported by implementing heat pumps with heat storage in the cities. These projects can be feasible by themselves but with the right electricity price, a town can benefit from making larger heat pumps and heat storages and thereby moving larger parts of the electricity consumption from hours with high demand to hours with low demand.

At the Faroe Islands the wind turbines have very nice wind conditions (frequently high wind speeds) for producing electricity evenly through the year. The wind power production is however lower during summer than the rest of the year that coincides with the heat demand being lower during summer than the rest of the year.

Both electricity and heat demand is higher during daytime than during the night. This causes some issues when introducing more electricity consumption (electric heating). This is accommodated by using heat storage where the heat production to some extend can be moved from day time to night time.

11.1 Technology capacity

In Table 11.1 capacity of heat pumps, electric boilers and heat storage is listed for the three project scenarios.

Table 11.1 *Capacity of heat pumps, electric boilers and heat storage in the three project scenarios.*

Scenario	Heat pump capacity, MW	Electric boiler capacity, MW	Heat storage capacity, MWh (m^3)
Individual heat pumps	2.2	3.6	1.3 (110)
Individual heat pumps with shared brine	2.2	3.6	1.3 (110)
District heating, seawater heat pump	1.6	1.8	14.6 (500)

For the two scenarios with individual heat pumps, the capacity is fixed at 6 kW heat pr. household heat pump. As a part of the heat pump is an electric boiler with a capacity of 10 kW. In the households, it is assumed that a 300 litres hot water tank is used as storage. For larger buildings, the capacities of the three technologies are scaled with the same capacity pr. MWh of heat demand.

For the district heating scenario two, the heat pumps with a total heat capacity of 1.6 MW heat is used. In addition to these three 600 kW electric boilers with a total capacity of 1.8 MW is established as back up. As heat storage, a 500 m^3 hot water tank is established.

The supply temperature in the buildings is assumed to be 55 °C in the individual heat pump scenarios. In the individual heat pump scenarios, the return temperature is assumed to be 45 °C. This results in a very low cooling of the hot water in the internal distribution system and the heat capacity of the hot water tank is therefore very little.

In the district heating scenario, the supply temperature is 60 °C and the return temperature is 35 °C. The higher cooling of the district heating water compared with the cooling of the brine means, that the heat capacity of the large heat storage associated with the district heating scenario is approx. 11 times higher than the individual hot water tanks even though the total volume is only approx. 4.5 times higher.

Heat pump capacity and storage capacity is further discussed in the sensitivity analysis (section 12.8).

11.2 Controlling

In all three project scenarios some central controlling of the heating systems are assumed possible.

In the two individual heat pump scenarios, the controlling ability is limited by the low heat storage capacity in the hot water tanks. In addition to this, the controlling ability in the shared brine scenario is limited during cold periods by the capacity of the brine network. If production was to be increased in some periods during the night, there can be a problem with increasing the flow of the brine.

Besides the thermodynamic/hydraulic limitations, there can be some issues for the system operator (SEV) to control more than 300 individual units simultaneously. An example is from the Danish R&D project HPCOM. In this project the remote control of individual heat pumps were tested. The problem here was that after shutting down the heat pumps it was impossible to making them start again by remote control. This was due to the way the heat pumps are produced today. This problem can be overcome, but it can take some time and limits the selection of heat pumps to choose from.

In the district heating scenario, the production units are gathered at one location and limited to two heat pumps and three electric boilers combined with only one heat storage instead of 333 of each in the individual heat pumps scenarios.

In the district heating scenario, it will also be possible to shut down the heat production for some hours if a major issue occurs in the electricity system requiring a shutdown of some large electricity consumers. As long as the distribution pumps can use a little bit of electricity and the storage has some heat stored, the heating system can continue to function for a while.

12 Sensitivity analysis

Though identified some deviations between the annual costs of the different scenarios many parameters are quite uncertain. Some of the major issues have been that it has been necessary to use prices from both the Faroe Islands, Denmark and Norway in this project. In addition to this district heating and the shared brine network is not that common on the Faroe Islands. In the following there will be made some sensitivity analysis to show how sensible the results are to the parameters.

12.1 Oil price

The oil price varies a lot. In this project, it has been fixed to approx. 7 DKK/litre corresponding to approx. 0.7 DKK/kWh. For the reference scenario to be feasible the average oil price should decrease to:

- 5.5 DKK/litres compared with the individual heat pump scenario
- 5.7 DKK/litres compared with the shared brine scenario
- 4.8 DKK/litres compared with the district heating scenario.

12.2 Oil boiler efficiency

The oil boiler efficiency is estimated at 85%. If the efficiency is increased to 100% the reference scenario still will not be feasible compared with the three project scenarios.

12.3 Electricity prices

In the main scenarios, it has been assumed that the electricity price for small consumers (individual heat pumps) are 1.51 DKK/kWh and for large consumers (district heating heat pump and distributions network pumps) are 1.39 DKK/kWh. In addition to this, it has been assumed that the electricity price decreases in both cases with 0.5 DKK/kWh at night.

12.3.1 Small and large consumer prices

Figure 12.1 shows the results of the four scenarios if the electricity price were the same for small and large consumers (1.51 DKK/kWh). In the scenarios, a price reduction during the night is still assumed.

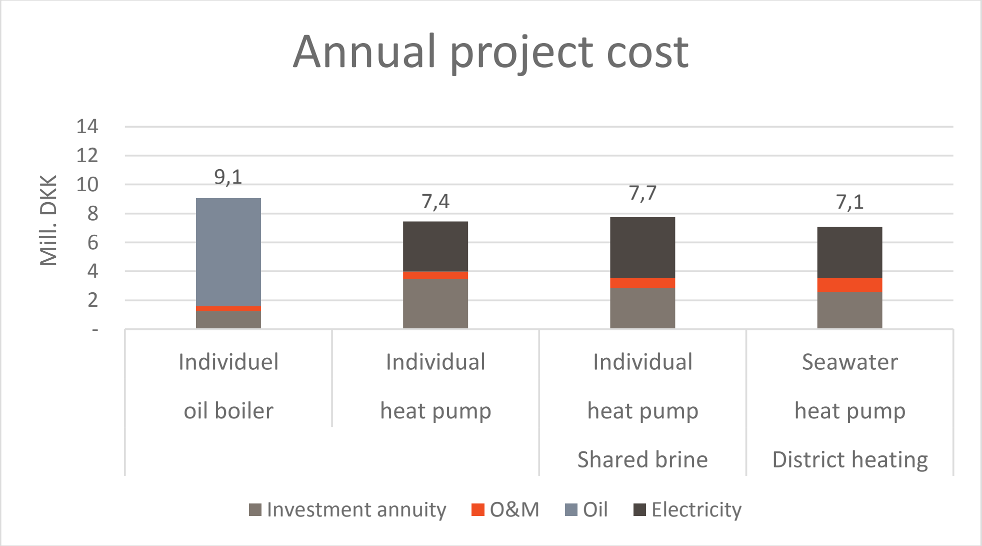


Figure 12.1 *Annual project costs in the four scenarios. Electricity price are different during day and night but the same for small and large consumers.*

For the reference scenario and the individual heat pump scenario, this has no influence. In the shared brine scenario it has some influence (electricity prices for the distribution pumps are increased). For the district heating scenario, it has a high impact increasing the annual project costs by approx. 0.4 Mill. DKK.

12.3.2 Small and large consumers prices day and night

In Figure 12.2 the results of the four scenarios are shown when the electricity price is the same (1.51 DKK/kWh) for all consumers at all times during the day (no night reduction).

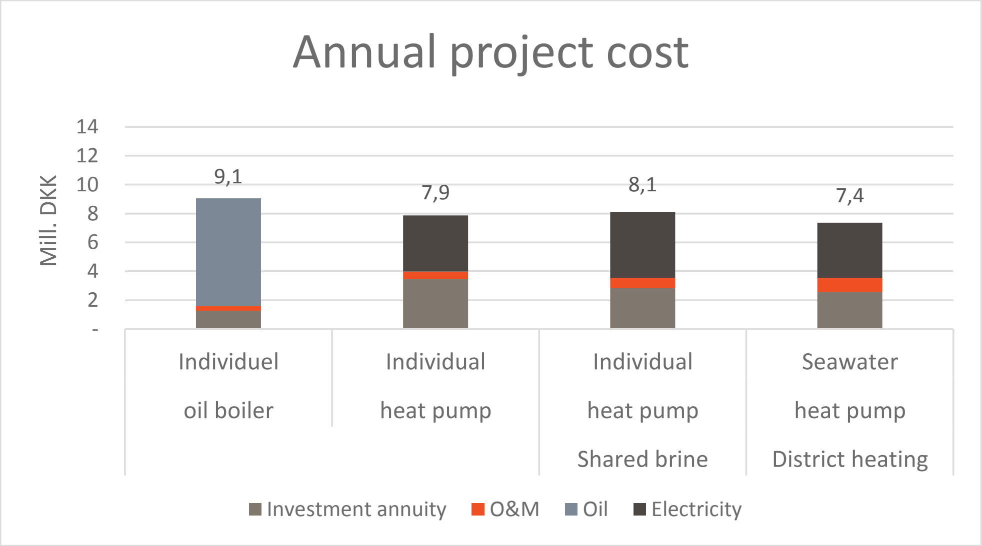


Figure 12.2 *Annual project costs in the four scenarios. Electricity price is the same during day and night and for small and large consumers.*

Of Course, this will have no effect on the reference scenario but it will increase the annual costs of the three project scenarios by approx. 400-700.000 DKK.

In both examples, the annual costs of the three project scenarios are lower than the reference scenario.

12.3.3 Level of electricity prices

The level of electricity price in the future is not known. If increasing the electricity prices by 50 % the annual project cost of the three project scenarios will increase significantly. Only the district heating scenario will still be feasible compared with the reference scenario. However, the cost levels are close between the two scenarios.

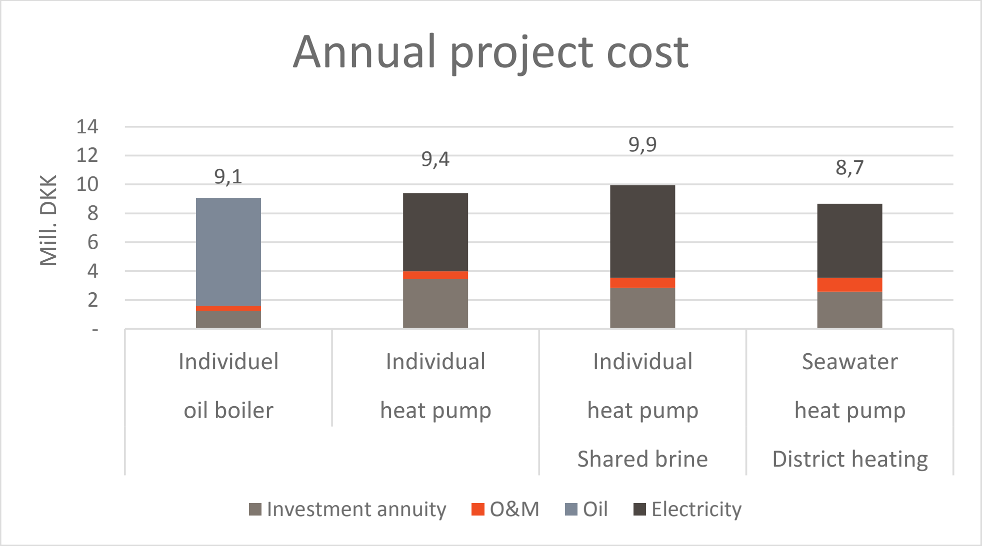


Figure 12.3 Annual project costs in the four scenarios. Electricity price is increased by 50 %.

In this example the electricity price is 2.3 and 1.8 DKK/kWh for small consumers during day time and night time respectively and 2.1 and 1.6 DKK/kWh for large consumers during day time and night time respectively.

If decreasing the electricity prices by 50 % the annual project cost of the three project scenarios will decrease significantly. The district heating scenario will still be the most feasible.

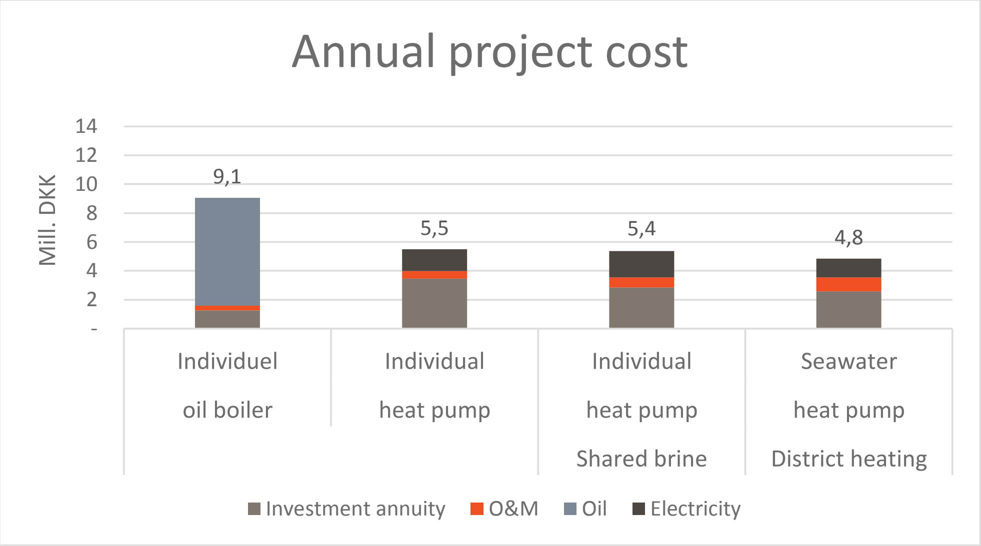


Figure 12.4 Annual project costs in the four scenarios. Electricity price is decreased by 50 %.

In this example the electricity price is 0.8 and 0.3 DKK/kWh for small consumers during day time and night time respectively and 0.7 and 0.2 DKK/kWh for large consumers during day time and night time respectively.

12.4 COP

The COP of the three project scenarios are:

- Individual heat pump scenario: 3.5
- Shared brine scenario: 3.75
- District heating heat pump: 3.8

Table 12.1 shows how much the COP needs to increase (+) or decrease (-) to break even with the other scenarios. An example is that the individual heat pump scenario will be feasible, as long as the COP is not reduced by more than 1.1. At the same time the COP of the individual heat pumps need to increase with more than 0.9 before the individual heat pumps is feasible compared with the district heating scenario.

Table 12.1 List of COP levels in the three project scenario to reach a break even with other scenarios.

Individual heat pumps scenario compared with	Break even COP
Reference scenario	- 1.1
Shared brine scenario	- 0.2
District heating scenario	+ 0.9
Shared brine scenario compared with	**Break even COP**
Reference scenario	- 1.1
Individual heat pumps scenario	+ 0.2
District heating scenario	+ 1.4
District heating scenario compared with	**Break even COP**
Reference scenario	- 1.6
Individual heat pumps scenario	- 0.7
Shared brine scenario	- 0.9

12.5 Number of connected users

Because of high investment costs in the district heating scenario for the district heating network, the production units and the storage, the feasibility is very sensitive when it comes to the number of buildings connected to the system. In this analysis the major units (production and distribution system) have been installed and the only costs that depends on the number of buildings connected to the grid is energy consumption and individual branch pipes and district heating units along with O&M.

For the reference scenario and for the shared brine scenario to be feasible compared with the district heating scenario the number of buildings connected can be as low as approx. 150. In the shared brine scenario, there is similar investments (brine network and distribution pumps) which means that this scenario is also affected by the low number of connected buildings.

For the individual heat pumps scenario to be feasible compared with the district heating scenario the number of buildings connected should be lower than approx. 240.

12.6 District heating heat loss

The heat loss within the district heating system is very difficult to determine. In this project, it was estimated to approx. 12%. If the heat loss where to increase by 28-30% the district heating scenario will not be feasible compared with the individual heat pump scenario and the shared brine scenario. Compared with the reference scenario the heat loss in the district heating system should be as high as approx. 60% before the district heating scenario no longer is feasible.

12.7 Investment costs

The investment costs are much higher in the three project scenarios compared with the reference scenario. For the reference scenario to be feasible, the estimated investment costs needs to increase by approx. 45-50% for the individual heat pump scenario and for the shared brine scenario. Compared with the district heating scenario, the investment costs need to be increased by approx. 90% of the reference scenario to be feasible.

12.8 Capacities

Because of the difference in the electricity prices in this project during daytime and night-time it is possible that it will be feasible for Leirvík to increase the capacity of the heat pumps and the heat storage and in this way be able to produce more heat during the night.

By increasing the heat pump capacity from 1.6 MW to 2.5 MW and increasing the heat storage capacity from 500 m^3 to 1.000 m^3 it will be possible to produce approx. 72% of the heat during the night. This will reduce electricity costs by approx. 350.000 DKK/year. The investment annuity will however increase by approx. 600.000 DKK/year. With the night reduction of the electricity price of 0.5 DKK/kWh it will not be feasible for Leirvík to invest in more heat pump and heat storage capacity. However, if the night reduction of the electricity price was approx. 0.65 DKK/kWh then the annual costs will be the same for the two scenario.

The increased heat pump and heat storage capacity can be of benefit for SEV but if the electricity prices are not creating the right incentive for Leirvík then this will not be relevant.

13 Environment

Today, approx. one third of the electricity and almost all heat production is based on oil. The target is to be CO_2 neutral by 2030 in the energy system at the Faroe Islands. When introducing electricity based heat production units the heat production is not automatically fossil free but the use of electricity in heat production can support the conversion to a fossil free energy system.

The CO_2 emission of fuel oil is approx. 280 kg/MWh. The annual oil consumption of Leirvík for heating purpose is estimated at approx. 10.600 MWh. This results in a CO_2 emission of almost 3.000 ton/year.

The CO_2 emission of the electricity used for the electric heating systems is unknown. In 2015, approx. one third of the produced electricity was based on oil. The heat pump systems should be able to use some of the excess electricity production from wind turbines. If the electricity used for heat pump units are assumed to be 75% based on renewables and only 25% based on oil and the electric efficiency of the oil generators are 40% the CO_2 emission is approx. 180 kg/MWh. The CO_2 emission for the three project scenarios will then be approx. 450-550 ton/year. This is a CO_2 reduction of approx. 80-85% compared with the reference scenario.

When the electricity system is 100% based on renewables the CO_2 emission from the heat pump systems will be zero.

For other emissions (NO_X, SO_2 and particles), the emissions will be reduced similarly.

In the short run, one of the important advantages with regard to the environment is that the emissions are removed from Leirvík immediately. The remaining 15-20% of the emissions left are emitted at the central production facilities.

Oil spill from the old oil tanks is a considerable risk. Often oil spill is not discovered before the oil tanks are removed and until then oil can keep pouring into the soil.

14 Next steps

This project has been developed based on assumptions and actual figures from many different institutions and countries. For the continuing of this project, these assumptions and figures should be reflected upon and some should be further analysed. Some of this is done in this chapter.

14.1 Prices

The prices of network pipes, heat pumps etc. are stated from several different people. For example, the district heating pipe costs are based on Danish experience and the brine network pipes are based on Faroese experience.

In this project, it has been assumed that the prices mentioned above is comparable. Transporting pipes to the Faroe Islands increases cost compared to Denmark but it is assumed that the other costs (digging, restoration etc.) is cheaper in the Faroe Islands than in Denmark. When comparing the other costs of the brine network with the other costs of the district heating network this seems to be correct that other costs are lower in the Faroe Islands compared with Denmark. Whether these cost differences are approx. equal is unknown.

In the continuing of this project, prices should be obtained by an entrepreneur.

14.2 COP's

COP's are very important for the outcome of the feasibility of the three project scenarios. The COP of the seawater heat pump is the most precise of the stated COP's where actual seawater temperatures are used for estimation. The COP's of the individual heat pump scenario and the shared brine scenario is based on roughly estimations from a Danish manufacturer of small heat pumps.

14.3 Buildings

The state of the buildings and the heating surfaces in the buildings are very important for the completion of the different projects. If the heating surfaces is not large enough for a supply temperature of approx. 55 °C, the buildings will reach only a suitable indoor temperature. In this case (the cold periods), it will be necessary to produce heat at a lower COP increasing electricity consumption. In the district heating scenario, the heat pump will still produce the heat but with lower COP. In the individual heat pump scenarios (individual and shared brine) the heat pumps will be supplied by the electric boilers.

The heating surfaces of the buildings in Leirvík should be analysed to see if they fit the desired criteria.

In addition to the heating surfaces, it is relevant to analyse if there are any feasible energy renovation actions, which should be completed before initiating this project. In general, for the purpose of sustainability (of nature and economy) energy savings is more favourable/has priority before shifting to renewable energy sources.

If the buildings are to be energy renovated and thus decrease the heat consumption the capacities of the technologies should be adapted to this future heat demand.

14.4 Interest rate

The interest rate is stated by US and used for both individual investments and shared investments. This rate could be analysed further as a next step. It could be that the rate for individual investments were different from the rate obtained for shared investments.

14.5 Consumers involved

In this project, only one building is excluded because of a poor location. Several other buildings are located poorly which can be analysed further. The optimal scenario could therefore be a combination of the individual heat pump scenario with individual brine pipe systems with one of the two scenarios with shared piping network (shared brine or district heating). Then most of the buildings could be heated by district heating or by individual heat pumps connected to the shared brine pipe network and the rest of the buildings can be heated by individual heat pumps with individual brine pipe systems.

14.6 Electricity prices

If the electricity consumption should be used in a sustainable way in the project scenarios, some agreements should be made between Leirvík and SEV. It is necessary for Leirvík to get an incentive to use electricity during periods with low electricity consumption. If not then there are no reasons for Leirvík to establish substations, electric boilers with controlling and large heat storage.

If the price difference between high cost and low cost electricity is high, it can be feasible for Leirvík to establish a larger heat pump capacity in the district heating scenario along with a larger heat storage moving a larger part of the electricity consumption from day to night.

It is therefore essential for Leirvík that appropriate agreements with SEV are made before continuing the project.

15 Conclusion

The main conclusion is that a conversion from fossil fuels to renewable heat production in sparsely populated areas is not only possible but also feasible compared with the current heat supply system. In this project three scenarios, alternatives to the current heat production system, was analysed. All three scenarios are feasible compared with the current heating system based on oil boilers.

In 2015 approx. one third of the electricity produced were based on oil. The rest of the electricity were produced by wind or hydro power. When implementing smart heating systems (heat pumps with heat storage) more wind power can be used. The actual RE part of the electricity consumed by the heat pump is not known but it is expected to be more than the average RE part (approx. 66 % in 2015). The smart heating systems will contribute to the implementation of more wind power production. Therefore the RE part of the electricity production is expected to increase additional.

The district heating scenario is expected to have a very high level of support for the implementation of wind power and the transition to 100 % renewable energy in The Faroe Islands.

The two scenarios with individual heat pumps (small and large brine) is almost equal with regard to the annual costs. The individual heat pump scenario where each buildings has its own brine pipes system is easy to implement with each building independent of other buildings. For shared systems (such as the shared brine scenario) most buildings should be attached to the system relatively fast for it to remain feasible. This can be difficult for those who has a new oil boiler.

The district heating scenario is the most feasible of the scenarios. This is due to high efficient heat production units and the possibility of using electricity at periods with a lower electricity production price.

The advantage of the district heating system is also the flexibility with regard to the heat production units. If, at some point, some new production possibility occur (e.g. a more efficient heat pump) it is possible to add this to the district heating network. In the scenarios with individual heat pumps, it will be much more comprehensive to change more than 300 units.

One of the central assumptions in the project is the use of heat pumps to implement wind power in the electricity system. Here district heating has the advantage of having approx. 5 units at the same place, which should be controlled. In the individual heat pump scenarios (small and large brine), there will be a need for controlling more than 300 units in just as many locations. This will not only be more difficult to manage but it can also cause further investments for the electricity system in the buildings. In addition to this, the total storage capacity is much higher in the district heating scenarios compared with the other scenarios.

Future heat demand can be decreased due to the energy renovation of buildings. If heating systems are established before renovating then the capacity of the technologies can be oversized. This will release free capacity in both heat pumps and heat storages enabling a larger part of the electricity to be moved from day time to night time.

Appendix A Oil consumption

The table below shows the buildings in Leirvík along with their oil consumptions. The numbers in grey were not stated in the data gathering process and are therefore assumed.

Table A.1 *Oil consumption by buildings in Leirvík. The consumption is stated by US for some buildings. The rest is assumed to have an annual consumption of 4,000 litres.*

	Building	Number	Oil consumption, litres oil/year
Households	Households, houses	315	3,000
	Household, Bústaðir	5	0 (individual heat pump)
	Household, Giljagarður	1	4,000
Commercial buildings	Effo	1	4,000
	Bovling	1	2,900
	Føroya Bjór	1	4,000
	Knettivirkið	1	4,000
	Tavan	1	- (own production)
	Norðfra	1	- (own production)
Public buildings	Kirkjan	1	3,000
	Missiónshús	1	4,500
	Hebron - samkomuhús	1	4,000
	Leirvíkar Skúli	1	60,000
	Frítíðarskúli	1	4,000
	Barnagarður	1	4,000
	LÍF - ítróttarhús	1	4,000
	Skótahús	1	1,400
	Bátasavn / Kommunuskrivstova	1	4,000
	Bygdarhús	1	4,000
	Lávusarhús	1	4,000
	Leirvíkar Arbeiðsmannafelag	1	4,000

The total oil consumption is approx. 1.06 mio. litres pr. year. With a density of 0.84 kg/litres of oil and a heating value of 42.7 MJ/litres of oil, the oil consumption corresponds to approx. 10,600 MWh pr. year. With an estimated heat efficiency of 85% for the oil boilers, the heat demand is approx. 9,000 MWh.

Appendix B Hydraulics

This appendix deals with the hydraulics of both the shared brine system and the district heating system. Common assumptions, pressure, elevation/level and flow among others are described.

B.1 Assumptions

- Heat demand
  - Households: 25 MWh/year
  - Large buildings:40 MWh/year
  - School: 500 MWh/year
- Temperatures
  - District heating:80°C/40°C
  - Brine: 10°C/7°C

The nominal demand used for dimensioning in the model is based on a yearly usage time of 4,000 hours.

The nominal demand is:

- Households: (25 MWh*1,000)/4,000 hours = 6.25 kW
- Large buildings: (40 MWh*1,000)/4,000 hours = 10 kW
- School: (500MWh*1,000)/4,000 hours = 125 kW

In total, the heat demand of the buildings is found to be approx. 2.3 MW heat. For the district heating scenario, the heat demand is assigned additionally 0.14 MW of heat in terms of heat loss.

The consumers are distributed as shown in the figure below (green dots are households and brown dots are large buildings incl. the school).

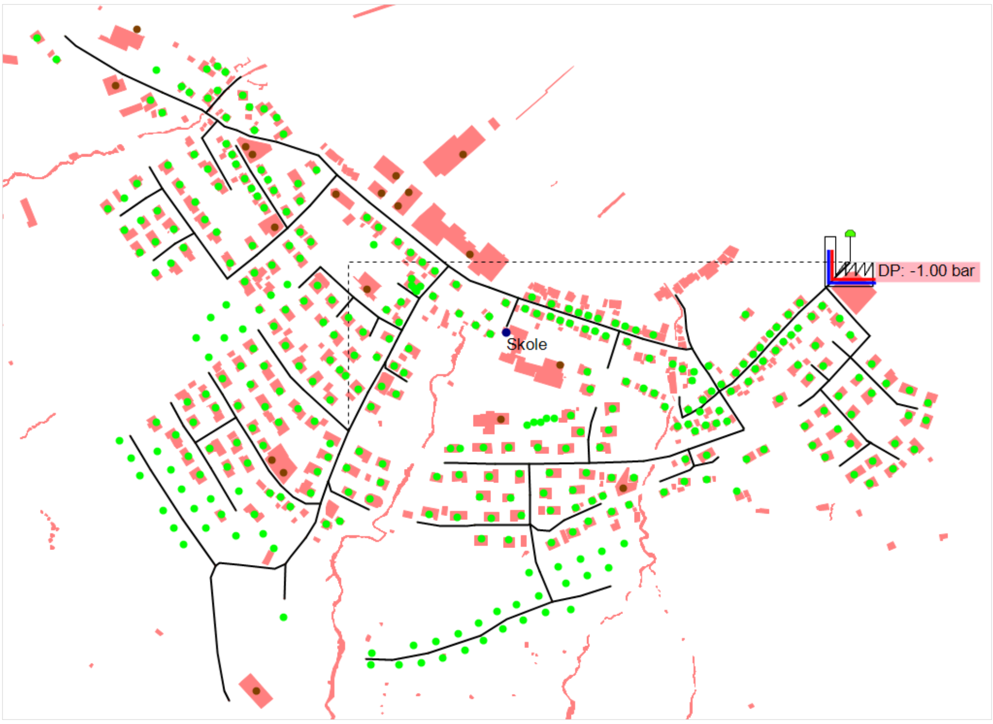


Figure B.1 Overview of the consumers (green and brown dots) in the project.

B.2 Elevation

The specific challenge in Leirvík is the difference in elevation. The elevation goes from 0 m to 60 m.

One consumer – the sports arena – is not included in these calculations since it is placed in elevation 100 m. The branch pipe for this specific building would be 300 m, which will not be feasible.

If only pumping from the heat plant by the sea it will be necessary to maintain a high static return pressure to overcome the differences in elevation. This results in a corresponding high supply pressure to ensure sufficient differential pressure at the consumers. This challenge can be solved with one or more pump stations in the distribution network.

The elevation points are manually entered based on the contour lines. Because of this, it is necessary if continuing this project, to verify these elevation points. Especially this project's current highest placed building (elevation of 60 m). In the figure below a map of Leirvík with elevation areas are shown. The actual levels will be used to determine the actual location of the pump station.

Figure B.2 *Overview of the levels in Leirvík.*

B.3 Current hydronic heat distribution system in buildings (district heating)

The current hydronic heat distribution systems in the buildings are not known. If the existing hydronic systems are not to be renovated the pressure should probably be limited to a max. of 6 bars and a test pressure of 9 bars.

It is recommended to pressure test some of the systems in buildings in the lower part of the city. In addition to this a pressure maintenance valve could be added to the buildings to avoid a to high pressure in the network.

It is assumed that there will not be any notable energy renovation actions and that the cooling will be limited. It is therefore assumed that the return temperature will not be lower than 35 °C.

B.4 Other assumptions

All calculations are based on the following assumptions:

- Pressure gradient max. 100 Pa/m
- Velocity max. 2 m/s
- Differential pressure min. 0,5 bar
- Return pressure min. 1,0 bar
- Supply pressure – no limitation but it is attempted to keep the pressure under 6 bars.

B.5 Pump system, shared brine

If the only pumping is from the heat station by the sea then the flow and level are as shown in the table below.

Table B.1 Flow and level of the pumping system in the shared brine scenario with pumps placed at the heat station.

	Flow [m³/h]	Level [bar]
Pumps, heat station		
Supply pump	712	2,4
Return pump	712	5,5

The calculation made for a supply temperature at 10 °C and a return temperature at 7 °C. The supply pressure will be up to 8 bars in peak load.

If a pump station is added to the distribution system the flow and level will be as shown in the table below.

Table B.2 Flow and level of the pumping system in the shared brine scenario with pumps placed on both the heat station and a pump station.

	Flow [m³/h]	Level [bar]
Heat station		
Supply pump	712	2.3
Return pump	712	3.5
Pump station		
Supply pump	125	2.5
Return valve	125	1.6

In intermediate load the flow and level will be as shown in the table below.

Table B.3 Flow and level of the pumping system in the shared brine scenario with pumps placed on both the heat station and a pump station. Intermediate load level.

	Flow [m³/h]	Level [bar]
Heat station		
Supply pump	390	1.4
Return pump	390	4.0
Pump station		
Supply pump	67	2.3
Return valve	67	2.2

The supply pressure will be up to 6.9 bars in peak load and 6.1 bars in intermediate load.

B.6 Pump system, district heating

The figure below shows the pressure in the district heating system at peak load. The calculation made for a supply temperature at 70 °C and a return temperature at 35 °C. The supply pressure will be up to 6.1 bars in peak load (orange area in the figure below).

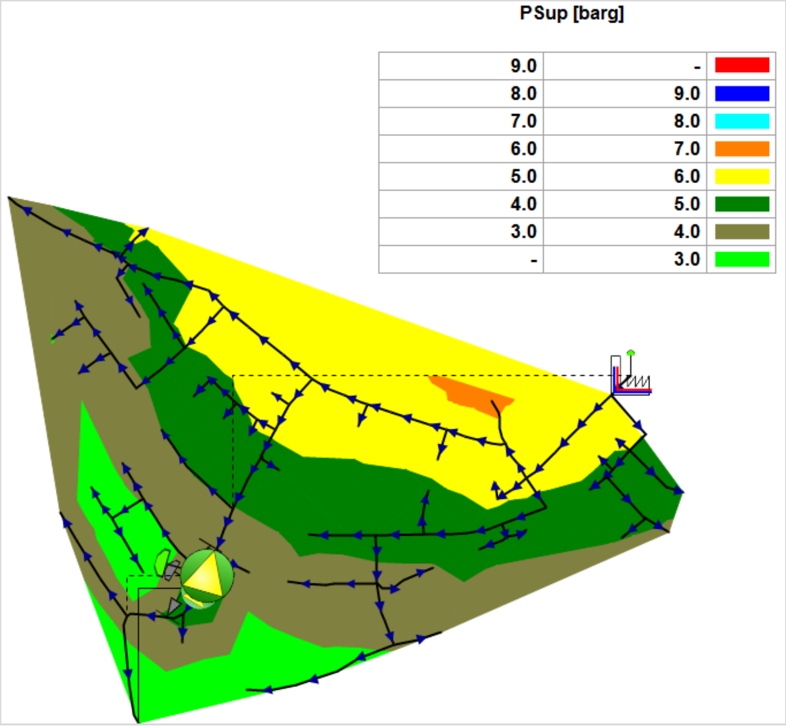


Figure B.3 Pressure overview of the district heating system.

If the only pumping is from the heat station by the sea the flow and level is as shown in the table below. Here the calculation is made for the intermediate load at 65 °C

Table B.4 Flow and level of the district heating system at the pumping station.

	Flow [m³/h]	Level [bar]
Heat station		
Supply pump	54	1,4
Return pump	54	5,5

If a pump station is added (here at level 30 m) the pressure profile is as shown in the figure below.

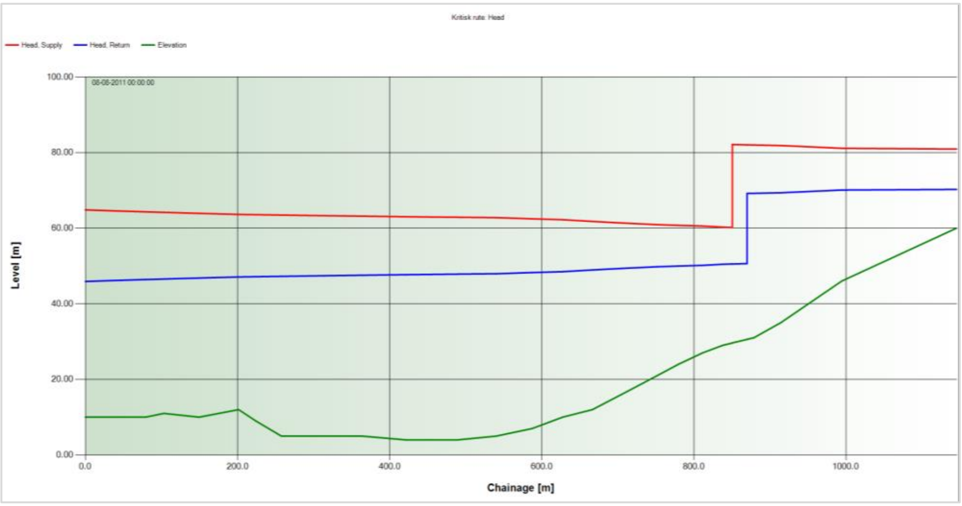


Figure B.4 Pressure profile in the district heating scenario.

If a pump station is added to the distribution system the flow and level will be as shown in the table below.

Table B.5 Flow and level in the district heating system at the heat station and a pump station.

	Flow [m³/h]	Level [bar]
Heat station		
Supply pump	54	1.4
Return pump	54	3.8
Pump station		
Supply pump	2.5	1.9
Return valve	2.5	1.8

The calculation made for a supply temperature at 65 °C and a return temperature at 35 °C. The supply pressure will be up to 5.6 bars in peak load.

Appendix C Pumps, shared brine

C.1 Costs

The prices for pumps for the brine network are obtained from the pump manufacturer DESMI and are based on an 'average' brine solution (brine fluid with a density of 1.3 kg/Litres). The pumps are incl. frequency converters.

Table C.1 Investment costs of pumps in the shared brine scenario.

Station	Pipe dimension	Price
Supply pump, heat station	PE400	165,000
Return pump, heat station	PE400	165,000
Total, heat station		**330,000**
Supply pump, pump station	PE200	50,000
Return pump, pump station	PE200	20,000
Building, pump station	-	1,000,000
Total, pump station		**1,070,000**
Total		**1,400,000**

C.2 Pumping power

The needed power for pumping is approx. 800 MWh that is only pumping from the heat station. This can be decreased by approx. 16% if a pump station is built in the distribution system. Annually, this reduction will corresponds to approx.150,000 DKK approximately. The additional investment cost of approx. 1 MDKK has therefore a short simple payback period[2] (approx. seven years).

The demand for power and corresponding demand for electricity are shown in the table below for the situation with only pumps at the heat station by the sea.

Table C.2 Power for pumping in the shared brine scenario with pumps at the heat station only.

	kW	**MWh**
Heat station		
Supply pump	22	195
Return pump	72	628
Total	94	**823**

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[2] Simple payback is defined as the investment cost divided by the annual savings: 1,070,000 / 150,000 = 7 years

The power demand and corresponding electricity demand when adding pump and valve at a pump station are shown in the table below.

Table C.3 Power for pumping in the shared brine scenario with pumps both at the heat station and at a pump station.

	kW	**MWh**
Heat station		
Supply pump	19	166
Return pump	54	475
Pump station		
Supply pump	5	47
Total	78	**688**

Appendix D Pumps, district heating

Prices for pumps to the district heating network is obtained from the pump manufacturer DESMI. The pumps are incl. frequency converters. Prices are shown in the table below.

Table D.1 Investment costs for pumps in the district heating scenario.

Station	Pipe dimension	Price
Supply pump, heat station	DN150	130,000
Return pump, heat station	DN150	130,000
Total, heat station		**260,000**
Supply pump, pump station	DN80	80,000
Return pump, pump station	DN80	30,000
Building, pump station	-	1,000,000
Total, pump station		**1,110,000**
Total		**1,370,000**

The needed power for pumping is approx. 100 MWh which is only pumping from the heat station. This can be decreased by approx. 24% if a pump station is built in the distribution system. Annually, this reduction will corresponds to approx. 32,000 DKK. The additional investment cost of approx. 1 MDKK corresponds to an annually cost of approx. 67,000 DKK. It is therefore not directly feasible to establish a pump station.

If the pump station is not established the pressure cannot be decreased to less than 6 bars. It is uncertain whether the internal water borne distribution systems in the buildings can handle a pressure this high. This is not known but based on Danish experience they will not be able to handle this.

The pressure issue can be handled in two ways. Either make the district heating units indirect (heat exchanger) or built a pump station.

In this project, the solution is chosen to be the pump station.

The power demand and corresponding electricity demand are shown in the table below for the situation with only pumps at the heat station by the sea.

Table D.2 Power for pumping in the district heating scenario when pumping from the heat station.

	kW	MWh
Heat station		
Supply pump	2.6	23
Return pump	10.3	90
Total	12.9	**113**

The power demand and corresponding electricity demand when adding the pump and valve at a pump station are shown in the table below.

Table D.3 Power for pumping in the district heating scenario when pumping from both the heat station and a pump station.

	kW	MWh
Heat station		
Supply pump	2.6	23
Return pump	7.1	62
Pump station		
Supply pump	0.2	1
Total	9.9	86

Appendix E Distributions pipes, shared brine

The brine network is established with PE pipes. The pipes are PN10 as the PN6.3 only come in a few dimensions.

Dimensions, trench meters and pipe costings are shown in the table below. Costs of valves, bends and T-pieces are not included in the table. Specific price costs are including digging.

Table E.1 Investment costs for the shared brine network.

Dimension	Trench length, m	Price, DKK/m	Price, DKK
PE63	734	*700*	513,728
PE75	685	*720*	492,962
PE90	766	*820*	628,354
PE110	710	*940*	667,650
PE125	296	960	284,278
PE160	565	1,020	575,968
PE200	453	1,060	480,390
PE225	390	*1,600*	623,380
PE250	47	1,600	75,538
PE315	339	1,920	650,474
PE400	202	2,000	403,014
Total	5,186	-	**5,395,736**

The specific prices are based on data from the Faroese consulting engineers SMJ associated with the Klaksvik project. Specific prices written in italic are assumed prices based on the stated prices.

In the table below, estimated width of the trench and the total cost of restoration are shown. It is assumed that there will be approx. 200 mm between the pipes and 200 mm on each side of the pipes. The total width of the trench will therefore be 600 mm plus the diameter of the two pipes. From the Klaksvik project, a price of 450 DKK/m² is stated for restoration. From the hydraulic model it is estimated that approx. 90% of the pipes will be put down in roads or likewise. In the table below the 90% is used for all pipes dimensions.

Table E.2 *Costs of restoration after the trench work.*

Dimension	Trench length, m	Width of trench, m	Price, DKK
PE63	734	0.73	215,818
PE75	685	0.75	208,069
PE90	766	0.78	241,979
PE110	710	0.82	235,791
PE125	296	0.85	101,898
PE160	565	0.92	210,519
PE200	453	1.00	183,465
PE225	390	1.05	165,848
PE250	47	1.10	20,939
PE315	339	1.23	168,873
PE400	202	1.40	114,534
Total	5,186	-	**1,867,732**

It is possible that more of the pipes can be put down in areas without the need for restoration. This could though increase the pipes length and therefore the cost of pipes and digging.

Cost of valves, bends and T-pieces are estimated at a cost of 200,000 DKK.
The total cost of the shared brine network is therefore as shown in the table below.

Table E.3 *Total costs of the shared brine network.*

	Cost, MDKK
Pipes incl. digging	5.4
Restoration	1.9
Valves, bends and T-pieces	0.2
Total	7.5

Appendix F Distribution pipes, district heating

For the district heating distribution pipes, the specific prices are based on experiences from projects in the Western Denmark. The prices are for series of two single pipes and restoration, bends and valves are included.

The trench length, specific trench prices and total prices for the district heating distribution pipes listed below. The cost of the pipes can be higher at the Faroe Islands but the trench work incl. restoration can be lower than in Denmark.

Table F.1 Investment costs of the district heating network.

Dimension	Trench length, m	Price, DKK/m	Price, DKK
DN32	2,434	2,258	5,497,560
DN40	537	2,305	1,236,976
DN50	677	2,467	1,670,462
DN65	253	2,613	660,682
DN80	580	2,740	1,588,650
DN100	165	3,123	513,902
DN125	339	3,421	1,159,022
DN150	202	3,753	756,237
Total	**5,185**	-	**13,083,490**

The dimensions are not very depending of the supply heat temperature. As this is an assumption of an almost fixed cooling in the buildings of 25-35 °C with the low cooling linked to a low supply temperature, and a higher cooling linked to a high supply temperature. It will of course have an effect on some of the pipes dimensions, which will be a bit larger when decreasing the supply temperature and therefore reducing the cooling.

Appendix G Heat loss, district heating

Heat loss is divided by loss in the main network (distribution) and individual branch pipes (from the main network to the individual buildings).

Table G.1 Heat loss in the district heating distribution pipes.

Dimension	Trench length, m	Heat loss, W/trench m	Heat loss, MWh/year
DN32	2,434	13	271
DN40	537	14	67
DN50	677	16	95
DN65	253	18	39
DN80	580	19	95
DN100	165	20	29
DN125	339	23	67
DN150	202	26	45
Total	**5,185**	-	708

Heat loss from the branch pipes is very difficult to calculate. Experience shows that heat loss in branch pipes typically is about 25-50% of the heat loss in the distribution pipes.

In this project, the heat loss in branch pipes is assumed to be 40% of the heat loss in the distribution pipes – approx. 283 MWh annually.

Therefore, the total heat loss is estimated at approx. 991 MWh. Because of the significant uncertainties when it comes to estimating the heat loss the heat loss is increased by 20% in this project, resulting in a total heat loss of approx. 1.190 MWh. Of this 850 MWh (8.3% of total heat production) is due to heat loss in the distribution network and 340 MWh (3.3% of total heat production) is due to heat loss in the branch pipes.

Appendix H Seawater as heat source

Figure H.1 shows the seawater depth outside Leirvík (www.kortal.fo) with two examples of location/trace for a seawater pipeline.

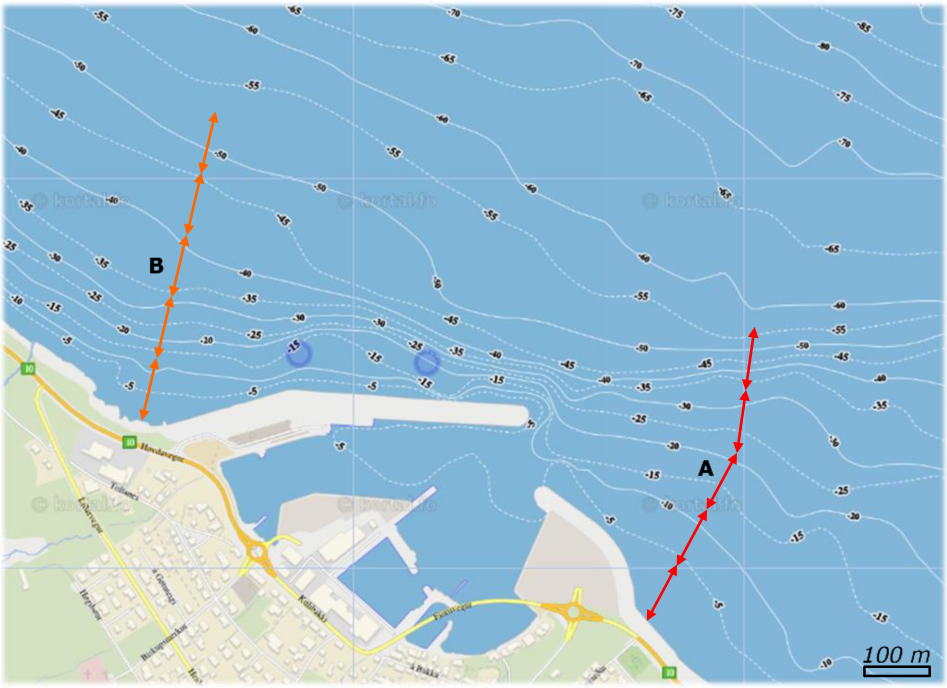

Figure H.2 shows the seabed profile for trace A and B and indicates acceptable conditions for placing a 300 to 400 m seawater pipeline outside Leirvík.

Figure H.1 Seawater depth outside Leirvík (www.kortal.fo).

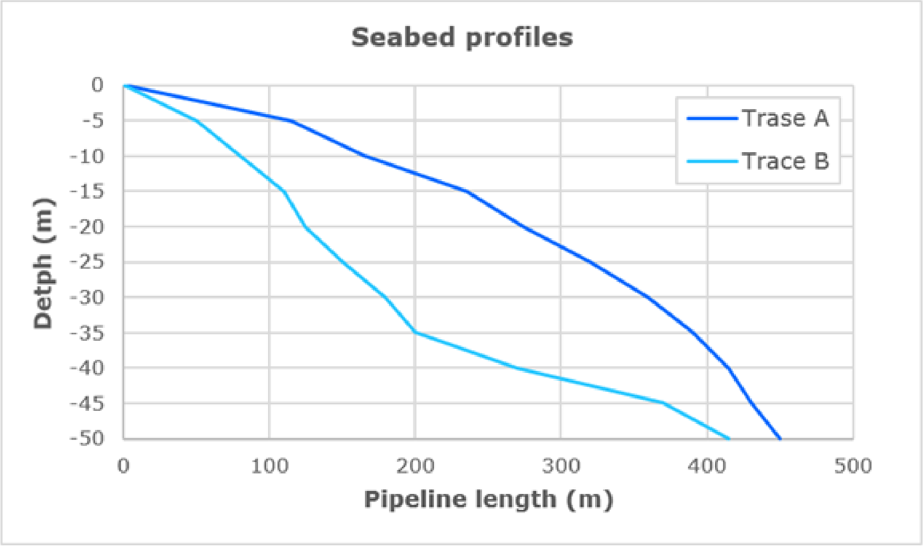

Figure H.2 Seabed profiles for two possible traces for seawater pipelines (A, B).

The seawater temperature at the Faroe Islands typically range from 6 to 11 °C with cyclic variation during the year, Figure H.3.

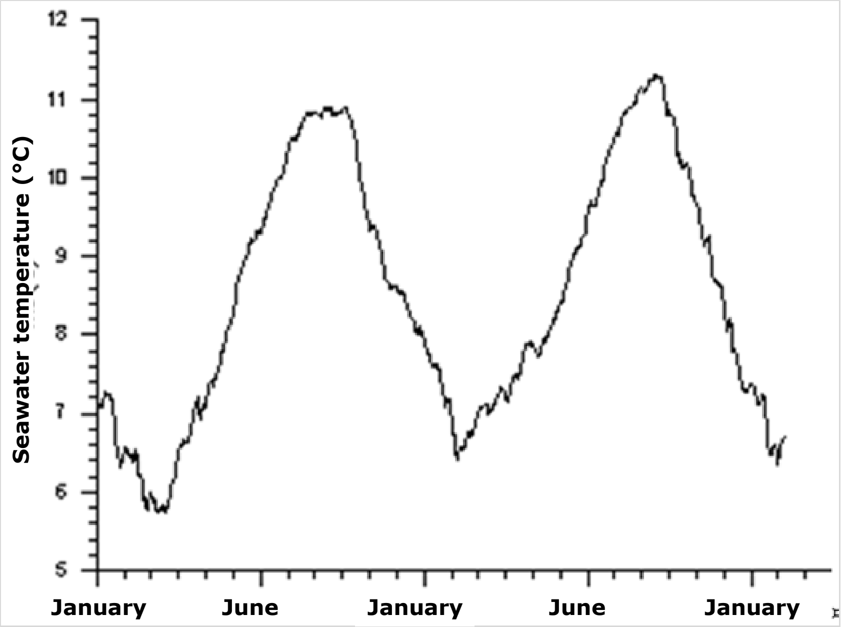

Figure H.3 *Measured seawater temperatures at the Faroe Islands.*

The maximum measured tidal range at Tórshavn, the Faroe Islands, is only *0.56 m*, Figure H.4.

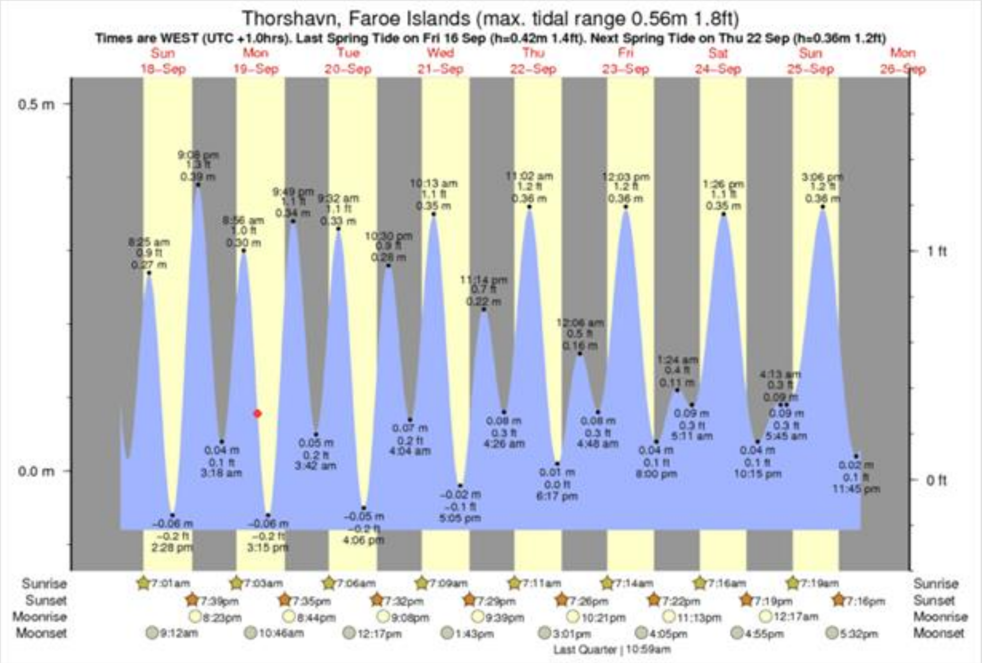

Figure H.4 *Measured tidal range at Tórshavn, the Faroe Islands (tide-forecast.com).*

Appendix I Heat pump working fluids

The type of working fluid and available technology determines the max. supply water temperature from a heat pump. Working fluids for medium/large-capacity heat pumps working with outlet water temperatures above 60 °C include:

- **HFC134a (R134a)** – Synthetic working fluid applicable for heat pumps supplying heat at high temperatures. Maximum outlet temperature:

- Single-stage units 60-65 °C (standard 28 bar pressure rating)
- Two-stage units 75-90 °C (40 bar)

The revised EU F-gas Directive of 01.01.2015 has the intention to phase-out the HFC working fluids by 2030. The main focus is on working fluids with a GWP[3] larger than 2,500 including R404A and R507A with GWP around 4,000, but other HFCs such as R410A (GWP 2100), R407C (GWP 1750) and *R134a (GWP 1440) will eventually be included*. For new medium- and large-capacity heat pump installations it is therefore highly recommended to avoid R134a and select a low- or zero-GWP working fluid in order to avoid a future retrofitting or in worst case scrapping of the heat pump units.

Figure I.1 Example – heat pump unit with HFC134a or R450A (max. 65 °C).

- **HFO1234ze** – Synthetic working fluid with negligible GWP (GWP_{HFO}=6) which developed to replace R134a in liquid chillers and heat pumps. The required compressor volume is about 25 % larger than that of R134a plants (higher investment costs), while the COP is more or less the same.

Maximum outlet temperature:

- Single-stage units 60-65 °C (28 bar) – scroll/piston/screw compr
- Two-stage units 75-90 °C (40 bar) – piston/screw compressors.

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[3] GWP – Global Warming Potential (GWP_{CO2} = 1)

Figure I.2 Example – heat pump unit with HFO1234ze (max. 65 °C)

- **Blends** (mixtures) of R1234ze and R134a, e.g. R450A (58%, 42%), has a moderate GWP (GWP_{R450A}=600), and can be used as a replacement for R134a. The maximum outlet water temperature with single- and two-stage system design is the same as for R134a and HFO1234ze.

- **Ammonia (R717, NH_3)** – Natural working fluid with 0 GWP (GWP_{R717}=0). Due to superior thermophysical properties of the fluid and industrial equipment standard R717 heat pumps achieve considerably higher COP than that of HFC and HFO plants, and the equipment lifetime is much longer. The investment cost is considerably higher. Maximum outlet temperature:

• Single-stage units	48-52 °C (28 bar) – piston/screw compr.
• Two-stage units	65-70 °C (40 bar) – piston compressors
• Single/two-stage units	80-82 °C (52 bar) – screw compressors
• Two-stage units	85-90 °C (60 bar) – screw compressors.

Figure I.3 Example – heat pump unit with ammonia/R717 (max. 82 °C)

Ammonia is very toxic and moderately flammable and classified in working fluid Group B2 according to the European standard EN378. Consequently, special safety measures are required in the design, construction and operation of R717 heat pumps and machinery room. This increases the costs of the installation compared to HFC or HFO heat pump plants.

- **Carbon dioxide (R744, CO_2)** – Natural working fluid with GWP 1 (GWP_{R744}=1). CO_2 heat pump systems can supply high-temperature water (60-85 °C), and due to the unique CO_2 heat pump cycle they achieve very high COP when they are used for domestic hot water (DHW) heating in regions with relatively low city water temperature (cold mains). However, in standard district heating systems with high return temperature (>50-70 °C) the COP will be considerably lower than that of HFC, HFO and ammonia heat pump plants. The technology is not recommended for a medium capacity heat pump installation in Leirvik.

- **Hydrocarbons (propane etc.)** – Natural working fluids with negligible GWP (GWP_{R290}=3). Hydrocarbon heat pumps can be designed for high outlet water temperatures. However, due to the flammability (A3 group, EN378), hydrocarbons are mainly recommended in low-capacity systems with small working fluid charge (< 3 kg per unit), i.e. not recommended technology.

Appendix J Seawater heat source system

Seawater heat source systems for medium/large-capacity heat pumps (>500 kW) are mainly designed as "open systems" where seawater is pumped from typically 30 to 50 m depth through a large diameter plastic pipeline (PE100, SDR17) to the heat pump system, cooled down 3-4 °C, at designed conditions and returned to the sea via a plastic pipeline. The seawater pumps are installed in a separate pump well by the seaside or in the heat pump machinery room if the heat pump plant is located close to the sea.

Seawater systems must be carefully designed and operated:

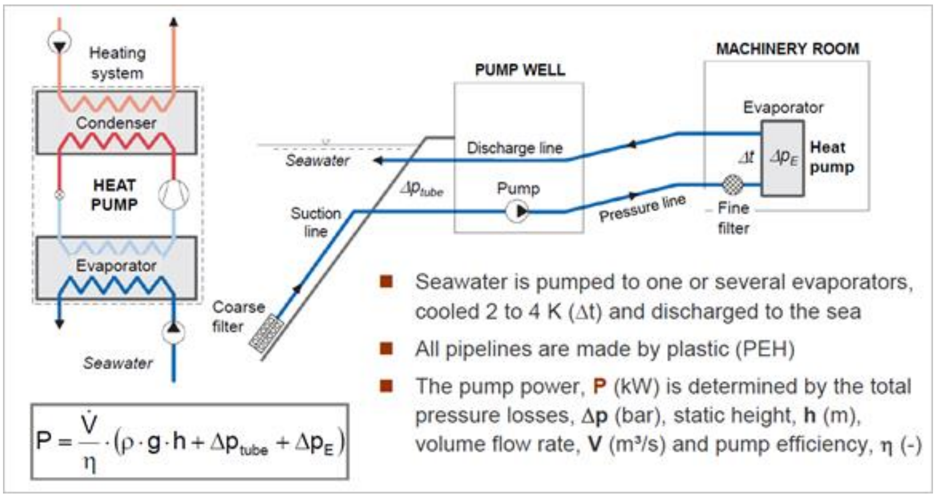
- *Corrosion* – titanium plate heat exchangers, pumps with bronze impeller or bronze casing/impeller, bronze valves etc. to minimize corrosion
- *Fouling/clogging* – inlet depth at minimum -20 to -40 m to minimize biological activity and consequent fouling in pipelines and heat exchangers, use of self-cleansing filter to prevent clogging of heat exchangers etc.
- *Freezing of water* – minimum seawater temperature requirement 2-3 °C and active compressor control to avoid local freezing in heat exchangers
- *Cavitation* – large diameter suction pipeline and location of seawater pumps 1-2 m below the lowest sea level to avoid cavitation.

In large seawater systems, a course filter is installed at the seawater pipeline inlet and self-cleaning fine filter is located after the seawater pumps before the heat exchangers. In addition to this, it is important to have a suitable depth of intake (at least 30 meters) to limit the biological activity along with speed in the seawater intake pipeline high enough to minimise fouling.

Open seawater systems have "direct" or "indirect" system design.

J.1 Direct system design

The seawater is cooled directly in the heat pump evaporators, which means that the evaporators must be corrosion proof (special design). The difference in altitude between the pump well and the heat pumps should be relatively low in order to minimize the energy use for the seawater pumps in the open loop.



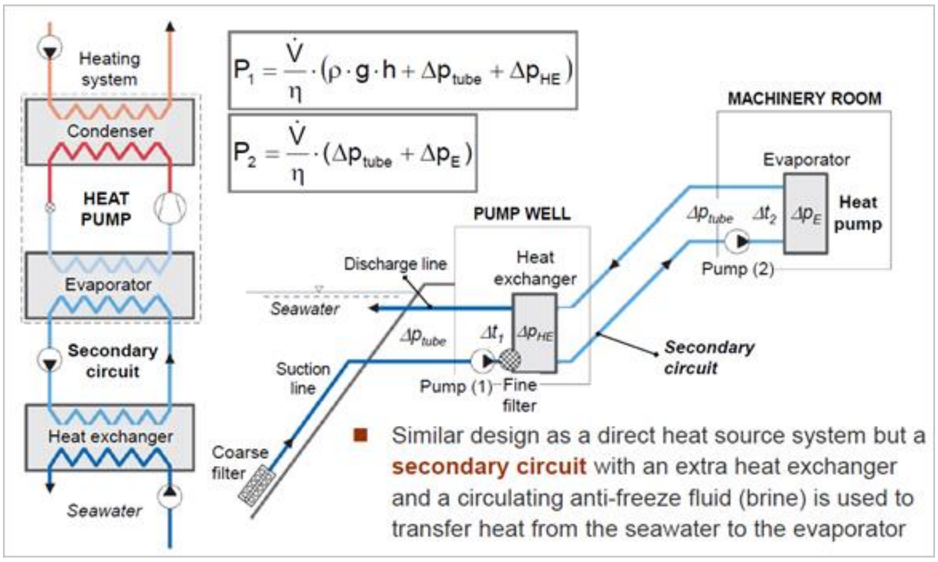
$$P = \frac{\dot{V}}{\eta} \cdot (\rho \cdot g \cdot h + \Delta p_{tube} + \Delta p_E)$$

- Seawater is pumped to one or several evaporators, cooled 2 to 4 K (Δt) and discharged to the sea
- All pipelines are made by plastic (PEH)
- The pump power, **P** (kW) is determined by the total pressure losses, **Δp** (bar), static height, **h** (m), volume flow rate, **V** (m³/s) and pump efficiency, η (-)

Figure J.1 *Principle illustration of an open, direct seawater system for a heat pump.*

J.2 Indirect system design

A secondary closed-loop brine circuit that comprises a corrosion-proof plate heat exchangers, brine pump and expansion system, installed between the heat pump evaporators and the seawater system. The secondary circuit cools the seawater and transports the thermal energy to the heat pump evaporators. Compared to a direct system standard heat pump units can be used and the total energy use for the pumps is considerably reduced, especially at large differences in altitude between the pump well and the machinery room. The COP for the heat pump will be 2-5% lower due to the extra temperature difference between the seawater system and the heat pump caused by the secondary circuit.



$$P_1 = \frac{\dot{V}}{\eta} \cdot (\rho \cdot g \cdot h + \Delta p_{tube} + \Delta p_{HE})$$

$$P_2 = \frac{\dot{V}}{\eta} \cdot (\Delta p_{tube} + \Delta p_E)$$

- Similar design as a direct heat source system but a **secondary circuit** with an extra heat exchanger and a circulating anti-freeze fluid (brine) is used to transfer heat from the seawater to the evaporator

Figure J.2 *Principle illustration of an open, indirect seawater system for a heat pump.*

It is recommended to use an *indirect seawater system* in a seawater heat pump installation in Leirvik since standard heat pump units can be used. Figure J.3 shows a typical design of a pump well for an open, indirect seawater system with pipelines, plate heat exchangers, seawater pumps, drainage pumps, filter and shut-off valves (COWI, 2016).

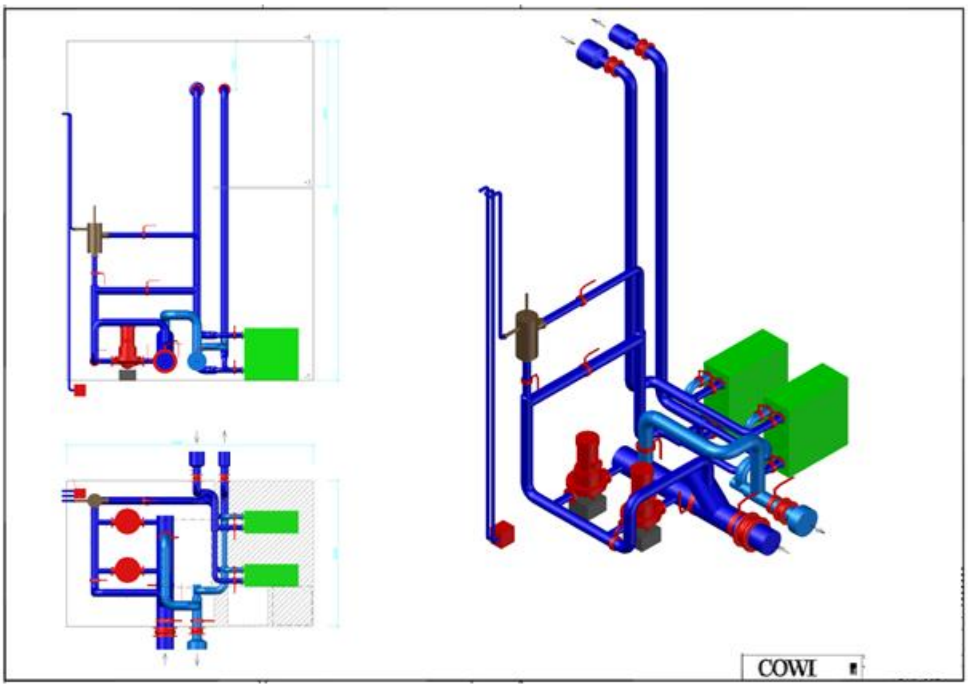


Figure J.3 *Typical design of a pump well for an open, indirect seawater system for a medium-capacity heat pump plant (COWI, 2016).*

Appendix K Heat pump system

K.1 Overall Design Concept

The heat pump system in Leirvik can be designed in several ways:

- A: 1 MW heat pump (base load) with 50% power coverage factor and 90% energy coverage factor + electro boiler (peak load).

- B: 2 MW heat pump (base/peak load) with 100% power/energy coverage factor + electro boiler (back-up)

- C: 2 MW heat pump with 100% power coverage factor and yet unknown energy coverage factor + electro boiler + thermal energy water storage for night-tariff operation of the heat pump.

Alternative A, a standard design concept for bivalent heating systems, which is the most cost/energy efficient design at normal boundary conditions. *Alternative B* will roughly have twice the investment costs compared to Alternative A, but the annual heat supply and consequently the annual energy saving will only be 10%-points higher. In *Alternative C*, the heat pump has the same heating capacity as Alternative B, but the heat is produced at a relatively low cost during low-tariff periods (at nights).

In the following analyses, the following has been assumed:

- Heat pump connected to an open and indirect seawater heat source system comprising a 400 m seawater pipeline as well as a pump well with pumps and heat exchanger connected to a secondary system.
- 8 °C / 5 °C inlet/outlet seawater temperature in plate heat exchanger
- 2 °C temperature difference across the seawater heat exchanger
- 60 and 80 °C supply water temperature from the heat pump
- Single-stage and two-stage heat pump units with HFO1234ze or ammonia (R717) as working fluids.

K.2 Coefficient of Performance (COP)

The Coefficient of Performance (COP)[4] for a heat pump mainly depends on the temperature levels for the heat source (e.g. seawater) and the heating system (e.g. district heating) as well as the quality of the heat pump incl. the system design (single-/two-stage etc.), working fluid, heat exchangers (type, size), compressors (type, capacity control) and expansion system (type, control).

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[4] COP = the ratio of the heating capacity (kW) and the input el. power (kW)

K.2.1 Estimated COP

The COPs for a seawater heat pump at full load at 60 °C and 80 °C outlet water temperature have been estimated on the basis of field monitoring data, manufacturer data (European Standard EN 14511) and manual corrections.

Table K.1 shows estimated Coefficient of Performance (COP) for different heat pump plants with approx. 1 MW total heating capacity at 8/5 °C seawater temperature, 6/3 °C inlet/outlet brine temperature for the evaporator as well as 60 °C and 80 °C outlet water temperature (c.f. *Chapter K.1*). Moreover, the maximum outlet water temperature for the ammonia (R717) and R450A / R134a heat pumps is 80-82 °C and 65 °C, respectively.

Table K.1 Estimated COPs for different 1 MW heat pump plants at 6/3 °C brine temperature and 60 °C / 80 °C outlet water temperature. Relative energy saving in %.

Heat Pump Plant	COP, 60 °C	COP, 80 °C	No. of heat pump units
HP1, 1-stage – R717	3.35	2.35	Single heat pump unit
HP2, 2-stage – R717	3.35	2.70	Single heat pump unit
HP3, 2 stage – R717	3.85	2.95	2 heat pump units in series
HP4, 1-stage – R450A	2.95	-	2 heat pump units in series
HP5, 1-stage –R134a	3.00	-	2 heat pump units in series

K.2.2 COP at Part Load

A heat pump system that supplies heat to a district heating system connected to residential and non-residential buildings will have large variations in the heating capacity. Medium- and large capacity heat pumps for high-temperature applications use reciprocating (piston) compressors or single/twin-screw compressor. In order to achieve a high COP *it is essential to apply high-efficiency compressors with suitable part load control*. Recommended control systems are:

- Cylinder unloading – piston compressors (stepwise capacity control)
- Variable speed drive (VSD) – inverter controlled motor
- Reciprocating (piston) compressors – from 100% to 20/25%
- Mono/twin screw compressors. Normally high-efficiency VSD from 50 to 100% capacity, and conventional (inefficient) slide valve control from 15 to 50%. *It is important to minimize slide valve control by using at least two screw compressors per heat pump unit or two units.*

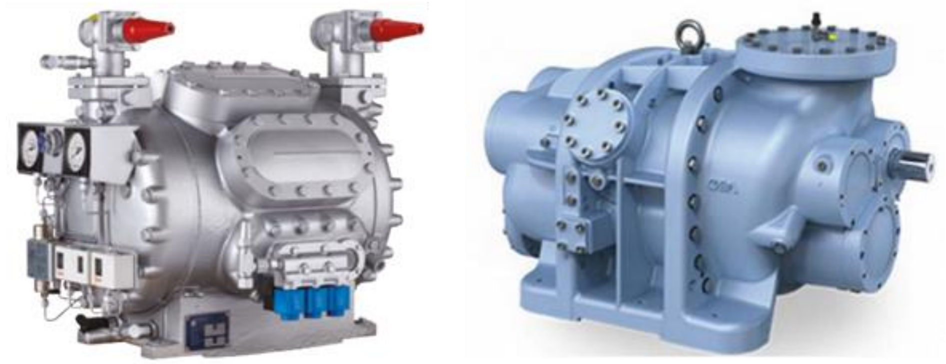

Figure K.1 *High-temperature VSD compressors – piston (left), screw (right).*

With energy efficient VSD compressor control, the COP drops about 5-7% when reducing the capacity from 100% to 50%.

K.3 Investment and Installation Costs

This chapter presents investment/installations costs for complete heat pump plants including seawater pipelines, pump well system, secondary system and different types of single- and two-stage heat pump units.

Boundary conditions:

- **1 MW** heat pump heating capacity
- **400 m** seawater pipeline (c.f. Figure H.2, trace A).

Heat Pump Units

Table K.1 shows investment/installation cost for different single- and two-stage heat pump plants with ammonia (R717), HFC or HFO as working fluid. The total heating capacity is 1 MW.

Table K.1 *Investment/installation costs for different 1 MW single- and two-stage heat pump plants with ammonia (R717), HFC or HFO as working fluid.*

Heat Pump Plant	Investment/installation costs, mill. DKK	No. of heat pump units
HP1, 1-stage – R717 – 80 °C	3.8	Single heat pump unit
HP2, 2-stage – R717 – 80 °C	5.0	2 heat pump units in series
HP3, 2 stage – R717 – 80 °C	5.9	2 heat pump units in series
HP4, 1-stage – R450A – 65 °C	1.1	2 heat pump units in series
HP5, 1 stage – R134a – 65 °C	0.9	Single heat pump unit
HP6, 1 stage – HFO – 65 °C	1.9	2 heat pump units in series

HP7, 1-stage – R134a – 65 °C	1.1	2 heat pump units in series

The single- and two-stage ammonia heat pump units are much more expensive than the HFC/HFO units, but they can supply heat at a considerably higher temperature, i.e. 80 °C vs. 65 °C. Moreover, due to more advanced design and use of steel tubing and components of the highest quality, they have much longer expected lifetime, e.g. 25 years vs. 15 years.

K.4 Seawater Heat Source System

The total investment/installation costs for a 400 m seawater suction pipeline and return pipeline (Ø350, PE100, SDR17), including concrete weights and coarse filter at the suction pipeline inlet is approx. 300,000 DKK.

If the pump well can be integrated in the machinery room, the total costs for the pump well, high-quality IE3 seawater pumps, drainage pumps, self-cleansing filter (Bernoulli type), titanium plate heat exchangers, valves/fittings in bronze, brine pumps and brine expansion system is approx. 2,000,000 DKK.

K.5 Maintenance costs

Regular maintenance of the heat pump system is essential in order to minimize operation problems and working fluid leakage as well as to maintain the heating capacity and COP (energy saving) of the plant during the entire lifetime. For heat pumps utilizing seawater as heat source, a maintenance programme includes maintenance of both the heat pump units and the heat source system.

A complete maintenance programme for a heat pump system includes regular plant inspection as well as annual/bi-annual maintenance (service).

Example of maintenance for heat pump units:

- Leakage check according to the F-gas Directive
- Oil change and possible oil analysis
- Inspection of compressors incl. possible change of compressor parts
- Lubrication of valve rods and shaft seal for open compressors
- Inspection/testing of expansion devices
- Adjustment/testing of automatic controllers
- Testing of safety controllers
- Test of safety systems (for ammonia heat pumps)
- Inspection of different components and equipment including inspection and possible cleaning of evaporators

Annual maintenance costs for heat pump units are by experience typically *2-4% of the investment costs*. Example – if the total costs of the heat pump units are 1.5 mill. DKK, the annual maintenance costs are 30,000-60,000 DKK/years. The annual maintenance costs are to a large extent dependent on the type of working fluid (HFC or ammonia) and type of compressors (scroll, piston, screw).

Example of maintenance for a seawater heat source system:

- Inspection/testing of pumps including inverters
- Inspection and possible cleaning of suction pipeline and coarse filter
- Inspection and maintenance of other components – valves, fine filter etc.
- Inspection of the secondary system incl. heat exchangers, brine pumps, pipelines, expansion system etc. – possible cleaning of heat exchangers
- Inspection of power supply and controllers

The annual maintenance costs for a heat pump seawater system with high-quality components are by experience *less than 0.5% of the investment costs*.

Appendix L Heat storage

The cost of heat storage is a combination of cost stated by the manufacturer 'FW Rørteknik' (FW pipe technique) and costs based on experience. All data are for Denmark.

The cost of the inner tank (without insulation and cap) and nitrogen unit is from the manufacturer.

The estimated cost is shown in Table L.1.

Table L.1 Investment costs of the heat storage.

Unit	Cost, DKK
Storage tank	1,100,000
Nitrogen unit	150,000
Foundation	250,000
Pipes, pumps, SRO etc.	800,000
Design and miscellaneous	300,000
Total	2,600,000

Reports and materials in this series

- Renewable energy supply and storage: Guide for planners and developers in sparsely populated areas.
- Guide report 1: Heat supply in Leirvík - Case Study
- Guide report 2: Technology catalogue
- Guide report 3: Economic and financial analysis
- Guide report 4: The project development process
- Fornybar energy og lagring i spredtbyge områder (an Excel based screening tool: Include data for your own local community and analyse the feasibility of optional solutions for renewable energy systems.)

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