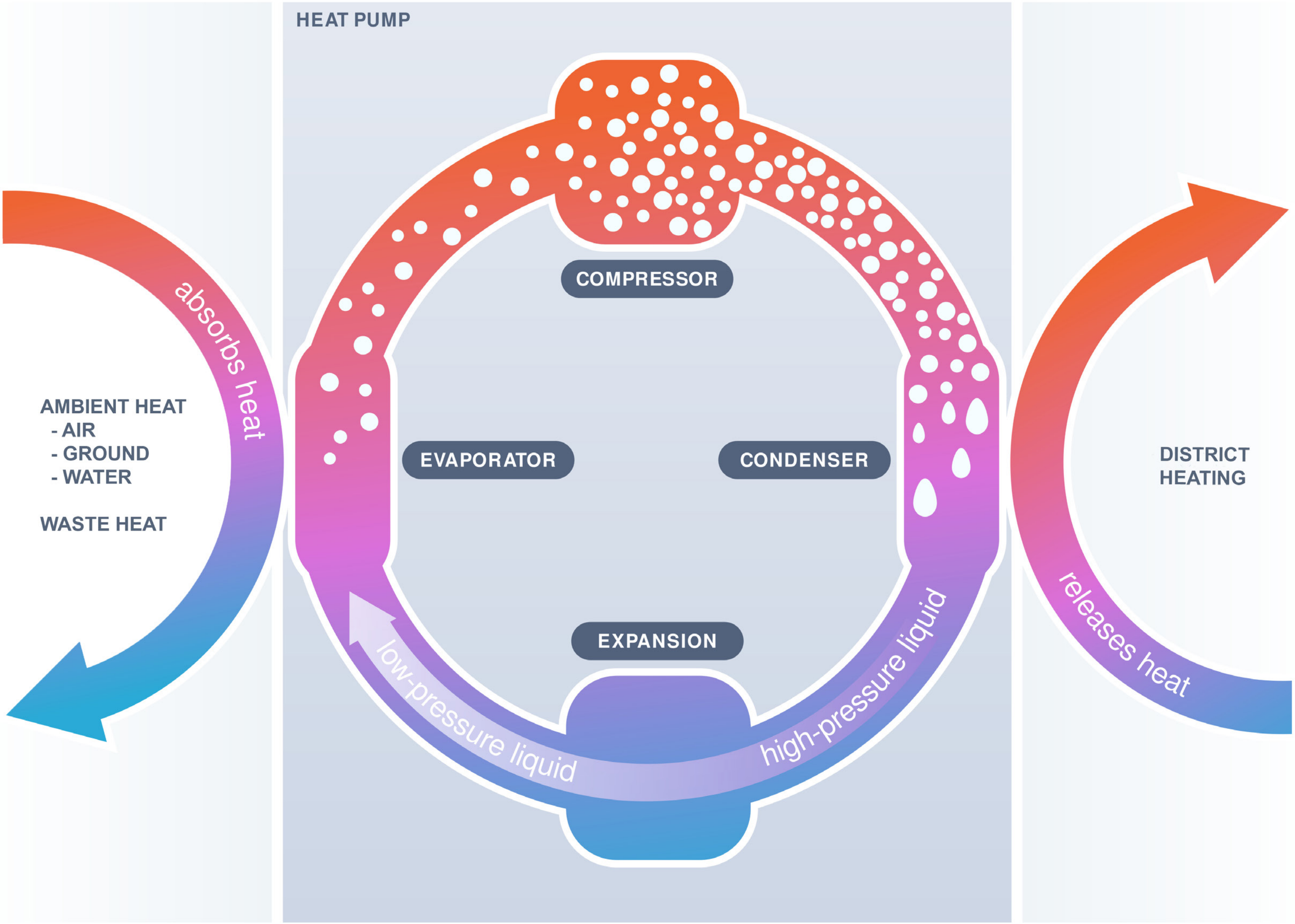
HEAT CIRCULATION INNOVATION PLATFORM NORTH SAVO HCIP-NS-PROJECT

LARGE HEAT PUMPS IN DISTRICT HEATING SYSTEMS

A STATE-OF-THE-ART STUDY



SAVONIA

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Abstract

The goal of Finland's energy policy is to gradually decrease the use of fossil fuels in energy production and move towards an emission-free energy system. In the district heating sector, the goal is to promote fossil fuel free heat production, to promote the use of related technologies such as waste heat recovery, heat storage and heat pump technologies. This state-of-the-art-study includes a review of prominent manufactures of large heat pumps as well as case studies of realized district heating heat pumps in Nordic countries.

In Finland in 2022 the share fossil fuels in district heating was 34 % and the share of heat recovery 13.2 % of which 3.8 % was realized with heat pumps. The present market share of heat pumps in district heating in other Nordic countries is also reviewed in this state-of-the-art-study.

The study also describes the development of district heating and cooling from the 1st to the 5th generation, and the role of heat pumps in it. In 4th generation district heating system, which is currently being developed, the aim is to lower the distribution temperature and increase share of renewables and waste heat either directly or with heat pumps in district heat production. Expanding district cooling networks, increasing number of data centres and in near future also PtX-plants increase amount of available waste heat.

District heating systems with increasing amount of electricity boilers, heat pumps and large thermal energy storage systems and with existing CHP-plants will have an important role in future energy production system, because they can efficiently balance the electricity production alternations of wind and solar electricity.

According to the fossil free scenario used in HCIP-NS-project, it was estimated that all fossil fuels used 2022 in Finland to produce district heat could be replaced either with biofuels or with electricity boilers or heat pumps using mainly surplus electricity produced with wind turbines. The share of large heat pumps in district heat production would be in fossil free scenario in Finland in 2030 12 %, and the installed capacity of heat pumps in district heat production would rise from 300 MW (2022) to 1,000 MW (2030).

This state-of-the-art study on large-scale heat pumps has been written within the project Heat Circulation Innovation Platform North-Savo (HCIP-NS) realized from 1.8.2021 to 30.10.2023. The project was realized by Savonia UAS Energy Research Centre organisation at Varkaus Campus.

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ABBREVIATIONS

1GDH	First generation of district heating
2GDH	Second generation of district heating
3GDH	Third generation of district heating
4GDH	Fourth generation of district heating
5GDHC	Fifth generation of district heating and cooling
ADC	Application Development Centre
ATES	Aquifer thermal energy storage
BTES	Borehole thermal energy storage
CFC	Chloro-Fluoro-Carbon
CHC	Combined heating and cooling
CHP	Combined heating and power
COP	Coefficient of performance
DH	District heating
DHW	Domestic hot water
EMEA	Europe, the Middle East and Africa
ERDF	European Regional Development Fund
ETES	Electrothermal energy storage
EVI	Enhanced vapor injection
GWP	Global Warming Potential
HCFC	Hydro- Chloro-Fluoro-Carbon
HCIP	Heat Circulation Innovation Platform
HCIP-NS	Heat Circulation Innovation Platform North-Savo
HFC	Hydro-Fluoro-Carbon
HFO	Hydro-Fluoro- Olefin
HP	Heat pump
HVAC	Heating, ventilation and air conditioning
HVACR	Heating, ventilation, air conditioning and refrigeration

IEA	International energy agency
JCI	Johnson Controls International
NECPs	National energy and climate plans
ODP	Ozone Depletion Potential
PID	Piping and instrumentation diagram
PTES	Pit thermal energy storage
PtX	Power-to-X
TEM	Työ- ja elinkeinoministeriö
TBV	Tietgenbyen's heating centre
TCES	Thermochemical energy storage
TES	Thermal energy storage
TSE	Turun Seudun Energiantuotanto Oy
TTES	Tank thermal energy storage
UAS	University of Applied Sciences
UK	United Kingdom
USA	United stated of America
VRE	Variable renewable energy
WSHP	Water source heat pumps

SYMBOLS

η_c	Carnot efficiency
η_{is}	Isentropic efficiency compressor
$P_{compr} = P_{in}$	Electricity power needed for compression
T_C	Condensing temperature
T_E	Evaporation temperature
Δh_{is}	Enthalpy change of ideal isentropic compression
Δh_{real}	Real enthalpy change in the compressor
$\Phi_{Cond} = \phi_{out}$	Heat flow from condenser
CaO	Calcium oxide
Cl_2	Chlorine
CO_2	Carbon dioxide
h	Enthalpy
H_2O	Water
H_2SO_4	Sulfuric acid
$LiBr$	Lithium bromide
$\dot{m}$	Mass flow
Na	Sodium
NH_3	Ammonia
p	Pressure
Q_a	Absorption energy of refrigerant
Q_{abs}	Energy released in absorber
Q_c	Condensing energy of refrigerant
Q_d	Desorption energy of refrigerant
Q_e	Evaporation energy of refrigerant
Q_{gen}	Energy brought into the generator
s	Entropy

1 Introduction

Markku Huhtinen

This state-of-the-art study on large heat pumps has been written within the project Heat Circulation Innovation Platform North-Savo (HCIP-NS) realized 1.8.2021 – 30.10.2023. The project, with 290 k€ budget, was financed mainly (76 %) by European Regional Development Fund (ERDF), granted by Regional Council of North-Savo. The rest of financing came from Savonia UAS and industrial partners.

The goal of Finland's energy policy is to gradually decrease the use of fossil fuels in energy production and move towards an emission-free energy system. In the district heating sector, the goal is to promote non-combustion heat production, to promote the use of related technologies such as waste heat recovery, heat storage and heat pump technologies. This is also the main goal of HCIP-NS-project.

HCIP-NS-project consisted of two parts: development project and investment project. Within the investment project was built in Savonia UAS Energy Research Centre a reactor for testing thermochemical energy storing reactions. All the other activities have been carried out in the development project.

The target groups of the project were:

- Companies generating waste heat in their production.
- Companies developing energy-efficient solutions and services.
- Companies interested in energy-efficient equipment deliveries.
- All stakeholders interested in the efficient use of energy.
- Decision makers of cities, municipalities, and other public organizations.
- Owners of companies and properties in different industries.

The goal of the project was to find out the sources of waste heat in North Savo and possibilities to utilize these sources in heat production promoting to reach at the regional level set target to create a carbon neutral in North-Savo by 2035. The goal of the project was also to promote business opportunities of North Savo Energy Cluster companies in this context. Companies participating in this project were Sumitomo SHI FW Energia Oy, Savon Voima Oy, Varkauden Aluelämpö Oy, HögforsGST Oy, Kuopion Energia Oy, Stora Enso Oyj, Suomivalimo Oy, and Lamit.fi Oy.

The project was realized by Savonia UAS Energy Research Centre organisation at Varkaus Campus. As project manager worked:

- Markku Huhtinen 1.8.2021-6.3.2022.
- Kirsi Kinnunen 7.3.2022-10.10.2022.
- Petteri Heino 11.10.2022-30.10.2023.

The research work was realized by:

- Raquel Mier-González; state of art reports, measurements.
- Leena Pöntynen; state of art report (Large heat pumps).
- Arto Luukkonen; design, construction and tests with TCES-reactor.
- Jukka Huttunen; design of TCES-reactor.
- Janne Ylönen; measurements.
- Kirsi Tukiainen; project assistant.

HCIP-NS-project was broken down into four work packages, the content of them is described in below.

1.1 WP1 Waste heat recovery

A lot of heat is generated in industrial production, some of which can be recovered and utilized. In many cases, however, waste heat is not utilized and recovered but is released into the environment with cooling water or process gases. Most waste heat is typically generated in the pulp and paper -, chemical – and metal industries.

The work package collected information on waste heat recovery opportunities and good case examples both as a literature review and from waste heat recovery studies realized by FINHCIP-UAS-network. The found good case examples have been published on webpage of HCIP-NS-project for the benefit of those interested.

In certain industrial sectors (including industrial painting, timber drying and foundry processes) with possibilities to new innovations, the possibilities for heat recovery were examined in more detail by means of an energy audit, estimating the amount of investment required and the repayment period.

In general, it is worthwhile to utilize waste heat in same process, but the energy companies involved in the project are ready to recover the waste heat into the district heating network as well.

1.2 WP2 Large heat pumps

Heat production with heat pump technology is becoming more and more common in Finland. More than one million heat pumps have already been installed in Finland (Sulpu). Companies in North Savo are well involved in the value chains and equipment deliveries of small heat pumps throughout Finland.

The profitability to use large or medium size heat pumps (100 kW – 2,000 kW) to recover heat from industrial processes has also improved so that there are several realized installations also in the area of North-Savo. There are Finnish suppliers for these devices, but at the moment they are not working in the area of North-Savo. There would be possibilities for the North Savo Energy Cluster equipment manufacturers to act as component, e.g., heat exchanger manufacture in these value chains.

In district heating, large heat pumps are also becoming more common. Large coal-fired power plants in coastal cities are planned partly to be replaced by tens of megawatts of heat pumps. At present, Finnish companies are not significantly involved in manufacturing of equipment related to large heat pumps or their deliveries, even if the products are well suited for the North Savo Energy Cluster equipment manufacturers.

In connection with this, the project investigated equipment manufacturers in connection with large heat pumps. The ultimate goal was to find out how equipment manufacturers in the North Savo energy sector could be involved in value chains related to the supply of large heat pumps.

This state-of-the-art study on large heat pumps has been written as part of this work package to provide a comprehensive review of the utilization of large heat pumps in industrial and district heating systems. Markku Huhtinen has written totally or partially chapters number 1, 2, 4, 7 and 8, while Raquel Mier-González has written totally or partially chapters number 3, 4, 5, 6 and 8. Some of the chapters are based on the research work done by Leena Pöntynen.

1.3 WP3 Energy storage

Several companies involved in HCIP-NS-project are particularly interested in the use of water reservoirs or soil as an energy storage connected to district heating network and on the other hand in thermochemical energy storage methods. In Varkaus it is investigated by Varkauden Aluelämpö Oy possibilities to store surplus energy from Riikinvoima power plant from summer to winter. In HCIP-NS-project it has been monitored the progress of the project. Also possibilities to store heat in the soil at the Savonia UAS Varkaus Energy Research Centre through the ground source heat pump system has been studied in the project.

A state-of-the-art study on energy storage systems has been written as part of this work package to give a comprehensive review of thermal energy storage, mechanical energy storage and chemical energy storage systems.

Within the investment project was built in Savonia UAS Energy Research Centre a reactor for testing thermochemical energy storing reactions. Because of the delay of components of the reactor so far only preliminary tests to find out the amounts of energy released and recovered in the reaction have been carried out with selected materials such as Na + Cl and CaO + H2O.

1.4 WP4 Dissemination

A platform has been created on the webpage of HCIP-NS-project (https://lampokiertoon.fi/en/heat-circulation-innovation-platform-hcip-ns/) to present comprehensively non-combustion heat production and heat recovery technologies, their implementers and the experiences gained. The aim was to provide answers to questions how energy consumption and costs could be decreased in companies, industrial processes, and buildings by utilizing elsewhere piloted innovations related to:

- Energy storage.
- Waste heat recovery.
- Heat pumps.

During the project a FINHCIP-UAS network has been established. To the network belong applied universities who are interested have carried out waste heat recovery, energy storage or heat pumps related research and case study projects. The current members of the FINHCIP-UAS network include the following UAS: Savonia, Xamk, Turku UAS, Novia, Centria, SAMK, and VAMK. The network arranged the first common seminar at Varkaus 10.5.2021. The presentations of that seminar are available on the webpage of HCIP-NS-project. There are also list and links to webpages of research projects carried out by UAS of the FINHCIP-UAS-network.

By arranged seminars and newsletters posted by Savonia-UAS to North-Savo companies they were informed of the results of the project and raised their awareness of their own waste energy flows and advised on the use of the data on the webpage of the HCIP-NS-project.

1.5 Conclusion

Savonia UAS Energy Research Centre at Varkaus is specialized in research related to environment friendly combustion technology. However, in this Heat Circulation Innovation Platform North-Savo (HCIP-NS)- project the goal was to promote non-combustion heat production, to promote the use of related technologies such as waste heat recovery, heat storage, and heat pump technologies.

A platform has been created on the webpage of HCIP-NS-project https://lampokiertoon.fi/en/heat-circulation-innovation-platform-hcip-ns/ to present comprehensively non-combustion heat production and heat recovery technologies, their implementers and the experiences gained. For example, there are collected information on

- good examples (related to energy storage, waste heat recovery and heat pump solutions)
- FINHCIP-UAS-network partners and their projects
- in the project organized seminars and webinars and their presentations

Within the HCIP-NS investment project it is improved Savonia UAS Energy Research Centre possibilities to carry out TCES (thermochemical energy storage) research by building a test reactor for these purposes.

During the project a FINHCIP-UAS network has been established. To the network belong applied universities who are interested and have carried out waste heat recovery, energy storage or heat pumps related research and case study projects. The aim is to continue this co-operation after this project aiming to international networking and preparation of new research openings and projects.

2 THEORETICAL BASIS OF HEAT PUMPS

Markku Huhtinen

2.1 Introduction

According to the second law of thermodynamic heat transfers itself from higher temperature to lower temperature. If it is wanted to transfer heat in the opposite direction, from lower temperature to higher temperature, then it is needed cycle processes and external energy.

These devices are called heat pumps or refrigerators depending on what is the main purpose; if it is to cool then the device is called refrigerator and if the purpose is to heat the device is called heat pump. With COP (coefficient of performance) it is described the ratio of produced heat energy to the external electrical energy needed for heat transfer from lower temperature to the higher temperature.

Heat pumps process may be implemented with several different ways. In this chapter it is explained how:

- closed cycle heat pumps
  - compressor heat pumps
  - absorption heat pumps
- open cycle heat pumps
  - compressor heat pumps

work, although the main focus in this report is on closed cycle compressor heat pumps.

2.2 Closed cycle compressor heat pumps

The main components of closed cycle compressor heat pumps are (as can be seen on figure 1):

- evaporator
- compressor
- condenser
- expansion valve

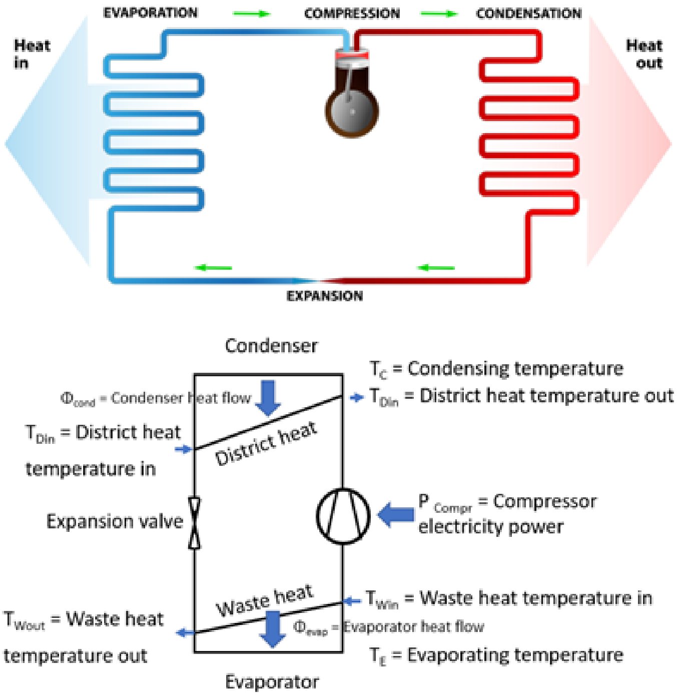


FIGURE 1. Closed cycle compressor heat pump.

2.2.1 Evaporator

Evaporator is a heat exchanger where, in heat pump process, circulating refrigerant is evaporated at low pressure with heat received from a heat source. The heat source may be outdoor air, ground rock, groundwater, river, lake, warm wastewater from sewage treatment plant, warm cooling water of data centre, industrial waste heat, etc. The warmer the temperature of the heat source is, the better COP is possible to reach. In the evaporator heat exchanger heat is transferred from warmer heat source to cooler evaporating refrigerant. When the refrigerant is evaporated in the evaporator, it is also slightly (4 - 6 °C) superheated in order to avoid the damaging entry of liquid refrigerant into the compressor.

2.2.2 Compressor

After the evaporator, the compressor compresses the gaseous refrigerant to so high pressure that its condensing temperature is higher than the temperature of the heated medium, which in district heat system is the circulating water in the network. To drive the compressor, additional energy is needed; normally heat pumps are driven with electric motors.

2.2.3 Condenser

After the compressor, pressurized vapor refrigerant flows to the second heat exchanger, called the condenser. In this heat exchanger, the refrigerant first cools from superheated temperature to condensing temperature, and then condensates from gaseous into liquid state, releasing the heat into the district heat network. If it is possible to further subcool the liquid refrigerant from condensing temperature and utilize the released heat, then it is possible to increase the COP compared to the process without subcooling.

2.2.4 Expansion valve

The condensed refrigerant then passes through a pressure-lowering device, the expansion valve, before entering again to the evaporator, where the cycle starts again. The expansion valve regulates the amount of refrigerant flowing into the evaporator so that all refrigerant evaporates and also superheats the desired 4 - 6 °C.

2.2.5 Coefficient of Performance (COP)

The efficiency of heat pump is described by the coefficient of performance (COP). It represents the ratio of the heat energy produced with the condenser (ϕ_out) to the external electrical energy consumed by the compressor (P_{in}).

$$COP = \frac{\phi_{out}}{P_{in}}$$

The COP -value for ideal Carnot-process may be calculated based on the condensing and evaporating temperatures of the refrigerant in the heat pump cycle, using the formula:

$$\mathrm{COP}_{Carnot} = \frac{T_C}{(T_C - T_E)}$$

where

T_C= condensing temperature (K)

T_E= evaporation temperature (K)

For the real heat pump process, the COP-value may be calculated from the previous formula by multiplying the ideal COPcarnot by the so-called Carnot efficiency:

$$\mathrm{COP} = \eta_c \frac{T_C}{(T_C - T_E)}$$

where

η_c= Carnot efficiency, COP of real process compared to the COP of ideal Carnot process

In the calculation example of figure 2:

$\eta_c = 0.6$

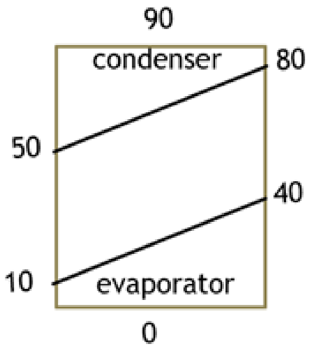
$T_L = 90\ °C + 273 = 363\ K$

$T_H = 0\ °C + 273 = 273\ K$

With these values, the COP of the real process is calculated as:

$$\mathrm{COP} = 0.6 \frac{363}{(363 - 273)} = 0.6\ \frac{363}{90} = 2.5$$

So, the amount of district heat produced by the heat pump is 2.5 larger than its electricity consumption.



$$COP_{real} = COP_{carnot} * \eta_{carnot} =$$

$$COP_{real} = 363 / 90 * 0,6 = 2,4$$

FIGURE 2. COP calculation example.

2.2.6 Refrigerants

Although the COP of a heat pump system mainly depends on its operating temperatures, the selection of refrigerant for the heat pump application has many important environment and also practical effects on the system design, size, investment and operating costs, safety, reliability, and serviceability etc.

A good refrigerant has the following properties (Engrraihan 2015):

- high latent heat of evaporation (-> small mass flow)

- good heat transfer properties (-> small temperature differences in heat exchangers)

- high critical temperature (if the process operates near critical point then COP degreases)

- low specific volume of vapour (-> small compressor)

- appropriate vapour pressure range (too low pressure (p<1 bar) may cause air leakages before compressor, while a high pressure ratio increases compression work)

- environmentally friendly (ODP (Ozone Depletion Potential) = 0, low GWP (Global Warming Potential))

- non-corrosive to metal

- non-flammable

- non-explosive

- non-toxic

- low-cost

There are available several refrigerants for heat pumps:

- natural refrigerants

- hydrocarbons (such as propane R290, isobutane R600a, propylene R1270)

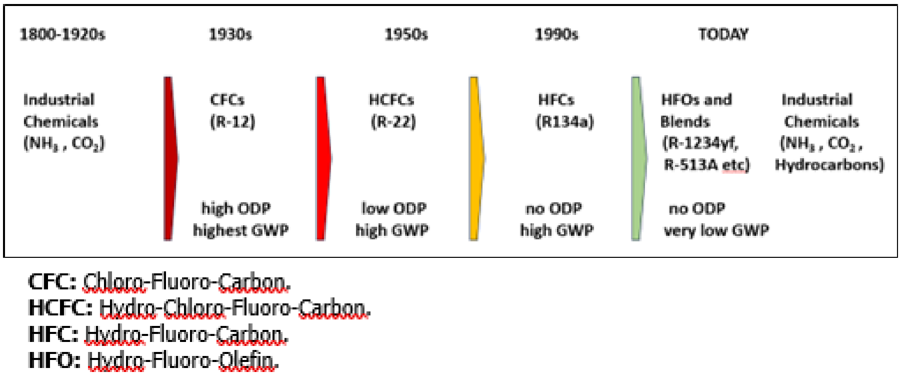
- inorganic substances (carbon dioxide CO2, ammonia NH3)

- halogenated hydrocarbons (halocarbons) are hydrocarbon compounds in which at least one hydrogen atom is replaced by a halogen atom, such as fluorine, chlorine, or bromine.

- CFC-refrigerants (Chloro-Fluoro-Carbon), totally halogenated, no hydrogen
- HCFC-refrigerants (Hydro- Chloro-Fluoro-Carbon), partly halogenated
- HFC-refrigerants (Hydro-Fluoro-Carbon), partly halogenated
- HFO-refrigerants (Hydro-Fluoro- Olefin), partly halogenated

In figure 3, it is shown how the use of different refrigerants has developed from the 19th century to the present day. First, industrial chemicals such as ammonia or carbon dioxide were mainly used. Roughly 100 years ago, based of systematic laboratory research, it was found that by replacing hydrogen atoms in hydrocarbons by halogen atoms, such as fluorine, chlorine or bromine, it was possible to form halogenated hydrocarbons. These compounds are stable, non-toxic, non-flammable, and have good refrigerant properties in many respects. These CFC- and HCFC-refrigerants were used for decades.

But then, towards the end of the 20th century, it was discovered that chlorine released in the decomposition of CFC- and HCFC- compounds destroys the ozone layer, which protects the atmosphere from ultraviolet radiation. The harmfulness of refrigerants to the ozone layer is described by the Ozone Depletion Potential (ODP) – number. As a reference refrigerant is used R11, for which the ODP-number is 1. For this reason, first the use of CFC-refrigerants and then also the use of HCFC- refrigerants have been prohibited with international agreements. These have been replaced with chlorine-free HFC- refrigerants.



CFC: Chloro-Fluoro-Carbon.
HCFC: Hydro-Chloro-Fluoro-Carbon.
HFC: Hydro-Fluoro-Carbon.
HFO: Hydro-Fluoro-Olefin.

FIGURE 3. History of refrigerant transition.

Later in the beginning of 21st century, attention has also been paid to the global warming caused by greenhouse gases of which carbon dioxide is the most well-known. The harmfulness of different gases regarding to global warming can be evaluated by its Global Warming Potential (GWP) – value. The GWP of a refrigerant represents its global warming impact relative to the impact of the same quantity of carbon dioxide over a 100 year period. Although emissions of halocarbons and their concentration in atmosphere are much smaller than carbon dioxide, their influence on global warming is significant. For example, for commonly used HFC refrigerants in heat pumps, R134a has a GWP of 1400 and R410A has a GWP of 2100. At the EU level, the aim with F-gas regulation 517/2014 is to increase the use of low GWP refrigerants and reduce the F-gas emissions by two-thirds by 2030 compared with 2014 levels. (European FluoroCarbons Technical Committee s.a.)

In table 1 it is listed some climate friendly alternatives for refrigerants used in heat pumps.

TABLE 1. Climate-friendly alternatives. for refrigerants used in heat pumps (European Commission s.a)

	Substance	GWP	Composition	Safety group	Replacement for
Natural refrigerants	R290 (propane)	3	-	A3	R134a, R407A, R410A
	R718 (H_2O)	-	-	A1	R134a, R407A, R410A
	R744 (CO_2)	1	-	A1	R134a, R407A, R410A
HFC-HFO blends	R454C	148	R32/1234yf	A2L	R410A
	R513A	631	R1234yf/134a	A1	R134a
HFCs	R32	675	-	A2L	R134a, R407A, R410A

2.2.7 Heat pump process in log(p),h-diagram of refrigerant

In figure 4, the heat pump process with the same evaporating and condensing temperatures (TE = 0 °C, TC = 90 °C) as in the example in figure 2 is drawn in log(p),h -diagram of refrigerant R600a. When this refrigerant is selected, the evaporation takes place at pressure p = 1.5 bar and the condensation at pressure p = 15 bar.

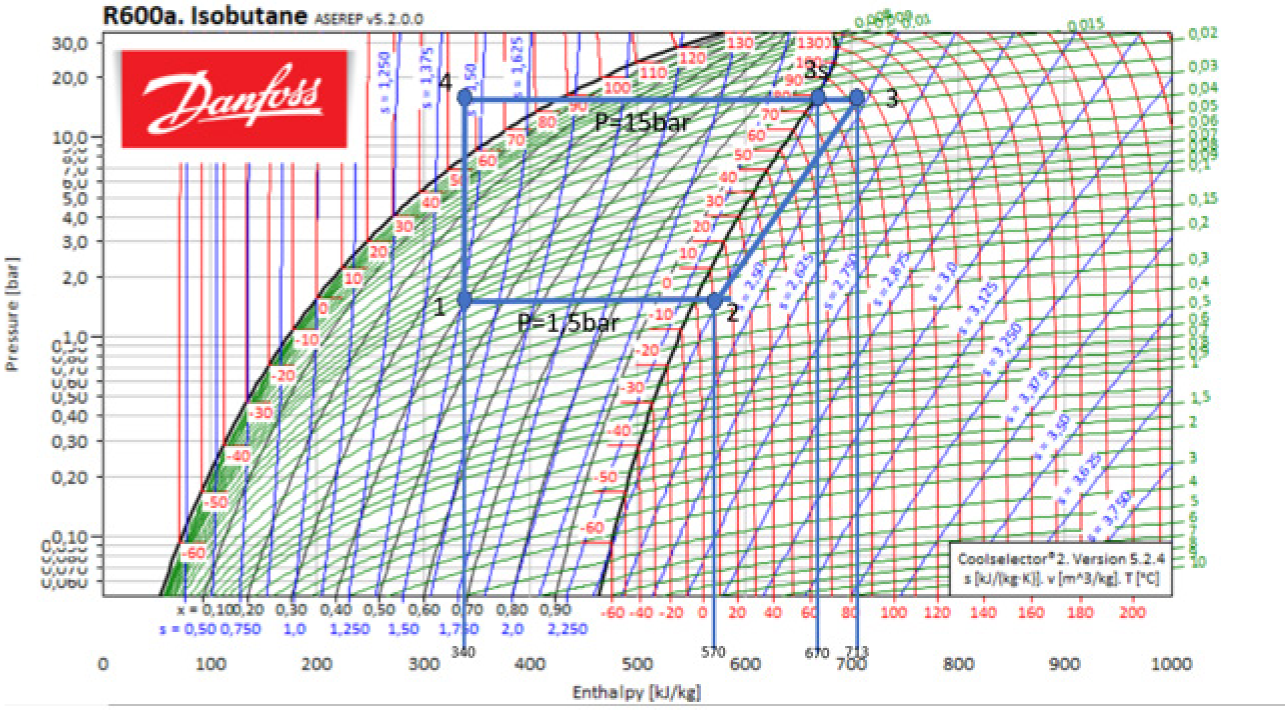


FIGURE 4. Heat pump process on logp,h-diagram Danfoss Coolselector 2 (Picture courtesy of Danfoss)

In the evaporator, the refrigerant is evaporated at a pressure of p = 1.5 bar and a temperature of TC = 0 °C. The amount of refrigerant flowing into the evaporator is regulated so that the refrigerant is superheated by 10 °C. Therefore, the state of the refrigerant is changing from point 1 to point 2 in the diagram.

After the evaporator, the refrigerant is compressed from 1.5 bar to 15 bar. If the compression would take place without losses, the process would be isentropic and the state of the refrigerant would change according to the s (entropy) = constant line in log(p),h-diagram, ending at point 3s. The enthalpy change of ideal isentropic compression is received from the diagram as:

$$\Delta h_{is} = h_{3s} - h_2 = 670 - 570\,\frac{kJ}{kg} = 100\ kJ/kg$$

In real compression, there are losses, and the amount of these losses can be evaluated with isentropic efficiency of compressor (η_{is}):

$$\eta_{is} = \frac{\Delta h_{is}}{\Delta h_{real}}$$

In real compression, there are losses, and the amount of these losses can be evaluated with isentropic efficiency of compressor (η_{is}):

$$\eta_{is} = \frac{\Delta h_{is}}{\Delta h_{real}}$$

If we suppose that the isentropic efficiency is in this case Ƞ_is=0.7, then we receive that the real enthalpy change in compressor is:

$$\Delta h_{real} = \frac{\Delta h_{is}}{\eta_{is}} = \frac{100}{0.7} = 143\ kJ/kg$$

So after the compression, the state of the refrigerant is at point 3, where the enthalpy is 713 kJ/kg, pressure 15 bar and temperature 104 °C.

In the condenser, the superheated refrigerant gas first cools down from 104 °C to the condensing temperature of 90 °C. It then condenses, and after that, it is supposed that it is possible to sub cool the liquid refrigerant to 55 °C, when the entering district heat has the temperature of 50 °C. So the state of the refrigerant in log(p),h-diagram changes from point 3 to 4 in condenser.

After the condenser, the refrigerant enters the expansion valve, where its pressure decreases from condensing pressure to evaporation pressure. The total enthalpy of the refrigerant does not change in expansion valve, but the energy released by pressure and temperature reduction (from 90 °C to 0 °C) evaporates a part of the refrigerant. In this case, the amount of evaporating refrigerant is 40 %.

TABLE 2. Process values of example heat pump process.

point	p (bar)	t (°C)	h (kJ/kg)
1	1.5	0	340
2	1.5	10	570
3s	15	90	670
3	15	104	713
4	15	55	340

With the circulating mass flow (ṁ) and enthalpies received from log(p),h-diagram, it is possible to calculate the heat flow from th condenser (Φ_Cond) and the electrical power needed for compression (P_compr). With these value, the COP of this process can be calculated as:

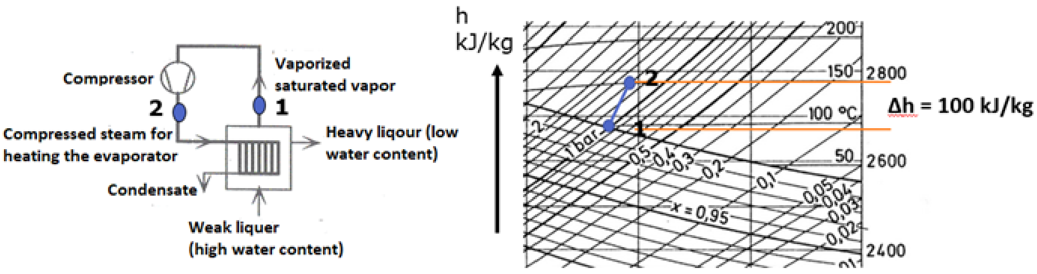
$$COP = \frac{\Phi_{Cond}}{P_{compr}} = \frac{\dot{m}\Delta h_{cond}}{\dot{m}\Delta h_{compr}} = \frac{h_3 - h_4}{h_3 - h_2} = \frac{713 - 340}{713 - 570} = \frac{373}{143} = 2.6$$

If the desired heat flow produced by the heat pump is 1 MW, then the compressor electricity consumption would be 385 kW, and the mass flow of refrigerant circulating in the process would be ṁ:

$$\dot{m} = \frac{\Phi_{Cond}}{\Delta h_{cond}} = \frac{1000\ kW}{373\ kJ/kg} = 2.7\ kg/s$$

2.3 Open cycle compressor heat pump

Open-cycle compressor heat pump processes are typically used in evaporators by compressing the water vapor released from the evaporator to a higher pressure so that when it condensates at a slightly higher temperature, it is possible to use its condensing heat for heating the same evaporator (see figure 5). The heat pump process is called open because condensate from the heat exchanger is not returned to the process.



Water vapor h,s-diagram

FIGURE 5. An example of open cycle compressor heat pump and its compression process in water vapor h,s-diagram

With an open cycle compressor heat pump, it is possible to reach extremely high COP-values. If the evaporator operates with the process values in figure 5, so that pressure in evaporator is 1 bar and evaporation takes place at 100 °C, and the released water vapor is compressed to 1.4 bar in which case its condensing temperature is 110 °C, then the temperature difference in the heat exchanger is 10 °C. The COP may be calculated with the same formula as in previous chapter:

$$COP = \frac{\Phi_{Cond}}{P_{compr}} = \frac{\dot{m}\Delta h_{cond}}{\dot{m}\Delta h_{compr}}$$

now

Δh_{compr} = 100 kJ/kg (see figure 5)

Δh_{cond} = latent heat of condensing of water vapor at 1.4 bar = 2,230 kJ/kg (steam table)

With these values we receive as a result:

$$COP = \frac{\dot{m}\Delta h_{cond}}{\dot{m}\Delta h_{compr}} = \frac{2230}{100} = 22.3$$

2.4 Absorption heat pump

In a closed-cycle absorption heat pump, it is used a two-component working fluid e.g. LiBr/H2O, where H2O is the refrigerant, as there is in the following example. Other alternative two-component working fluids could be NH3/H2O or H2SO4/H2O. There are four main heat exchangers (see figure 6) in closed cycle absorption heat pump, of which condenser and evaporator are the same kind of heat exchangers and for the same purposes as in closed-cycle compressor heat pump. Here, the refrigerant H2O circulates, evaporating at low pressure in the evaporator and taking the needed heat for evaporation by cooling the waste heat source. It then condenses in the condenser at higher pressure, releasing the condensing heat of H2O for heating purposes.

In an absorption heat pump, instead of compressor there are absorber and generator. In the absorber, the refrigerant (H2O) coming from the evaporator is absorbed by the concentrated LiBr/H2O-mixture coming from the generator, at the same pressure as in the evaporator but at a higher temperature (see figure 7, where it is shown the vapor pressure diagram of LiBr/H2O). Normally, the heat released from the absorber, consisting of condensing and absorption energy of H2O, is also utilized for heating purposes. From the absorber, the diluted LiBr/H2O-mixture is pumped to the generator where a higher pressure prevails. In the generator, part of H2O is evaporated from LiBr/H2O-mixture by primary energy heat. The H2O evaporating in the generator is then transferred to the condenser and the concentrated LiBr/H2O-mixture is transferred back to the absorber.

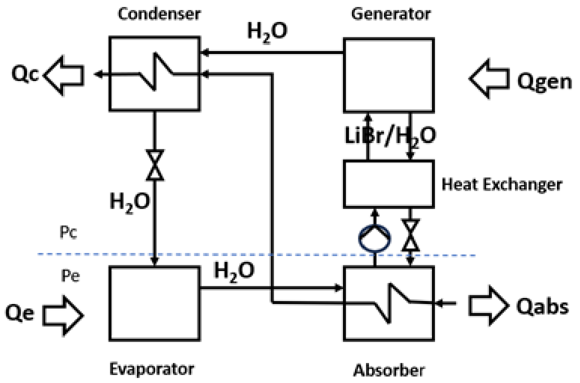


FIGURE 6. Closed cycle absorption heat pump

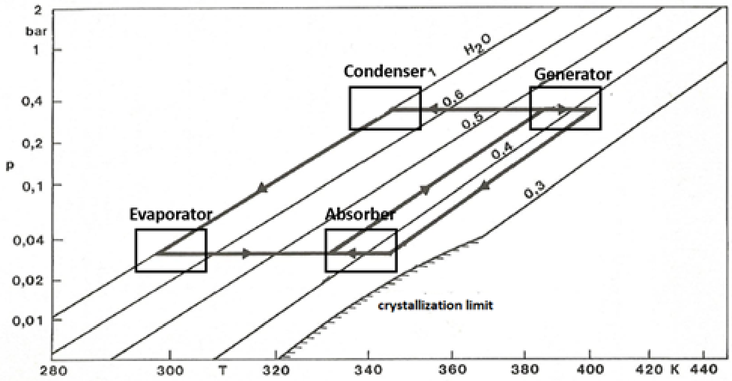
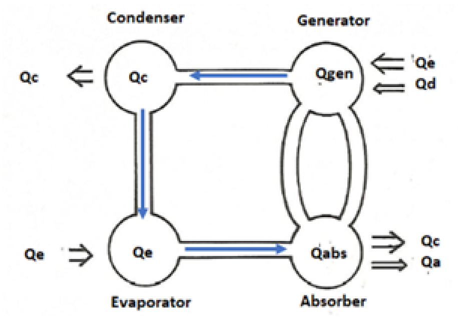


FIGURE 7. Vapor pressure of LiBr/H2O-mixture (Ekono Oy, Imatran Voima Oy: Feasibility of Absorption Heat Pump in Heat Production in Finland, Ministry of Trade and Commerce, series D:120 1985)

2.4.1 COP-calculation of absorption heat pump

In figure 8, it is shown the energy balance of an absorption heat pump.



Qe = evaporation energy of refrigerant
Qc = condensing energy of refrigerant
Qa = absorption energy of refrigerant
Qd = desorption energy of refrigerant
Qabs = in absorber released energy = Qc+Qa
Qgen = into generator brought energy = Qe+Qd

FIGURE 8. Energy balance of a closed cycle absorption heat pump

When calculating the COP of a closed cycle absorption heat pump, the energy for heating purposes Qout is received from both the absorber and the condenser, while the primary energy brought into heat pump Qin is the heat flow brought into the generator.

$$COP = \frac{Q_{out}}{Q_{in}} = \frac{Q_c + Q_{abs}}{Q_{gen}} = \frac{Q_c + Q_c + Q_a}{Q_e + Q_d}$$

For conceptual calculation of COP of closed cycle absorption heat pump, it can be approximated that Qe = Qc, Qa = Qd and Qa = 50 % of Qe. With these assumptions, we obtain:

$$COP = \frac{Q_c + Q_c + Q_a}{Q_e + Q_d} = \frac{Q_c + Q_c + Q_a}{Q_c + Q_a} = 1 + \frac{Q_c}{Q_c + Q_a} = 1 \ldots..2 \approx 1.7$$

So the COP on closed cycle absorption heat pump is between 1 to 2, depending on the ratio of absorption and condensing heat of refrigerant. If the ratio is 50% , then the COP is ~1.7.

One advantage of absorption heat pump systems is that they can deliver a much higher temperature lift than the other systems, and their COP does not decline steeply at higher temperature lift.

2.4.2 Temperature transformer

It is possible also to change the flow direction of the refrigerant in an absorption heat pump as shown in figure 9. The process splits a medium-temperature waste-heat stream to one higher-temperature stream and one lower-temperature stream. In this case, if only the high temperature heat released from the absorber is possible to utilize for heating purposes and there is no need to use the low temperature material flow for cooling, the COP is less than one, typically ~0.7.

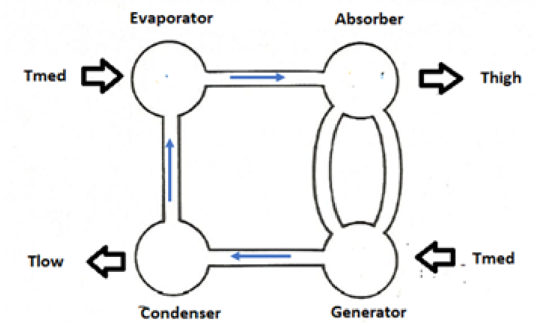


FIGURE 9. Principle of closed cycle absorption heat pump working as heat transformer

3 MAIN MANUFACTURES OF LARGE HEAT PUMPS

Raquel Mier González

Several companies are known for manufacturing large heat pumps. Some prominent manufacturers in this field that are reviewed in the following sections include Carrier, Daikin, Danfoss, Friotherm, GEA Refrigeration, Johnson Controls, Ochsner, Star Refrigeration, Siemens Energy, and Viessmann. The Finnish companies Calefa, Oilon, Suomen Tekojää and Tehoilma are also reviewed. Other well-known heat pump manufactures include Combitherm, Durr Thermea, Engie, Hybrid Energy, Kobe Steel, Mayekawa, and Vicking Heating Engines.

Over the past few years, there has been a steady increase in the variety of high-temperature heat pump models available in the market. In figure 10, several high-temperature heat pump models from different manufacturers are compared regarding compressor type, refrigerant, heating capacity, and heat supply temperature. As can be seen, the great majority of these heat pumps use screw and piston compressors while a minor part use turbo compressors. Regarding the refrigerants, the most used are R245fa, R717 (NH3), and R134a, as well as R1234ze(E) and R744 (CO2). Almost 50 % of these selected heat pumps have a maximum heat supply temperature below 100 °C, while only a couple of them cross the barrier of 130 °C.

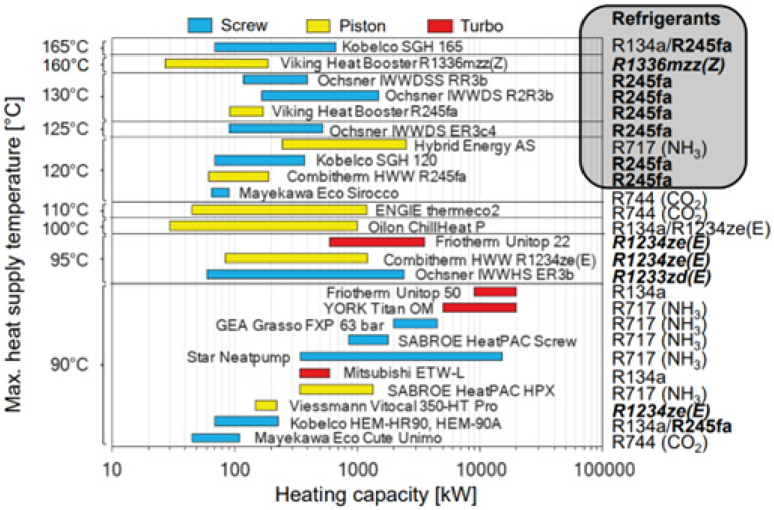


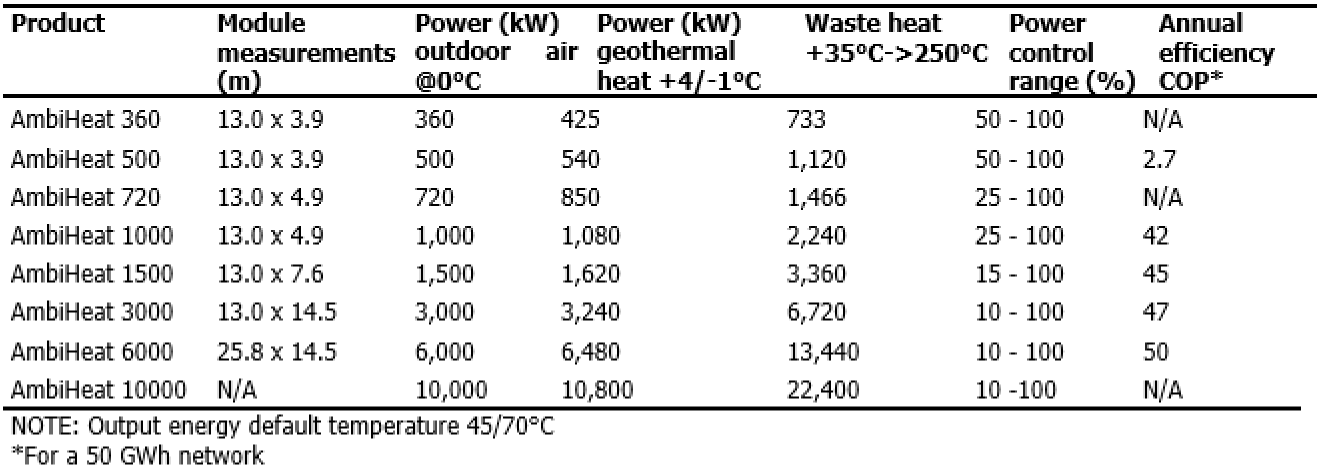
FIGURE 10. Comparison of different large heat pumps (Arpagaus, Bless, Uhlmann, Schiffmann & Bertsch 2018)

3.1 Calefa

Calefa is a Finnish company specialised in providing turnkey solutions for industrial waste heat and ambient energy. Calefa's turnkey projects include from pre-studies and project planning to installations and the aftercare of the whole system. Calefa's heat pump modules, known as AmbiHeat, offer possibilities to harness the energy from the surroundings, i.e., outdoor air, geothermal heat, waterways, industrial waste heat, or solar energy, to produce heating and cooling either to the customer company's own use or to the district heating network. According to Calefa, they have delivered about 200 systems since its foundation in 2013. (Calefa s.a.) The company's turnover in 2022 was €11.3 million (Asiakastieto s.a.).

Calefa offers eight standard sizes for their heat pump plants from 350 kW to 10 MW. In table 3 are listed the main characteristics of these different AmbiHeat modules. (Calefa 2021.)

TABLE 3. Heat pump modules by Calefa (Calefa 2021)



Product	Module measurements (m)	Power (kW) outdoor air @0°C	Power (kW) geothermal heat +4/-1°C	Waste heat +35°C->250°C	Power control range (%)	Annual efficiency COP*
AmbiHeat 360	13.0 x 3.9	360	425	733	50 - 100	N/A
AmbiHeat 500	13.0 x 3.9	500	540	1,120	50 - 100	2.7
AmbiHeat 720	13.0 x 4.9	720	850	1,466	25 - 100	N/A
AmbiHeat 1000	13.0 x 4.9	1,000	1,080	2,240	25 - 100	42
AmbiHeat 1500	13.0 x 7.6	1,500	1,620	3,360	15 - 100	45
AmbiHeat 3000	13.0 x 14.5	3,000	3,240	6,720	10 - 100	47
AmbiHeat 6000	25.8 x 14.5	6,000	6,480	13,440	10 - 100	50
AmbiHeat 10000	N/A	10,000	10,800	22,400	10 -100	N/A

NOTE: Output energy default temperature 45/70°C
*For a 50 GWh network

FIGURE 11. AmbiHeat by Calefa (Calefa 2021)

Calefa has successfully implemented its technology in several projects. For instance, in the city of Mäntsälä AmbiHeat heat pump plant is used to recover excess heat from Yandex data centre and produce district heat. Also in the chemical plant of Kiilto Oy in Lempäälä and in the pharmaceutical factory of Orion in Turku, Calefa's heat pump systems use waste heat from the industrial processes to produce heat for the manufacturing facilities. In the cities of Lahti, Runosmäki and Puumala district heating is produced from wastewater, ambient air, and ambient air and solar energy, respectively, by means of heat pumps by Calefa. All these examples are described in the next chapter 5.4.

3.2 Carrier

Carrier Global Corporation, commonly referred to as Carrier, is an American global company specializing in heating, ventilation, air conditioning, and refrigeration systems. It was founded in 1915 by Willis Carrier and has since grown to become a prominent player in the HVACR industry. Carrier operates 51 factories and 39 research and design centres worldwide with more than 53,000 employees serving customers in more than 180 countries. (Carrier s.a.) In terms of financial performance, Carrier Global achieved a revenue of $20.4 billion in 2022 (Zippia s.a.).

Carrier has a strong commitment to innovation and research. Carrier invests in cutting-edge technologies and collaborates with industry partners, universities, and research institutions to drive advancements in HVACR systems. An example of this is the centre of excellence specialized in heat pump and chiller innovation located in Montluel, France (Carrier 2019). Carrier has also recently invested in a research and development centre of excellence in Italy. This new centre will focus on the development of heat pumps, hydrogen-ready boilers and IoT-enabled solutions. The facility is planned to be built by the end of 2023. (Carrier 2022a.)

TABLE 4. Carrier's main heat pumps for district heating applications (Carrier 2023a, Carrier 2023b)

	AQUAFORCE 61XWHZE	**HEATCO$_2$OL**	**AQUAFORCE 30XWHVZE**
Type	High temperature water-source heat pump	High temperature water-source heat pump	Medium temperature water-source heat pump
Nominal capacity	200 - 2,500 kW	400 - 2,200 kW	200 - 2,000 kW
Hot water temperature	up to 85 °C	up to 90 °C	up to 55 °C
Refrigerant	HFO R-1234ze	R744 (CO_2)	HFO R-1234ze

Carrier offers a wide range of products and services and is the European leader in the supply of commercial heat pumps above 50 kW. Few years ago, Carrier entered the market of industrial heat pumps designed for district heating purposes that have the capability to generate hot water reaching temperatures as high as 90 °C. Carrier has successfully sold more than 200 units of these heat pumps so far. (Carrier 2023a.) In table 4 are listed the main heat pumps for district heating by Carrier.

Carrier heat pumps have been installed in numerous projects. In Padborg (Denmark), a 1.2 MW HeatCO2OL heat pump uses greywater from the local dairy factory to provide district heating for the city. The heat pump works with CO2 natural refrigerant and presents a COP of 3.7. (Carrier 2023b.) Carrier was also the supplier of the two 4.5 MW heat pump installed in Riihimäki (Finland), where they are used to recover heat from flue gases and district heating return water. Another example of successfully implemented Carrier technology is the case of Bahnhof Data Centres in Stockholm (Sweden), where two AquaForce 61XW heat pumps use waste heat from the data centres to provide district heating (Carrier 2022b).

In 2022 Carrier obtained the Air Conditioning Project of the Year Award for a decarbonization project in London. Three AquaForce 61XWHZE heat pumps were installed for the extraction of thermal energy from an aquifer located 200 meters beneath the city and the recovery of waste heat from the existing CHP plant to produce hot water at 80 °C.

The heat pumps will provide up to 4 MW of heating and 2.8 MW of cooling to residential and business customers, using R-1234ze as refrigerant. (Carrier 2023a.)

Six AquaForce 61XWHZE heat pumps with an output of 12 MW provide hot water at temperatures up to 80 °C for district heating in the communes of Rosny sous Bois and Noisy Le Sec in Paris (France). The heat pumps use heat from a geothermal heat source located at 1.8 km depth. (Carrier 2023a.) Also in France, in the Museum of Civilizations of Europe and the Mediterranean (MuCEM) in Marseille, a Carrier heat pump was installed to provide heating and cooling for the museum using seawater as a source. In Geneva (Switzerland), two AquaForce 30XW screw water-to-water heat pumps using R-1234ze were installed to recover waste heat from a data centre and produce district heating. (Carrier 2019.)

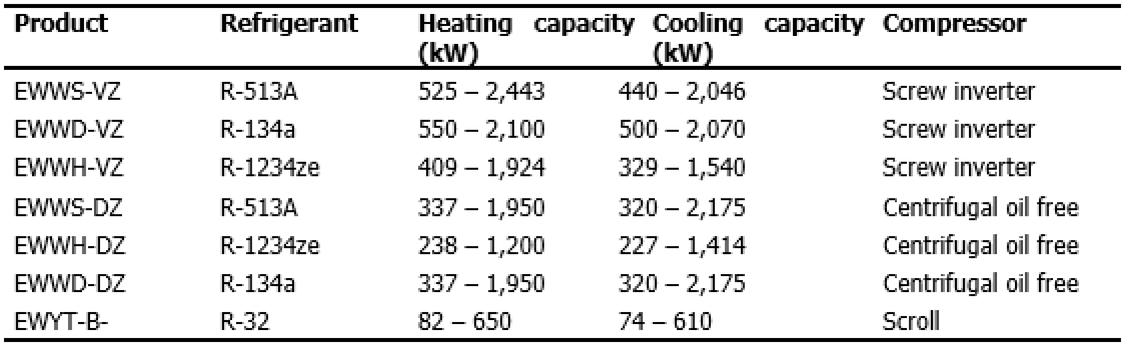
3.3 Daikin

Daikin Industries Ltd. is a multinational company that specializes in air conditioning, heating, ventilation, and refrigeration systems. It is one of the world's largest manufacturers of HVACR equipment and solutions. The company was founded in 1924 in Osaka, Japan, by Akira Yamada and has since grown into a global industry leader with operations in 145 countries. Its subsidiary Daikin Europe, headquartered in Ostend (Belgium) and with 12 major manufacturing facilities distributed throughout Europe, provides HVACR solutions for Europe, the Middle East and Africa (EMEA) since 1972. (Daikin 2018.) Daikin Industries Ltd. turnover in fiscal year 2022 was €28.2 billion (Daikin 2023).

Daikin invests in research and development to create energy-efficient and environmentally friendly products for the HVACR industry. Examples of this are the Technology and Innovation Centre (TIC) established in Japan in 2015 and the EMEA Development Centre (EDC), which main headquarters are located in Ostend and Ghent (Belgium), established in 2012. The EDC serves as the base development centre to test and develop new technologies and products for EMEA markets. (Daikin 2018.)

Daikin Europe announced in 2021 its strategic management plan “Fusion 25”, a 5-year plan to accelerate the company’s growth. The plan focuses on three strategic growth areas: becoming carbon neutral by 2050, being a total solution provider, and creating healthy indoor air. (Daikin 2021.) Within this plan, substantial investments are planned to expand its R&D and production capacity for advanced heat pumps. In 2022 a new state-of-the-art production line for the manufacturing of air to water heat pumps was opened in Daikin’s factory in Ostend (Belgium), doubling the plant’s production capacity (Daikin 2022a). Currently, the company is planning the addition of two more production lines in that factory and, furthermore, the construction of a new development complex in Ghent as support to the above-mentioned EMEA Development Centre (Cooling post 2022).

TABLE 5. Examples of Daikin heat pumps (Daikin s.a.)



Product	Refrigerant	Heating capacity (kW)	Cooling capacity (kW)	Compressor
EWWS-VZ	R-513A	525 – 2,443	440 – 2,046	Screw inverter
EWWD-VZ	R-134a	550 – 2,100	500 – 2,070	Screw inverter
EWWH-VZ	R-1234ze	409 – 1,924	329 – 1,540	Screw inverter
EWWS-DZ	R-513A	337 – 1,950	320 – 2,175	Centrifugal oil free
EWWH-DZ	R-1234ze	238 – 1,200	227 – 1,414	Centrifugal oil free
EWWD-DZ	R-134a	337 – 1,950	320 – 2,175	Centrifugal oil free
EWYT-B-	R-32	82 – 650	74 – 610	Scroll

Some Daikin heat pumps and their main properties are shown in table 5. As can be observed, Daikin makes use of different compressor technologies and refrigerants in its heat pumps. In 2020, EWYT-B- heat pump was launched to the market. This heat pump is suitable for residential and light industrial application, with the ability to produce hot water up to 60 °C. Three EWYT-B- air to water heat pumps with a total cooling/heating capacity of 1,016 kW were successfully integrated in the existing HVAC system of a university campus in Cartagena (Spain). (Daikin 2022b.)

FIGURE 12. Daikin EWYT-B- heat pump (Daikin s.a.)

3.4 Danfoss

Danfoss is a global leader that offers a wide range of products and solutions in the field of heating, ventilation, air conditioning and refrigeration (HVACR), motor control and mobile machinery. Danfoss was founded in 1933 in Nordborg, Denmark, by Mads Clausen and now it serves customers in more than 100 countries with 97 factories in 20 different countries. (Danfoss s.a. -b.) In terms of financial performance, Danfoss achieved a turnover of €10.3 billion in 2022 (Danfoss s.a. -a).

Danfoss is strongly committed to sustainability, and in 2022 the company launched its Core & Clear 2025 strategy to continue its green growth transformation. In the same year, the company's largest production facility in Nordborg reached carbon neutrality. Danfoss' goal is to become carbon neutral in all their operations by 2030. (Danfoss s.a. -b.)

Danfoss is also committed to innovation so that they can improve the performance of their products and solutions. Danfoss has established several Application Development Centres (ADCs) and Centres of Excellence globally. ADCs house state-of-the-art laboratories and test facilities to support research, development, and innovation, focusing on specific areas or industries. In the area of climate solutions, four application development centres exist around the world. One of these centres is located at Danfoss's headquarters in Nordborg (Denmark), and it focuses on developing innovative solutions for various industries, including air conditioning, residential heat pumps, commercial refrigeration and transport refrigeration. (Danfoss s.a. -c.)

Danfoss does not manufacture large heat pumps but the components that go into the heat pumps such as oil-free compressors and other components including electronic controls, sensors and system protectors, filter driers and different types of valves. Danfoss can provide about 50 to 70 % of the total value of the heat pump. Danfoss not only provides the components but also designs, tests, and optimizes them to the specific application. (Danfoss 2021b.)

Three Geoclima heat pumps with Danfoss compressors were installed in Ringsted district heating company (Denmark) in 2020 and since then its reliance on fossil fuels was reduced by 97 % (Danfoss 2023). Danfoss oil-free water to water heat pumps are also used at Danfoss's headquarters in Nordborg to recover excess heat from the data centres to provide heating for the building. In 2024, the recovered heat will provide 25 % of the total heat supply for the 250,000 m2 headquarters.

3.5 Friotherm

The first heat pumps in Europe were built in Switzerland by the companies Sulzer and Escher-Wyss in Winterthur and Zurich, respectively. In this country, 35 heat pumps were manufactured and installed mainly by these two companies between 1938 and 1945. In 1972, Sulzer acquired Escher-Wyss. Friotherm AG originates from this Sulzer group, although it became legally independent in 2005. Friotherm is headquartered in Frauenfeld, where design, engineering, research and development, and compressor manufacturing take place. (Zogg 2008, 24; Friotherm s.a. -a.) Friotherm annual revenue was $18 million in 2021 (RocketReach s.a.).

Friotherm currently operates in multiple countries, with branch offices in France, Sweden, Germany, Brazil, and China. Friotherm provides tailor-made solutions for their clients, using their wide range of heat pumps and chillers. The company is known for successfully manufacturing large-scale heat pump/chiller units for district heating and cooling systems and industrial applications. Friotherm liquid chillers incorporate Danfoss turbocor compressors. The different ranges of capacity and condensation temperature that are covered by these heat pumps and chillers can be seen in figure 14. In table 6 are listed some of the units commonly used in district heating and cooling systems. (Friotherm s.a. -a.)

FIGURE 13. Friotherm heat pump in Katri Vala plant, Helsinki (Picture courtesy of Helen Oy)

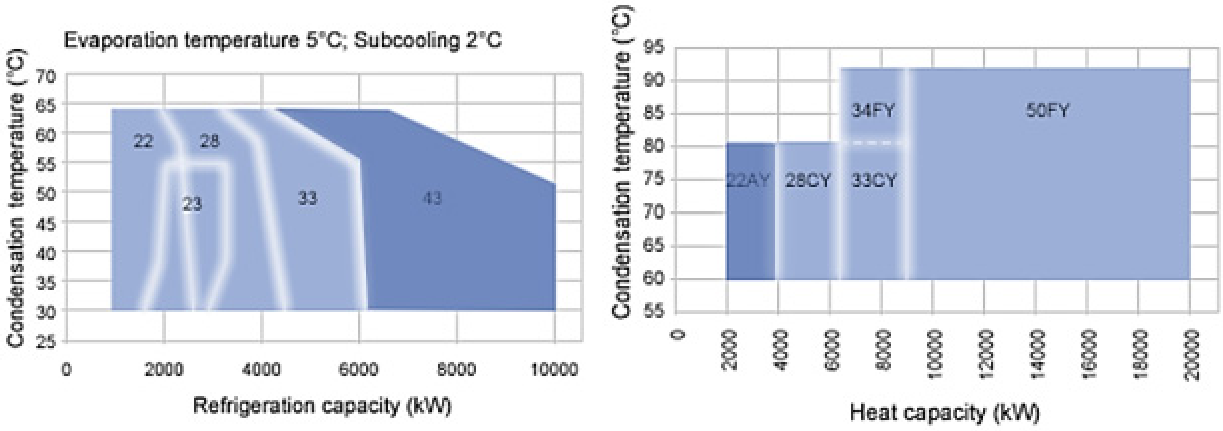


FIGURE 14. Capacities of Friotherm heat pumps and chillers (Friotherm s.a. -b.)

Friotherm heat pumps are used in numerous projects. In chapter 5 is collected information about several cases where Friotherm heat pumps were chosen for district heating systems, including:

- Lund district heating and cooling production plant in Lund, Sweden, with three Unitop® 33/28C units and 27.9 MW of total heating capacity.

- Sysav waste incineration plant in Malmö, Sweden, with two Unitop® 28C heat pump units and 19 MW of total heating capacity.

- Värtan Ropsten district heating plant in Stockholm, Sweden, with six Unitop® 50FY units and 180 MW total heating capacity.

- Fornebu district heating and cooling production plant in Oslo, Norway, with one Unitop® 28/22CY and one Unitop® 33/28 unit and 13.7 MW of total heating capacity and 17.6 MW of total cooling capacity.

- Sandvika district heating and cooling production plant in Oslo, Norway, with two Unitop® 28C heat pump units and 13 MW of total heating capacity and 9 MW of total cooling capacity.

- Lysaker district heating and cooling production plant in Oslo, Norway, with two Unitop® 28/22 and 9.1 MW of total heating capacity and 10.5 MW of total cooling capacity.

- Skøyen Vest district heating plant in Oslo, Norway, with two large heat pumps type Unitop 50FY and 34FY and 27.6 MW of total heating capacity.

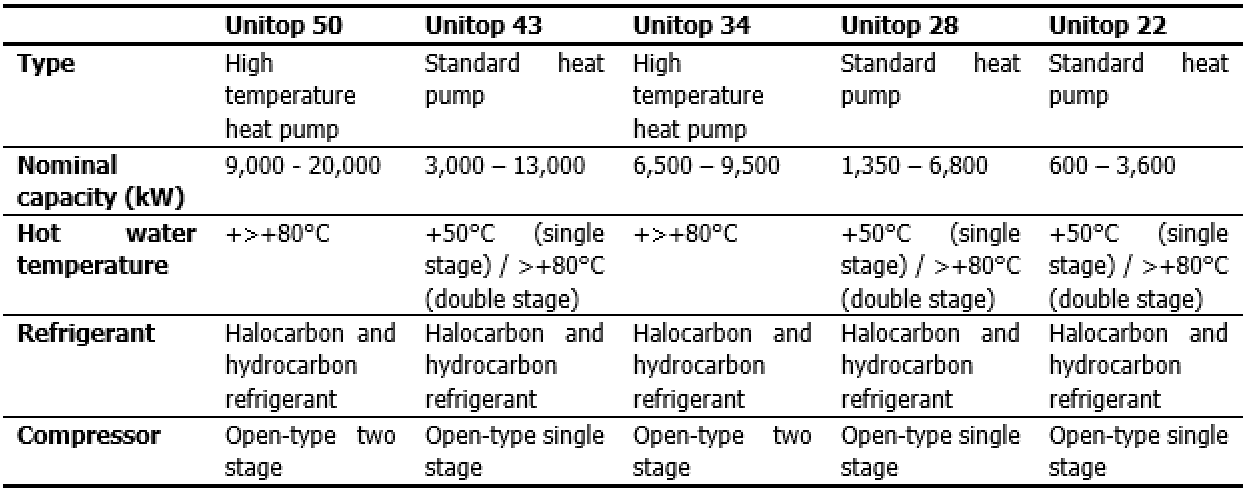
- Katri Vala heating and cooling plant in Helsinki, Finland, with seven Unitop® 50FY heat pump / chiller units and 155 MW of total heating capacity and 103.5 MW of total cooling capacity in 2023.

- Heat pump plant near Suomenoja power plant in Espoo, Finland, with three Unitop 50 FY heat pumps and 60 MW of total heating capacity.

- Kakola heating and cooling plant in Turku, Finland, with two Unitop 50 FY and 42 MW of total heating capacity and 29 MW of total cooling capacity.

- Heat pump plant in Vuosaari power plant in Helsinki, Finland, with one Unitop 43/28 and 13 MW of total heating capacity and 9.5 MW of total cooling capacity.

TABLE 6. Selection of Friotherm large heat pumps (Friotherm s.a. -b.)



	Unitop 50	**Unitop 43**	**Unitop 34**	**Unitop 28**	**Unitop 22**
Type	High temperature heat pump	Standard heat pump	High temperature heat pump	Standard heat pump	Standard heat pump
Nominal capacity (kW)	9,000 - 20,000	3,000 – 13,000	6,500 – 9,500	1,350 – 6,800	600 – 3,600
Hot water temperature	+>+80°C	+50°C (single stage) / >+80°C (double stage)	+>+80°C	+50°C (single stage) / >+80°C (double stage)	+50°C (single stage) / >+80°C (double stage)
Refrigerant	Halocarbon and hydrocarbon refrigerant	Halocarbon and hydrocarbon refrigerant	Halocarbon and hydrocarbon refrigerant	Halocarbon and hydrocarbon refrigerant	Halocarbon and hydrocarbon refrigerant
Compressor	Open-type two stage	Open-type single stage	Open-type two stage	Open-type single stage	Open-type single stage

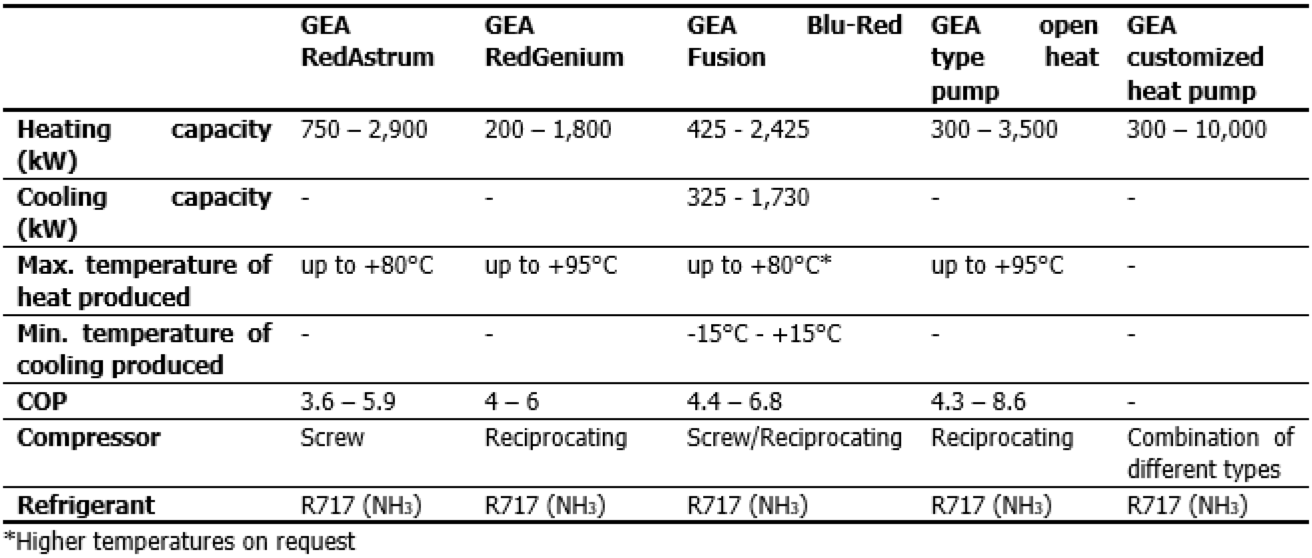
3.6 GEA Group

GEA Group, commonly known as GEA, was established in 1881 in Frankfurt, Germany. GEA is specialized in providing process solutions for various industries, including food, dairy, beverage, chemical and pharmaceutical industries. The company is headquartered in Düsseldorf and comprises five business units that employ more than 18,000 employees located in 62 countries across the world. Regarding its financial performance, the company's turnover was approximately €5,2 million in 2022. (GEA 2023a.)

Over the years, the company has grown into one of the world's largest suppliers of systems and components offering a broad portfolio of products and services. This includes separation and flow technologies, liquid and powder technologies, food and healthcare technologies, farm technologies, and heating and refrigeration technologies. GEA provides comprehensive customer support including installation, maintenance, spare parts service, and training to ensure optimal performance and minimize downtime. In table 7 are presented some properties of GEA heat pump series. (GEA 2023a.)

GEA is strongly committed to sustainability and helps its customers to reduce their environmental footprint enhancing the efficiency and sustainability of production processes. GEA's products and services contribute to reduce greenhouse gas emissions as well as plastic usage and food waste, supporting the green transition. GEA presented in 2021 its corporate strategy "Mission 26" that set ambitious goals for 2026. The aim of the strategy is to accelerate the company's sustainable and profitable growth, with a great focus on sustainability, innovation, and digitalization. GEA aims to increase its R&D spending by 45 % over the next years and to reduce its greenhouse gas emissions to net zero by 2040. (GEA 2021.)

TABLE 7. GEA heat pump series (GEA s.a.)



	GEA RedAstrum	**GEA RedGenium**	**GEA Blu-Red Fusion**	**GEA open type heat pump**	**GEA customized heat pump**
Heating capacity (kW)	750 – 2,900	200 – 1,800	425 - 2,425	300 – 3,500	300 – 10,000
Cooling capacity (kW)	-	-	325 - 1,730	-	-
Max. temperature of heat produced	up to +80°C	up to +95°C	up to +80°C*	up to +95°C	-
Min. temperature of cooling produced	-	-	-15°C - +15°C	-	-
COP	3.6 – 5.9	4 – 6	4.4 – 6.8	4.3 – 8.6	-
Compressor	Screw	Reciprocating	Screw/Reciprocating	Reciprocating	Combination of different types
Refrigerant	R717 (NH_3)	R717 (NH_3)	R717 (NH_3)	R717 (NH_3)	R717 (NH_3)

*Higher temperatures on request

GEA has successfully implemented its technology in several projects. For instance, two GEA RedAstrum units provide 1.4 MW of cooling and over 2 MW of heating at a European airport, using groundwater as the heat source. In the food industry, a producer of fresh prepared foods and chilled ready meals installed a GEA heat pump with 470 kW of cooling capacity and 760 kW of heating capacity, which eliminated the need of boilers. (GEA 2023b.) Mars chocolate factory in Veghel, the Netherlands, acquired a customized heat pump system with a heating capacity of 1.4 MW and a COP of 5.9. The heat pump harnesses low-temperature heat from refrigeration units to heat water to up to 63 °C for different processes and uses within the plant. (European Heat Pump Association 2019.)

GEA supplied two heat pumps with a total capacity of 6 MW to Gateshead Mine in United Kingdom (UK), where they recover heat from the naturally heated water from the mine to provide district heating (Refrigeration World 2023). Four GEA heat pumps with a total heating capacity of 40 MW were installed in Malmö, Sweden. These heat pumps use waste heat from a sewage treatment plant and an incinerator plant to supply hot water at about 66 °C to the district heating network, providing heat for a total of 10,000 homes. (Vahterus s.a.)

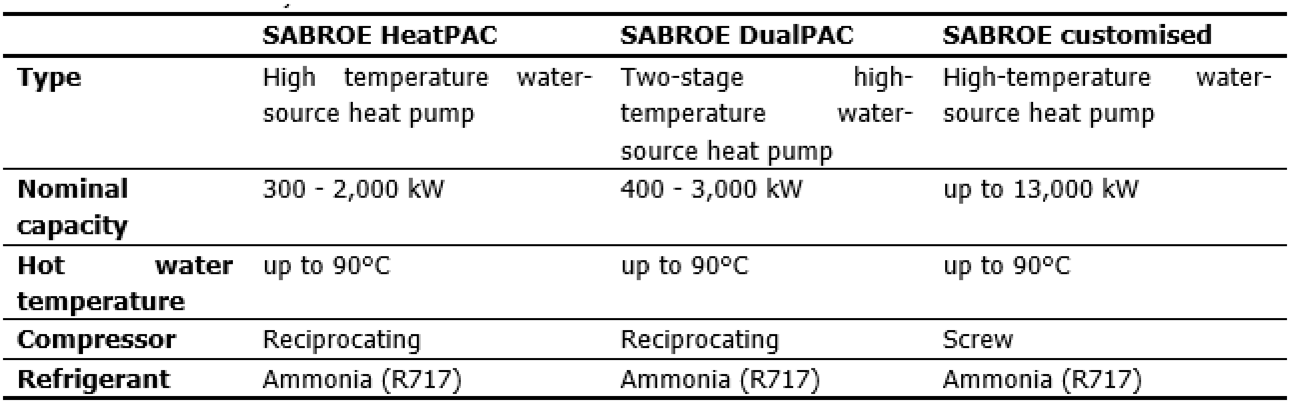
3.7 Johnson Controls

Johnson Controls International (JCI) is a leading developer and manufacturer of a wide range of cutting-edge solutions, including security, fire-detection and HVAC systems. Their innovative solutions are designed for industrial, commercial and residential buildings. Founded in 1885 by the American Warren S. Johnson, the company has its headquarters in Cork, Ireland, and operates globally from there and from Milwaukee (USA) and Shanghai (China). Johnson Controls has presence in more than 150 countries with a network of 2,000 offices. In terms of financial performance, Johnson Controls achieved an annual revenue of $25.3 billion in 2022. (Wikipedia 2023.)

One fundamental pillar of Johnson Controls is sustainability. The company is reducing its own emissions and developing new products so customers can meet their environmental goals too. In 2021, Johnson Controls joined The Climate Pledge, a community of companies committed to reach net-zero carbon emissions by 2040. (Johnson Controls s.a.) Furthermore, the company is planning to expand its heat pump production, which will reinforce JCI as a leader of sustainable buildings. In early 2023 they announced the acquisition of the Norwegian based Hybrid Energy AS to enhance their high-temperature heat pump portfolio. (Johnson Controls 2023a.)

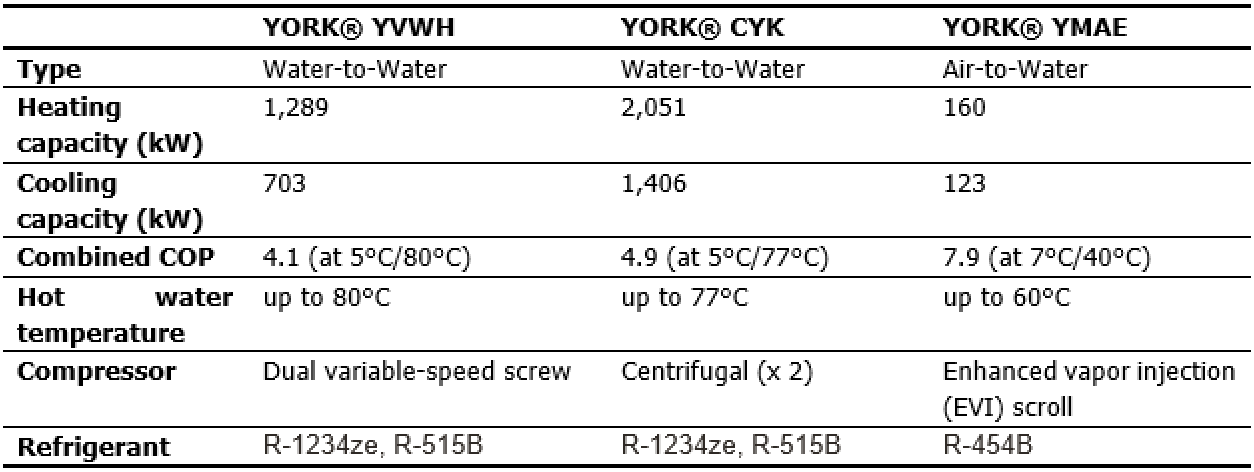
Johnson Controls manufactures high-temperature heat pumps for district heating and industrial applications to help their clients to lower emissions and reduce energy requirements. For this application, they offer Sabroe heat pumps, which main properties are listed in table 8. According to JCI, the coefficient of performance (COP) that can be achieve using these heat pumps is up to 4.5 for renewable sources, up to 5.8 for data centres, up to 8.5 for waste heat recovery and even higher performance for simultaneous use of heating and cooling (Johnson Controls 2020d). Johnson Controls also manufactures York water to air and water to water heat pumps and is planning to expand its portfolio of York pumps with the units listed in table 9.

TABLE 8. Johnson Controls Sabroe heat pump series (Johnson Controls 2020a; Johnson Controls 2020b; Johnson Controls 2020c)



	SABROE HeatPAC	**SABROE DualPAC**	**SABROE customised**
Type	High temperature water-source heat pump	Two-stage high-temperature water-source heat pump	High-temperature water-source heat pump
Nominal capacity	300 - 2,000 kW	400 - 3,000 kW	up to 13,000 kW
Hot water temperature	up to 90°C	up to 90°C	up to 90°C
Compressor	Reciprocating	Reciprocating	Screw
Refrigerant	Ammonia (R717)	Ammonia (R717)	Ammonia (R717)

TABLE 9. Johnson Controls new York heat pump series (Johnson Controls 2023b; Johnson Controls 2023c; Johnson Controls 2023d)



	YORK® YVWH	YORK® CYK	YORK® YMAE
Type	Water-to-Water	Water-to-Water	Air-to-Water
Heating capacity (kW)	1,289	2,051	160
Cooling capacity (kW)	703	1,406	123
Combined COP	4.1 (at 5°C/80°C)	4.9 (at 5°C/77°C)	7.9 (at 7°C/40°C)
Hot water temperature	up to 80°C	up to 77°C	up to 60°C
Compressor	Dual variable-speed screw	Centrifugal (x 2)	Enhanced vapor injection (EVI) scroll
Refrigerant	R-1234ze, R-515B	R-1234ze, R-515B	R-454B

In chapter 5 is collected information about several cases where Johnson Controls heat pumps were chosen for district heating systems, including (David et al. 2017, Grøn Energi 2022):

- TBV plant in Odense, Denmark, which includes nice Johnson Controls screw compressors on ammonia heat pumps with 23.9 MW of total heating capacity.

- Kalundborg plant in Kalundborg, Denmark, with three parallel sets of two pieces serially connected Dual-Pac heat pumps and 10 MW of total heating capacity.

- Taarnby in Copenhagen, Denmark, with four heat pumps and 6.5 MW of total heating capacity.

- Martsal district heating plant, in Denmark, where two heat pumps with a total heating capacity of 4 MW were installed in 2021.

- Skjern paper mill in Denmark, with four heat pumps and 5.2 MW of total heating capacity.

- Bjerringbro district heating plant in Denmark, with 3 heat pumps and 3.7 MW of total heating capacity, which make use of waste heat from the pump manufacturer Grundfos.

- Esplanade plant in Helsinki, Finland, with two heat pumps and 22 MW of total heating capacity and 15 MW of total cooling capacity.

Other examples of large-scale heat pumps supplied by Johnson Controls include:

- Brædstrup district heating plant in Denmark, with a 1.2 MW heat pump (David et al. 2017).

- Sig district heating plant in Denmark, with a 1 MW air-to-water heat pump. The heat pump converts the energy in the ambient air to hot water and it can deliver 60 °C hot water. (Prendergast 2019.)

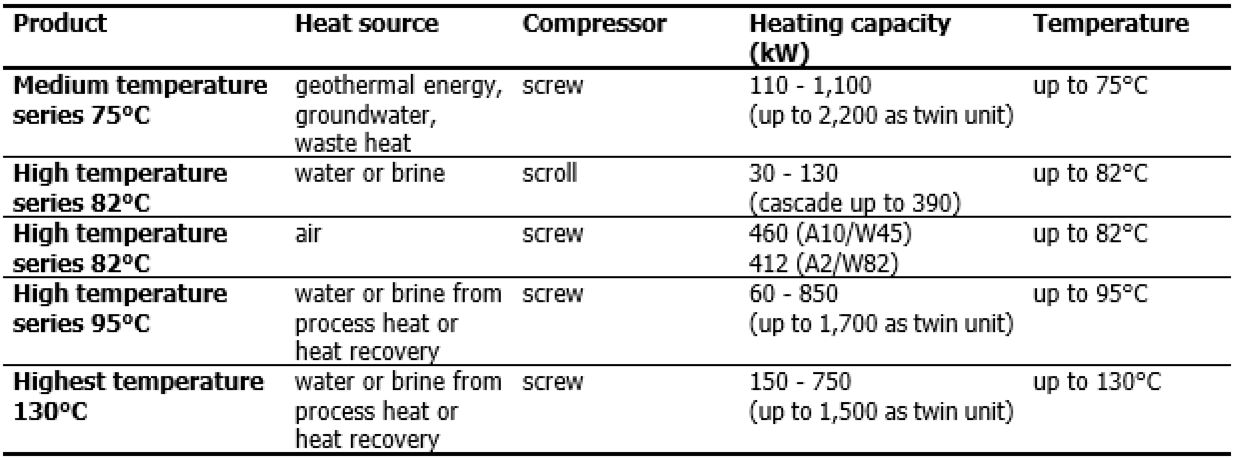
- Four 15 MW heat pumps in Hamburg, Germany, that supply district heating from wastewater (Johnson Controls 2023e.)

3.8 Ochsner

OCHSNER family business was established in Austria back in 1872 as a manufacturer of appliances and pumps, and in 1978 Karl Ochsner founded OCHSNER Heat Pumps GmbH. Since 1992, OCHSNER has specialised exclusively in heat pumps and has become one of the leaders of the sector. The company's main markets are Austria, Germany and Switzerland, as well as many other European countries and China. The company employs around 500 workers and achieved sales of around €100 million in 2022. (OCHSNER s.a.; OTS 2022.)

OCHSNER's broad product range includes hot water heat pumps, air source heat pumps, brine/water geothermal heat pumps, groundwater heat pumps, storage tanks, and high-capacity heat pumps. In addition to the products, they provide a comprehensive customer service including commissioning, repairs, spare parts, and leakage tests. In 2016 OCHSNER Energietechnik, a sister company of OCHSNER Heat Pumps GmbH, was established. This company focuses solely on high-capacity heat pumps. Its product portfolio includes heat pumps with large range of outputs of up to 2.5 MW and flow temperatures of up to 130 °C, covered by several series. General information about these heat pump series is gathered in table 10.

TABLE 10. OCHSNER heat pump series (OCHSNER heat pumps 2022)



Product	Heat source	Compressor	Heating capacity (kW)	Temperature
Medium temperature series 75°C	geothermal energy, groundwater, waste heat	screw	110 - 1,100 (up to 2,200 as twin unit)	up to 75°C
High temperature series 82°C	water or brine	scroll	30 - 130 (cascade up to 390)	up to 82°C
High temperature series 82°C	air	screw	460 (A10/W45) 412 (A2/W82)	up to 82°C
High temperature series 95°C	water or brine from process heat or heat recovery	screw	60 - 850 (up to 1,700 as twin unit)	up to 95°C
Highest temperature 130°C	water or brine from process heat or heat recovery	screw	150 - 750 (up to 1,500 as twin unit)	up to 130°C

OCHSNER is actively involved in combating global warming and contributing to climate protection as a partner of the WWF CLIMATE GROUP. OCHSNER plays a significant role in helping to protect the climate also through intensive research and development for even more reliable, silent, energy efficient and energy saving products. OCHSNER invests about 6 % of turnover and 15 % of its personnel resources in R&D annually. Such investments can lead to the development of innovative solutions that align with their goal of combating global warming and protecting the environment. The company makes use of an own certified test bench for large machines for the development and testing of their products, which shows their commitment to ensuring the quality and performance of their cutting-edge technology. (OCHSNER heat pumps 2022.)

OCHSNER heat pumps are designed for various residential, commercial and industrial applications. At Forlanini district in Milan, Italy, two Ochsner heat pumps with a total heating capacity of 1.7 MW and a COP of 4.6 use groundwater as heat source to supply hot water at a temperature of 50 – 75 °C. The heat pumps, that use R134a as refrigerant, provide reserves to guarantee a reliable heat supply and, at the same time, reduce the excessively high groundwater level. (European Heat Pump Association 2019.)

In Vienna, Austria, a 255-kW Ochsner heat pump was installed to increase the capacity and the efficiency of the district heating system. The heat pump, with a COP of 5.3 and ÖKO1 as refrigerant, uses the return line of the district heating system at 45 °C to provide a flow temperature of 70 – 85 °C. Similarly, in Mänttä-Vilppula, Finland, a 158-kW steam-temperature heat pump uses the return line of the district heating system at 45°C – 55 °C as heat source to supply water at 70 - 120 °C. In this case, the COP is 2.0 and the refrigerant is ÖKO1. (European Heat Pump Association 2019.)

In the office building of Vattenfall Europe in Hamburg, Germany, two 360-kW heat pumps with a COP of 5.0 and R134a as refrigerant, supply a flow temperature of 35 – 45 °C to heat up the building from waste heat from the IT centre. At the University of Burgundy in Dijon, France, a heat pump recovers waste heat from a data centre cooling system to provide heating and hot water for the building. The heat pump has 420 kW of heating capacity and 255 kW of cooling capacity with a combined COP of 4.2. (European Heat Pump Association 2017.)

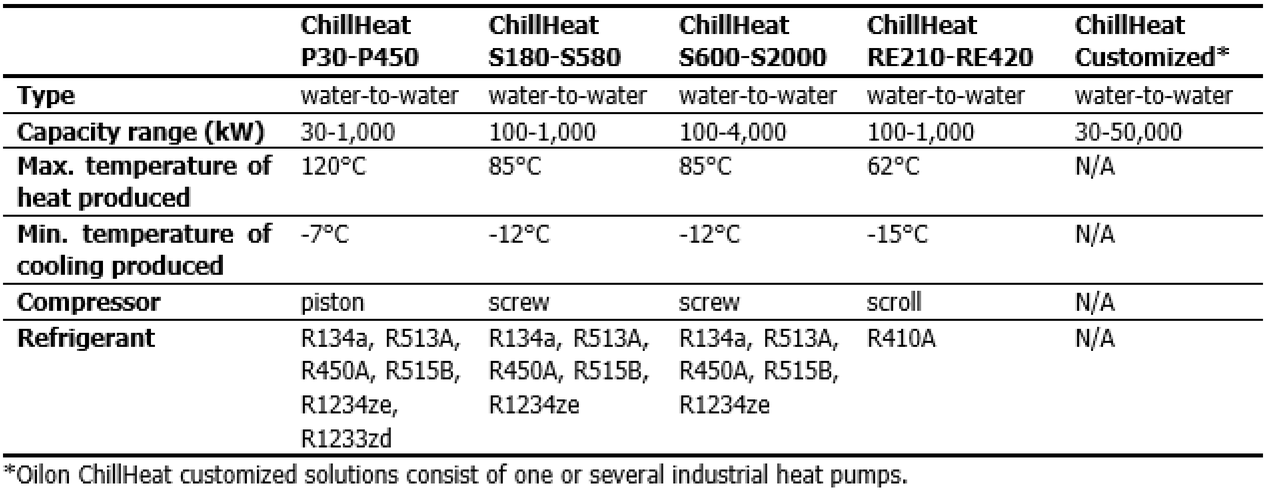
3.9 Oilon

Oilon is a Finnish company that specializes in the design, manufacture, and marketing of energy-efficient and environmentally friendly heating solutions. The company was founded in 1961 and has since established itself as a leading provider of various heating technologies, particularly in the field of burners, industrial heat pumps and ground source heat pumps. Oilon has factories in Finland, USA, and China, and a sales network that covers over 70 countries. (Oilon s.a.) Regarding its financial performance, Oilon Group's turnover was about €85.2 million in 2022 (Oilon 2023).

Oilon has a strong focus on research and development to continuously improve the energy efficiency and environmental performance of its products, investing about 6 % of its annual turnover to R&D. The research and development activities are carried out in two research centres, both located in Lahti, Finland, as well as in test benches at the manufacturing facilities. Oilon's commitment to sustainability is also visible in its intention to reduce the company's greenhouse gas emissions by at least 46 % from the levels recorded in 2019. Moreover, Oilon's products and services help customers reach their environmental goals. (Oilon 2022b.)

Oilon offers a wide range of burners and heat pumps for various industrial, commercial and residential applications. Its ChillHeat product family is made up of high energy-efficiency heat pumps suitable for both heating and cooling applications, including combined heating and cooling, refrigeration applications, heat recovery from industrial processes, wastewater and flue gases as well as heat extraction from ambient air and ground. Oilon ChillHeat heat pumps and their main properties are shown in table 11. Besides P, S and RE ChillHeat series, Oilon also offers end-to-end solutions, i.e., customized solutions for district heating and cooling, industrial process heating and cooling or large building heating and cooling. In addition to design and manufacture, end-to-end solutions include commissioning, maintenance, and training. (Oilon 2022a.)

TABLE 11. Oilon heat pump series (Oilon 2022a)



	ChillHeat P30-P450	**ChillHeat S180-S580**	**ChillHeat S600-S2000**	**ChillHeat RE210-RE420**	**ChillHeat Customized***
Type	water-to-water	water-to-water	water-to-water	water-to-water	water-to-water
Capacity range (kW)	30-1,000	100-1,000	100-4,000	100-1,000	30-50,000
Max. temperature of heat produced	120°C	85°C	85°C	62°C	N/A
Min. temperature of cooling produced	-7°C	-12°C	-12°C	-15°C	N/A
Compressor	piston	screw	screw	scroll	N/A
Refrigerant	R134a, R513A, R450A, R515B, R1234ze, R1233zd	R134a, R513A, R450A, R515B, R1234ze	R134a, R513A, R450A, R515B, R1234ze	R410A	N/A

*Oilon ChillHeat customized solutions consist of one or several industrial heat pumps.

Oilon has installed its solutions both in Finland and internationally. Examples of this are presented below. In Dalian, China, eight ChillHeat P-series heat pumps were delivered to the largest battery park in China, where they are used for cooling the vanadium flow batteries and producing district heating for the local DH company. (Oilon 2022b.)

At Copenhagen Airport, in Denmark, a ChillHeat P300 using R1234ze as refrigerant recovers heat from exhaust gas from a natural gas boiler to produce heat for the local heating network. The heat pump has a heating capacity of 623 kW, a cooling capacity of 470 kW, and a COP of 4.0. At E.ON data centre in Stockholm, Sweden, two ChillHeat P300 using R1234ze as refrigerant recovers heat from the data centre to produce district heating. The heat pump has a heating capacity of 860 kW, a cooling capacity of 590 kW, and a COP of 4.8. (Oilon 2021.)

At Snellman plant in Pietarsaari, Finland, refrigeration waste heat is recovered via two ChillHeat P300 heat pumps and the water produced at about 90 °C is used as sterilization water and for drying spaces after washing. The heat pump's heating capacity is 1,067 kW, its cooling capacity is 768 kW, and its COP is 3.5, while the refrigerant in it is R1234ze. (Oilon 2021.) A container that accommodates a combined heating and cooling (CHC) plant consisting of two ChillHeat P300 was installed in Kuopio, Finland. The CHC plant has a heating capacity of 970 kW, a cooling capacity of 650 kW, and a combined COP of 4.8. The plant supplies the excess heat from cooling to a DH network. (Oilon 2022c.)

FIGURE 15. Oilon ChillHeat S600 - S2000 industrial heat pump (Oilon 2022a)

3.10 Tehoilma Oy

Markku Huhtinen

Kuopio-based company Tehoilma is specialized in humidity control and solution cooling. The company's products are based on heat pump technology, which achieves high energy efficiency.

Dry-Air air drying products have been manufactured and sold in Finland and also abroad for several decades. Air drying products cover various needs, from small dehumidifiers for laundry drying rooms to dehumidifiers for indoor ski halls, ice rinks and timber dryers.

FIGURE 16. DRY-AIR dehumidifier heat pump (Picture courtesy of Tehoilma)

W-Therm solution coolers are used in special applications where standard solution coolers are not so suitable for use. W-Therm solution coolers are used e.g. for cooling cold water pools in spas and in the internationally known SnowTek temperature-independent snowmaking systems, where the water solution must be cooled down to below 0 oC.

Tehoilma designs and delivers air drying and solution cooling devices according to the special needs of customers, flexibly looking for the solution that best suits the customer at any given time.

3.11 Siemens Energy

Siemens Energy AG was founded as an independent company in 2020, after a restructuring in Siemens Group, and has since become a global leader in the energy business. The company is headquartered in Munich, Germany, and has presence in over 90 countries, 92,000 employees worldwide, and an annual revenue of €29 billion, as of 2022. Siemens Energy offers products and solutions for almost the entire energy value chain, including power and heat generation (e.g., gas turbines, steam turbines, generators, and heat pumps), renewable energy systems (e.g., wind power, hydro power, biomass power, solar power, and hydrogen solutions), grid technologies, energy storage systems, and more. (Siemens Energy 2023a; Siemens Energy 2023b.)

The annual investment in research and development is about €1 billion. Siemens Energy has established Global Innovation Centres to drive partnerships and co-creation in Berlin (Germany), Abu Dhabi (United Arab Emirates), Orlando (United States of America) and Shenzhen (China), with a total of 5,300 employees. Siemens Energy is collaborating with 10 of the top 25 world-ranked universities and 22 start-ups through Siemens Energy Ventures. The fields of innovation are decarbonized heat and industrial processes, energy storage, condition-based service interventions, resilient grids and reliability, and power-to-X. (Siemens Energy 2023a.)

Siemens Energy is strongly committed to sustainability. Its goal is to decarbonize energy systems along the entire energy value chain thanks to their low- or zero-emission power generation, transport and storage, and reducing greenhouse gas emissions and energy consumption in industrial processes. Also, they aim to decarbonize their own business, continuously improving their performance and becoming climate-neutral in own operations by 2030. (Siemens Energy 2023a.)

TABLE 12. Heat pump series from Siemens Energy (Siemens Energy 2020)

Product	Heating capacity (MW)	Cooling capacity (MW)	Hot water temperature	Refrigerant
SHP-STC-XX W/S	5 - 70	N/A	up to 150°C	N/A
SHP-C600/C750	15 - 45	5 - 25	up to 100°C	R1234ze(E)

In table 12 large-scale heat pumps by Siemens Energy are listed. Siemens Energy is building a heat pump with a heating capacity of up to 8 MW at the cooling plant operated by Vattenfall at Potsdamer Platz in Berlin, Germany. Electricity from renewable sources and waste heat are used by the heat pump to deliver hot water at temperatures of 85 °C – 120 °C, depending on ambient conditions, in the district heating network. (Siemens Energy 2021.) The energy supplier MVV with GKM power plant in Mannheim, Germany, chose a SHP-C600 heat pump to provide district heating using the river Rhine as energy source. The commissioning is planned in autumn 2023. The heating capacity of the heat pump is 20 MW and the supplied temperature up to 99 °C. (Siemens Energy 2020.) In table 17 in chapter 5.1 are presented more examples where large heat pumps by Siemens were installed in district heating plants.

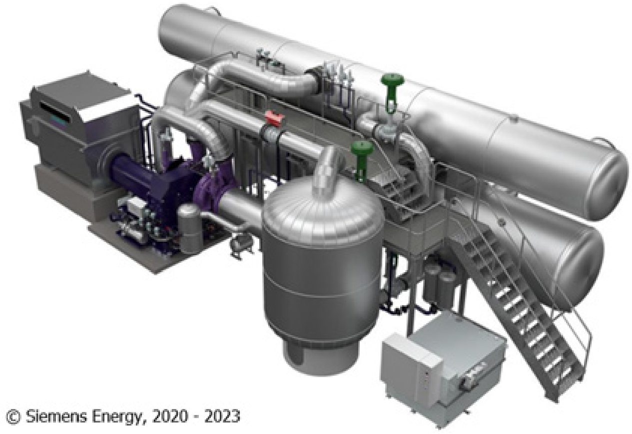

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FIGURE 17. SHP-C600/C750 heat pump from Siemens Energy (Siemens Energy 2020)

3.12 Star Refrigeration

Star Refrigeration was founded in 1970 in Glasgow, United Kingdom (UK), by the engineers Stephen Forbes Pearson, Anthony Brown, and Robert Campbell. The company is specialized in industrial refrigeration and cooling systems. Star employs about 450 workers across the country and operates in over 50 countries with an annual turnover of over £50 million. (Star Refrigeration s.a.)

Star Refrigeration delivers innovative and reliable products including packaged refrigeration systems, chillers, heat pumps, controls, and more. In addition, it offers services such as installations, maintenance, data monitoring and training among others. (Star Refrigeration s.a.)

TABLE 13. Neatpump heat pump series from Star Refrigeration (Star Refrigeration 2021)

Product	Heating capacity (kW)	COP	Hot water temperature	Refrigerant
Water source heat pump	100-10,000	N/A	up to 85°C**	R717 (NH_3)
Air source heat pump	500*	up to 4.4	up to 70°C	R717 (NH_3)

*Larger capacity can be considered on request.

**Up to 120°C in specific cases

Star Refrigeration Group is comprised of six business units including Star Renewable Energy. This unit is specialized in natural working fluid heat pumps for medium to large applications. These heat pumps, called Neatpumps by the company, are available with capacities up to 10 MW with multiple modules offering a higher capacity. In table 13 are presented the main characteristics of these heat pumps. (Star Refrigeration 2021.)

FIGURE 18. Neatpumps from Star Refrigeration (Picture courtesy of Star Refrigeration Ltd)

Some installations of large scale Neatpump heat pumps for district heating include Queens Quay, Drammen and Hillpark projects. In Clydebank Queens Quay two water source heat pumps with a total heating capacity of 5.2 MW were installed. The heat pumps will produce district heating from heat from a nearby river, reducing local carbon footprint by 60 %. (Star Refrigeration 2021.)

The project in the municipality of Drammen in Norway is described in more detailed in chapter 5.2. Since 2011, three Neatpump with a total capacity of 13.5 MW provide hot water up to 90 °C for district heating using seawater from a nearby fjord as heat source (Sitra 2019a.) In Hillpark Drive in Glasgow, UK, a 400-kW air source Neatpump extracts heat from ambient air to deliver hot water to the network. (Star Refrigeration 2021.)

3.13 Suomen Tekojää Oy

Suomen Tekojää Oy is a family-owned company founded in 1997. Its production facilities are located in Parkano, Finland. The company offers comprehensive solutions for refrigeration, air handling, industrial cooling and heat pump systems. They provide services for the entire life cycle of the project: design, manufacturing, installation and maintenance. Suomen Tekojää employs 75 workers and delivers its products to 25 countries. The company's turnover in 2020 was €13 million. (Suomen Tekojää 2022.)

The company's core competence areas are refrigeration system solutions for ice sports and industry facilities. With solid experience they also provide solutions for air handling, heating and building management systems.

Suomen Tekojää's equipment operates in more than 800 facilities.

Suomen Tekojää's heat pumps could be used with various heat sources such as geothermal heat, condensation heat, air, water and exhaust gas scrubber. Heat pumps can also use a combination of heat sources. Some installations of Suomen Tekojää's heat pumps include (Suomen Tekojää s.a):

- A 2-MW geothermal heat pump system providing heating energy for Vantaa Ikea store.

- A heat pump connected to the exhaust gas scrubber of solid fuel power plant in the municipality of Vieremä.

- Refrigeration containers for Vesileppis ice arena and ski tunnel in the municipality of Leppävirta. Heat pump is used to raise the temperature of low-temperature waste heat released from the refrigeration equipment.

- Refrigeration solutions for tunnel freezers, freezer and cool storages in Botnia Freeze logistics center in the city of Seinäjoki. Heating energy generated by condensation heat pump is transferred to the district heating network.

- Ice rink refrigeration container in the municipality of Lestijärvi. The refrigeration container also operates as a heat pump providing heating energy for the nearby school.

3.14 Viessmann

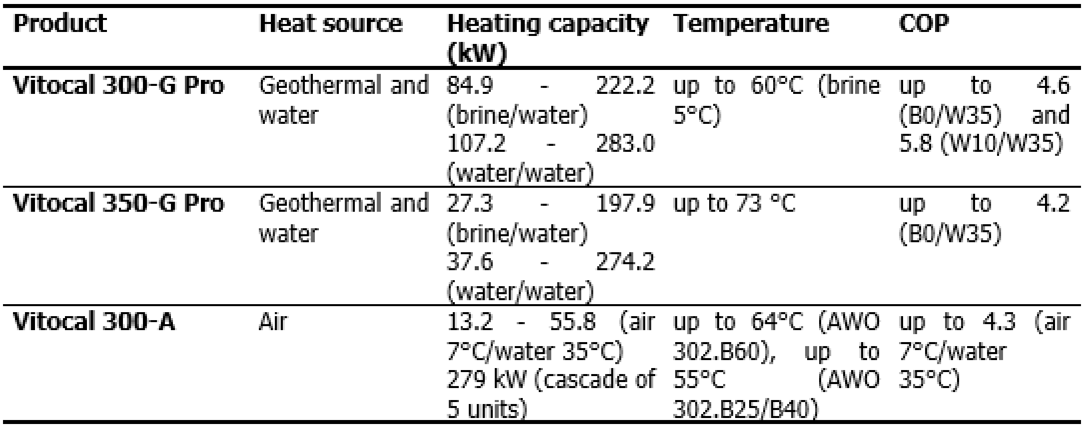
Viessmann Group is a leading international manufacturer of heating, cooling, ventilation, refrigeration, energy generation, and energy storage systems. The company was founded in 1917 by Johann Viessmann and is headquartered in Allendorf (Eder), Germany. Viessmann employs 14,500 workers and operates on a global scale, with 22 manufacturing companies, 68 distribution offices, and 120 sales branches distributed in many countries worldwide. Viessmann has a strong presence in Europe, North America, and Asia. Regarding its financial performance, the company's turnover was €4 billion in 2022. (Viessmann s.a. -a; Viessmann s.a. -b.)

Viessmann is known for its high-quality, innovative and energy-efficient products and solutions. Viessmann invested €50 million in the state-of-the-art development centre Technikum in Allendorf (Eder), which is the nucleus of innovation at Viessmann. The centre was inaugurated in 2017 and it comprises, for instance, 250 workstations, 12 climate room and 3 labs. About 100 employees work in the centre developing ideas, building and testing prototypes, and continually optimizing the products and solutions. (Viessmann 2023a.)

Viessmann is also known for its commitment to sustainability and strong focus on renewable energy technologies. They develop and produce systems that harness renewable energy sources such as solar, wind, geothermal, and biomass. These solutions help reduce greenhouse gas emissions and promote a transition towards more sustainable energy usage. Furthermore, the company aims to become climate neutral in all their operations by 2050 following its "LEAP to Net Zero" climate strategy. The acronym LEAP means lead by example, empower people to act, advocate to foster a movement and partner to scale impact. (Viessmann 2023b.)

Viessmann offers a wide range of sustainable products and solutions for residential, commercial, and industrial applications. Their product portfolio includes gas and oil-fired boilers, heat pumps, solar thermal systems, biomass boilers, cogeneration plants, refrigeration systems, and more. Since Viessmann acquired KWT AG, which was established in 1979 in Worb, Switzerland, they have offered large heat pumps for industrial applications to produce heating with geothermal energy, groundwater, ice and waste heat (Table 14). They also provide tailored heat pump systems which output capacity can be extended if required, for example with a cascade of several heat pumps. (Viessmann & KWT s.a.)

TABLE 14. Vitocal heat pump series from Viessmann (Viessmann 2022a; Viessmann 2022b; Viessmann 2022c)



Product	Heat source	Heating capacity (kW)	Temperature	COP
Vitocal 300-G Pro	Geothermal and water	84.9 - 222.2 (brine/water) 107.2 - 283.0 (water/water)	up to 60°C (brine 5°C)	up to 4.6 (B0/W35) and 5.8 (W10/W35)
Vitocal 350-G Pro	Geothermal and water	27.3 - 197.9 (brine/water) 37.6 - 274.2 (water/water)	up to 73 °C	up to 4.2 (B0/W35)
Vitocal 300-A	Air	13.2 - 55.8 (air 7°C/water 35°C) 279 kW (cascade of 5 units)	up to 64°C (AWO 302.B60), up to 55°C (AWO 302.B25/B40)	up to 4.3 (air 7°C/water 35°C)

Two Vitocal 350-G Pro heat pumps with a total heating capacity of 600 kW and a COP of 4.3 were installed in NORD Drivesystems in Gadebusch, Germany. The heat pumps, that use R134a as refrigerant, recover process heat from coolant in metal casting to supply hot water up to 65 °C to produce heating for the facility. Another Vitocal heat pump with a heating capacity of 107 kW and a cooling capacity of 84 kW is used in Vorbach GmbH & Co. KG manufacturing plant in Kaufbeuren, Germany, to heat the office complex from waste heat from the machinery manufacturing process. The heat pump's COP is 4.7, the refrigerant used is R134a, and the maximum supplied temperature is 70 °C. (European Heat Pump Association 2019.)

The company Laumer Bautechnik, located in Bavaria, Germany, installed a Vitocal heat pump with a heating power of 198 kW and a COP of 4.8. The heat pump, which uses R407C as refrigerant, supplies water at the required 37 °C utilizing as heat source the heat from outer walls of the fabrication plant that is stored in a ground heat storage. Two Vitocal heat pumps with a total heating capacity of 586 kW and a COP of 4.4 were installed in Bergheim district heating network in Germany. The heat pumps, that use R134a as refrigerant, use sump water extracted from a mine as heat source and supply hot water up to 73 °C. Underneath the parking lot of a new office building in Nagold, Germany, a Vitocal heat pump produces heating and hot tap water using an ice-storage tank as heat source. The heating and cooling capacities of the heat pump are 73 and 100.8 kW, respectively. The COP is up to 4.9 and the maximum heating temperature is 60 °C. (European Heat Pump Association 2017.)

4 PRESENT MARKET SHARE OF LARGE HEAT PUMPS IN DISTRICT HEATING IN NORDIC COUNTRIES

Markku Huhtinen, Raquel Mier González

4.1 Introduction

Nordic countries have developed their heating systems based on local needs and resources. Most Nordic countries (Denmark, Sweden and Finland) have high share of district heating (roughly 50 %) in the heating sector. Norway, which has had in use huge hydropower resources for cheap electricity production, is an exception compared to other Nordic countries. In Norway, the share of district heating in the heat sector has been very low, comprising only 3 % a decade ago. But since then, it has grown to present 10 % with the increase of waste to energy plants.

Traditionally, district heat in large systems has been produced mainly centrally in CHP (combined heat and power) - power plants that produce both electricity and heat, and only in small district heat systems and in large systems so called peak demand of district heat is produced with heating centres producing only heat. When most of district heating is obtained as cogeneration in CHP- power plants significant savings are achieved compared to the case that the generated electricity would be produced in separate condensing power plants, where more than half of the fuel energy used for electricity production would be transferred to the environment as waste heat.

The spread of district heating has had also other positive environmental effects. The air quality in cities has improved significantly because in large CHP- power plants and heating centres, the energy produced by burning can be generated with good efficiency, and the flue gases can and should be cleaned efficiently according to regulations.

Some ten to twenty years ago, most part of district heat in Nordic countries was produced with fossil fuels such as coal, natural gas, and milled peat. But nowadays, when aiming ambitiously to CO2-emission reduction and to carbon-neutral heat production, the share of fossil fuels in district heat production in Nordic countries is very small and energy sources used are mainly renewable.

Earlier as explained the only waste heat used for district heat production was waste heat from CHP-power plants, and the district heat system was a one-way system where energy companies produced heat, and it was transferred to consumers via district heating pipes. Nowadays, in a two-way district heating system, customers of district heating companies have the opportunity to sell surplus heat to district heating network. So today, district heat is produced to an increasing extent also by utilizing various waste heat sources either directly or with the help of heat pumps.

In the following, it is looked more closely the development of district heating and its current situation, as well the use of large heat pumps in the production of district heat in Nordic countries, i.e., Denmark, Sweden, Finland, and Norway.

4.2 Overview of district heating and share of large heat pumps in Denmark

Denmark is a global forerunner in district heating. The first Danish district heating network was built in 1903 as a waste incineration CHP plant. Since then, the country has successfully implemented numerous district heating systems, which provide efficient and sustainable heating solutions to millions of its inhabitants. Today, about 64 % of Denmark's households are connected to district heating systems for space heating and domestic hot water. (Danish Energy Agency 2019.) The success of district heating in Denmark can be attributed, in part, to the implementation of favourable public policies and regulations that have actively promoted and supported its growth. These policies aim to reduce greenhouse gas emissions, enhance energy efficiency, and increase the utilization of renewable energy sources.

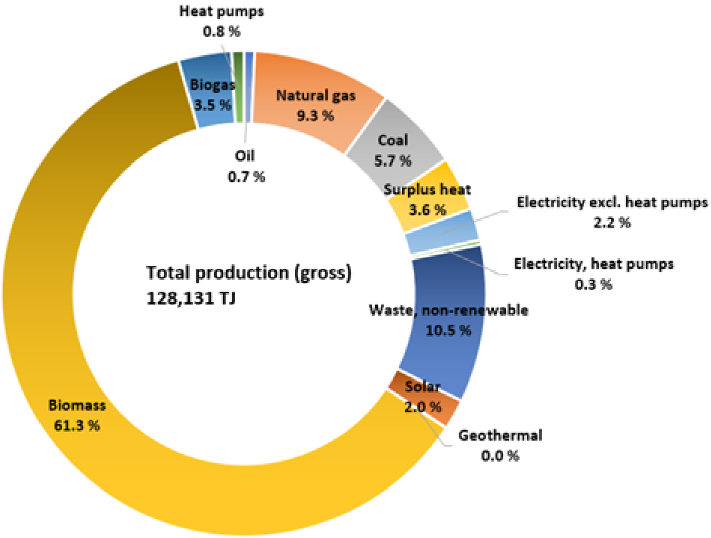


FIGURE 19. District heating production by fuel in Denmark, 2020 (Adapted from Danish Energy Agency 2022)

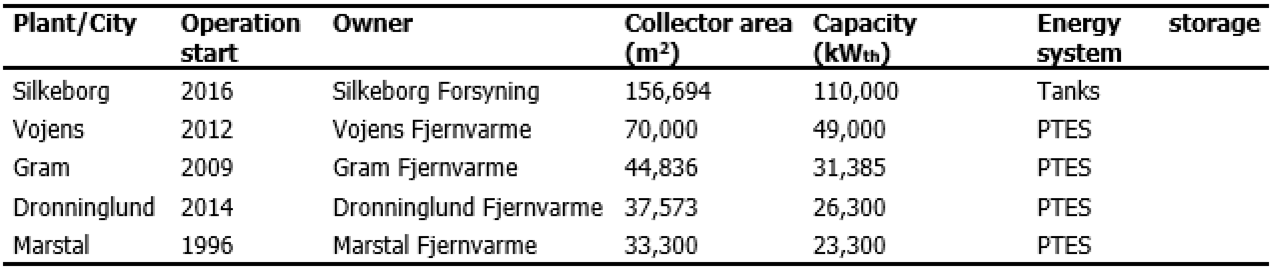
As can be seen in figure 19, the energy supply for DH in Denmark is already largely based on renewable energy sources, especially on biomass (e.g., renewable waste, wood, straw, and bio-oil). Other energy sources include non-renewable waste, natural gas, coal, waste heat, biogas, electricity, solar, heat pumps, oil and geothermal. This diverse mix of heat sources contributes to the sustainability and flexibility of the overall system. The heat pump capacity within the Danish district heating systems has increased in recent years, and experts expect this trend to continue as fossil fuels are phased out. (Danish Energy Agency 2022.)

In Appendix 1, there is a map of heating in Denmark created by the Danish Energy Agency (2020) that includes district heating networks, natural gas networks and heat producing installations. Throughout the country, district heating is generated in over 400 plants and distributed to end users via approximately 60,000 km of pipes. Regarding the production plant type, district heating is generated at large-scale CHP units, small-scale CHP units, district heating units and by auto producers. In 2020, CHP units accounted for 65.5 % of the total district heating produced in Denmark, with large-scale CHP units contributing 31.2 %, small-scale CHP units contributing 13.4 %, and CHP units at auto producers contributing 21.0 %. (Danish Energy Agency 2022.)

In order to achieve Denmark's goal of becoming climate neutral by 2050 and the goal of decarbonizing Danish district heating systems by 2030, a high integration of renewable energy sources such as wind and solar power into the energy system is required. Denmark has experienced a significant expansion of large-scale solar heating in recent years. In fact, Denmark is among the world leading countries in integrating large-scale solar heating into the DH systems. In the database by Solar District Heating (2017), 109 large-scale solar heating plants over 700 kWth were identified in Denmark by the end of 2017. The largest plants include Silkeborg, Vojens, Gram, Dronninglund and Marstal (Table 15).

Silkeborg plant is the largest of these plants, with over 155,000 m2 of collector area and 110 MW of solar thermal capacity. In 2021, Silkeborg Forsyning invested in an electric boiler with a heating capacity of 50 MW, and in 2024, a 22 MW air-to-water heat pump system will be commissioned. This equipment will replace their current reliance on natural gas. (Silkeborg Forsyning 2021.)

TABLE 15. Largest solar district heating plants in Denmark (Adapted from Solar District Heating 2017)

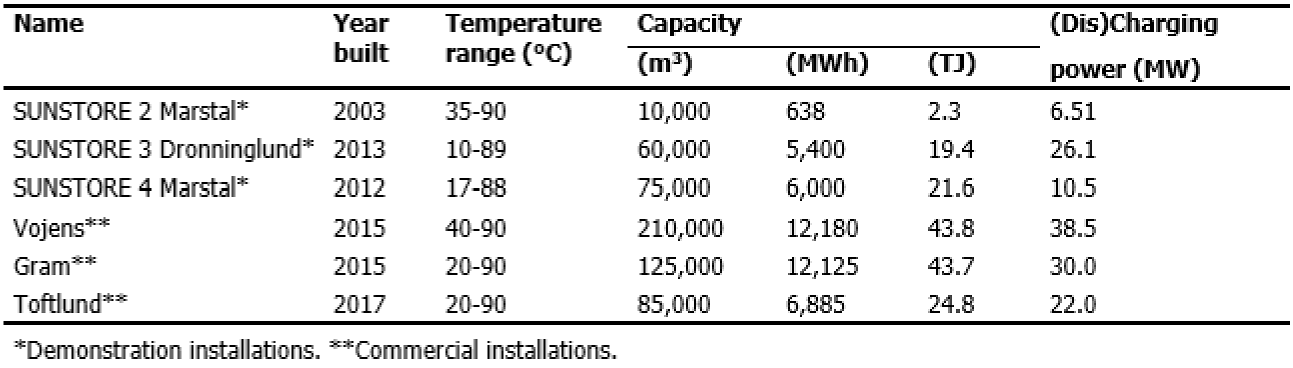


Plant/City	Operation start	Owner	Collector area (m^2)	Capacity (kW_{th})	Energy storage system
Silkeborg	2016	Silkeborg Forsyning	156,694	110,000	Tanks
Vojens	2012	Vojens Fjernvarme	70,000	49,000	PTES
Gram	2009	Gram Fjernvarme	44,836	31,385	PTES
Dronninglund	2014	Dronninglund Fjernvarme	37,573	26,300	PTES
Marstal	1996	Marstal Fjernvarme	33,300	23,300	PTES

The integration of variable renewable energy sources such as solar into the energy system requires storage systems that enable storage of energy produced during off-peak hours for use during peak demand. Danish district heating networks are equipped with short-term heat storages, enabling combined heat and power plants to optimize cogeneration according to the electricity demand without compromising the heating supply. If there is excess supply of electricity, the CHP plant can decrease its production, while if there is a higher electricity demand, the CHP plant can increase its production. Typically, short-term heat storage consists of a large insulated steel tank with a capacity corresponding to about 12 hours of full load heat production. (Patronen et al. 2017.)

When a large percentage of heating is required from the solar heating plant or when there is need to store energy from summer to winter, a long-term or seasonal heat storage is necessary. Long-term storages have been implemented at least at six district heating plants in Denmark: Vojens, Gram, Dronninglund, Brædstrup, Marstal and Toftlund. Seasonal heat storages consist mainly of pit thermal energy storage (PTES) and borehole thermal energy storage (BTES) systems. PTES systems in Denmark and their main properties are listed in table 16.

TABLE 16. Pit thermal energy storage systems in Denmark (Wyrwa et al. 2022)



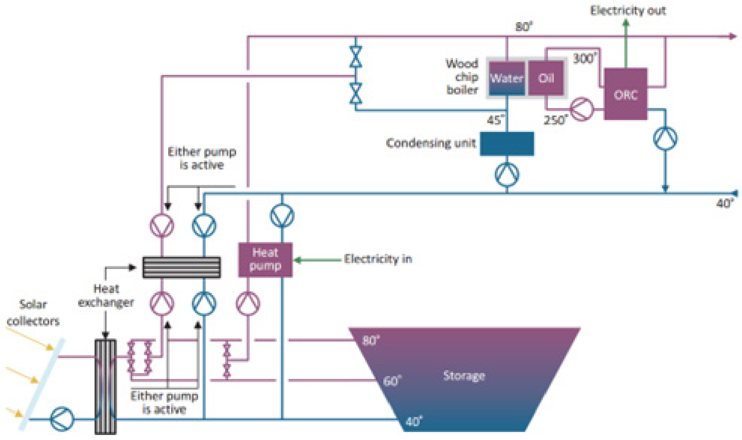
Name	Year built	Temperature range (°C)	Capacity			(Dis)Charging
			(m^3)	(MWh)	(TJ)	power (MW)
SUNSTORE 2 Marstal*	2003	35-90	10,000	638	2.3	6.51
SUNSTORE 3 Dronninglund*	2013	10-89	60,000	5,400	19.4	26.1
SUNSTORE 4 Marstal*	2012	17-88	75,000	6,000	21.6	10.5
Vojens**	2015	40-90	210,000	12,180	43.8	38.5
Gram**	2015	20-90	125,000	12,125	43.7	30.0
Toftlund**	2017	20-90	85,000	6,885	24.8	22.0

*Demonstration installations. **Commercial installations.

The SUNSTORE project developed in Denmark aimed to demonstrate the potential of a flexible 100 % renewable-based energy system. SUNSTORE consists of a large thermal energy storage (e.g., PTES, BTES or TTES), solar collectors responsible for heating up the storage, and a heat pump that utilizes the storage as a heat source combined with a CHP plant. Additionally, the heat pump extends solar production, minimizes heat loss from the storage and increases the overall storage capacity. This concept was first studied in the demonstration plants of Dronninglund and Marstal. (PlanEnergi 2018.)

The pit thermal energy storage at Dronninglund solar district heating plant, situated in an abandoned gravel pit, has a capacity of 60,000 m3. Additionally, the plant features 37,573 m2 of solar collectors, an 8 MW natural gas boiler, and 6 MW engines. (PlanEnergi 2018.) Originally, Dronninglund plant included a bio-oil boiler driven absorption heat pump with a heating capacity of 5.2 MW and a cooling capacity of 2.1 MW. However, the absorption heat pump and bio-oil boiler were replaced by a compression air-to-water heat pump in 2021. (European Heat Pump Association 2021.)

Marstal district heating's long-term storage is a 75,000 m3 pit thermal energy storage with water as storage medium. Marstal SUNSTORE 4 plant comprises a 15,000 m2 solar collector field, a CHP system consisting of a low emission 4.0 MW wood chip thermal oil boiler, a 750 kW ORC, and a heat pump. SUNSTORE 4 plant complements the existing SUNSTORE 2 demonstration plant including about 18,300 m2 of solar collectors, a 2,100 m3 steel tank water storage and a 10,000 m3 pilot pit thermal energy storage. (PlanEnergi 2018.) In 2021, Marstal Fjernvarme decided to replace the 1.5 MW (thermal) heat pump with CO2 as refrigerant by two ammonia heat pumps with a total capacity of 4 MW (Ammonia21 2021).



Source: PlanEnergi Nordjylland representatives (2013), Personal Communication.

FIGURE 20. Diagram of the district heating system in Marstal plant as of 2013 (Picture courtesy of PlanEnergi)

Vojens district heating plant features the largest PTES in the world, with a volume of 200,000 m3. The storage medium utilized in this system is water and is separated from the district heating water by a heat exchanger. Thanks to the PTES, the solar plant can deliver more than 50 % of the annual heat demand of the DH network. In addition to the 70,000 m2 of solar collectors for heating production, the plant relies on 3 gas engines, a 10 MW electric boiler, an absorption heat pump, and gas boilers. (Roussel 2020.)

The plant in Gram features the second largest PTES in Denmark, with a volume of 125,000 m3. The solar collector field with an area of about 44,800 m2 provides heat that is stored in the PTES. Besides the pit heat storage, the plant features a 2,300 m3 steel tank. Additionally, the plant comprises a 900 kW compressor driven heat pump, a 6.5 MW natural gas engine, an 8 MW electric boiler and two natural gas boilers for spare capacity. The plant also harnesses excess heat from a nearby carpet factory. (PlanEnergi 2018.)

Brædstrup district heating plant features a solar collector field of 18,600 m2, a 1.2 MW high-pressure screw compressor heat pump and a 10 MW electric boiler, although there is still a need for natural gas boilers as peak load. The plant also features a seasonal energy storage system consisting of accumulation tanks of a total of 7,500 m3 and a BTES system comprising 48 boreholes, each drilled to a depth of 45 m. (PlanEnergi 2018.)

Toftlund's PTES was installed in 2017 and has a volume of 85,000 m3. The heat sources for the PTES are primarily a 26,000 m2 solar thermal collector field and heat from a 3 MW absorption heat pump which is driven by a gas fired boiler or an electrical boiler. In addition, it receives indirectly heat from the CHP unit. The heat pump cools down the storage during winter. (Solar District Heating 2017; Ramboll 2020.)

Pit thermal energy storage systems are not pressurized and therefore the maximum temperature is approximately 85 – 90 °C. Pit heat storages present thermal stratification, and the optimal stratification is achieved when hot water is injected on the top and cold water is extracted from the bottom. In practice, diffusers are arranged at different heights of the PTES, and based on the year-round operating conditions diffusers work either as inlet or outlet. The mentioned PTES systems in Denmark are charged to about 80 – 90 °C during summer and discharged down to about 10 – 20 °C during winter. The pit storage system can be used directly or as heat source for the heat pump. (PlanEnergi 2018.)

The integration of PTES and heat pumps in existing solar district heating plant enhances the efficiency and the flexibility of the system. The incorporation of heat pumps reduces the carbon emissions when renewable energy sources are utilized for the HP. In some of the mentioned PTES systems, the heat pump helps to cool down the bottom of the storage, decreasing its temperature below the surrounding ground temperature. Thereby, there is a significant energy recovery of the thermal losses experienced during the summer. The heat pump can also be used to preheat the return line of the district heating network before entering the CHP plant, which increases the COP of the heat pump. Furthermore, when the storage temperature falls below the required level and electricity prices are at a moderate level, the heat pump comes into play to efficiently meet the energy demands.

In order to achieve Denmark's goal of becoming climate neutral by 2050, the country is implementing a comprehensive energy system transformation and expanding its district heating infrastructure, aiming to connect more households, businesses, and public buildings. In fact, Denmark is already experimenting the transition to the fourth generation of district heating. Ongoing research and innovation focus on optimizing energy efficiency (e.g., by reducing the DH network's temperatures), exploring new heat sources, and implementing smart grid technologies.

4.3 Overview of district heating and share of large heat pumps in Sweden

In Sweden, first district heating system was built in Karlstad in 1948, and in the 1950s district heating systems were introduced in Sweden's largest cities: Malmö (1951), Gothenburg and Stockholm (1953), and then Linköping and Västerås (1954). The more rapid development, however, started in the 1960s and nowadays practically all towns/cities in Sweden have a DH system, and today of around half of homes and premises in Sweden are heated by district heat.

In Nordic countries, Sweden has been forerunner introducing large heat pumps in district heat production. This can be seen in the figure below. Until 1980, district heat was completely produced by oil, and after that, there has been a major shift to a variety of fuels and energy sources including the introduction of large heat pumps.

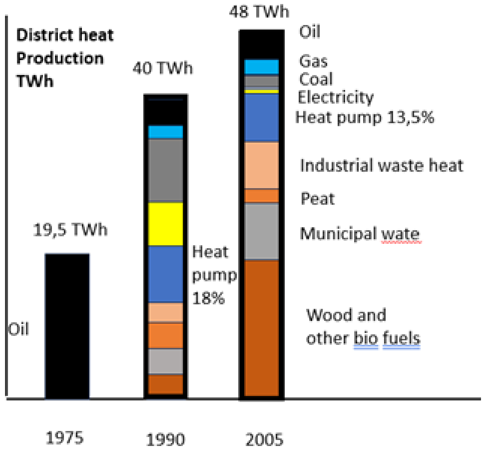


FIGURE 21. Development of energy sources in district heat production in Sweden (Ericsson 2009)

In the 1970s, Swedish energy company Vattenfall started to build nuclear power plants, and the first large-scale commercial nuclear power reactor was taken into operation in 1972. Over the following 13 years, a total of 11 other nuclear power reactors were taken into operation in Sweden. So, in the 1980s, cheap electricity produced with nuclear power plants became available in Sweden. That is why it was profitable to use electricity boilers and heat pumps for district heat production. In the 1980s, over 1,500 MW of large heat pumps for district heat production were installed in Sweden. The biggest share of district heat produced with heat pumps was 18 % in the early 1990s. These large heat pumps may have a capacity of up to 40 MW and are often located at wastewater treatment plants using municipal or industrial wastewater as heat source. Although those heat pumps were highly profitable, no new heat pumps were installed in the 1990s. That is why the share of district heat produced with heat pump has declined.

The present situation of energy sources of district heat production is seen from the figure below.

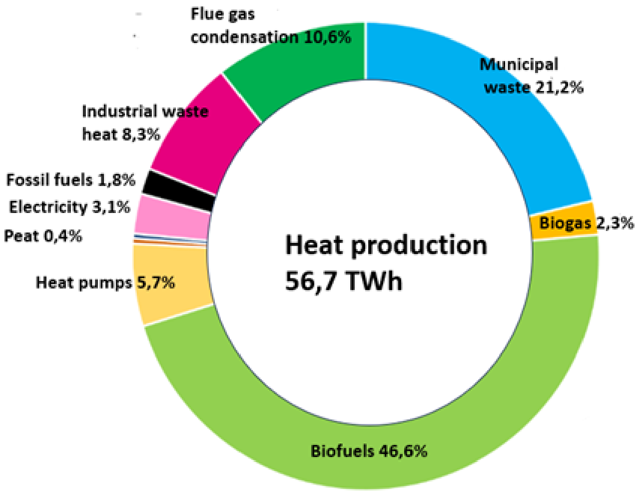


FIGURE 22. Energy sources of district heat production in Sweden 2022 (adapted from Energiföretagen 2023)

In 2022 the DH production was 56.7 TWh of which 5.2 TWh was lost in the distribution. The main energy source was biomass with 26.4 TWh (46.6 %). The remaining production was based on 12.2 TWh of municipal waste (21.2 %), 4.7 TWh of industrial waste heat (8.3 %), 6.0 TWh flue gas condensation (10.6 %), 3.2 TWh of heat from heat pumps (5.7 %), 1.2 TWh of fossil fuels (coal, oil, natural gas and peat) (2.2 %) and 1.8 TWh of heat from electric boilers (3.2 %).

4.4 Overview of district heating and share of large heat pumps in Finland

The first district heat systems in Finland were built in the 1950s. Nowadays, district heating is the most popular way to heat buildings with a market share of 46 % (Figure 23).

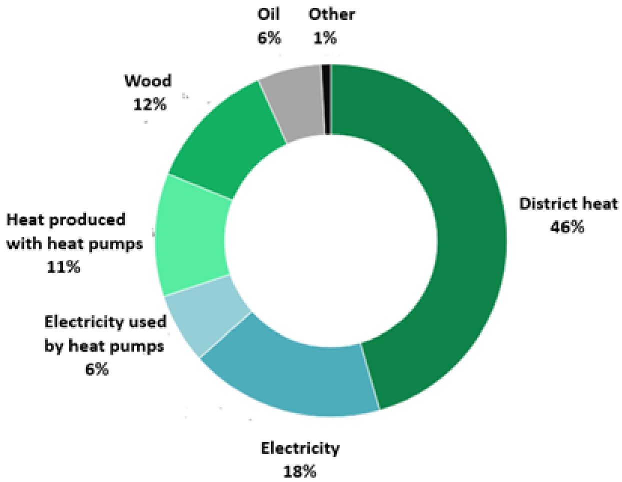


FIGURE 23. Market share of different heating systems in Finland (residential and service buildings) in 2021 (Tilastokeskus Energia 2022)

The development of market share of different energy sources in district heat production is shown in the figure below. First, in the 1950s and 1960s, district heat was produced by oil. The first CHP-power plants built in Finland used either oil or coal as fuel. In the 1970s, natural gas pipe line was built from Russia to Finland, first to South-East Finland and later in the 1980s to the whole South-Finland, making possible the use of gas in district heat production. In 1970, the energy crisis raised the price of oil, so that in Finland, with political guidance, it was decided to promote the use of domestic fuels and especially peat in energy production.

So from the 1990s to the 2020s, district heat was produced in Finland by using:

- in large cities on coast in CHP - power plants coal as fuel,

- in large cities inland in CHP-power plant peat as fuel,

- along the natural gas pipe line in South Finland mainly in combined cycle CHP- power plants natural gas as fuel,

- in smaller cities peat or biofuel as fuels in heat centres,

- oil as fuel only in reserve or peak heat centres.

Finland in its’ National Climate and Energy Strategy has set the goal of being carbon neutral by 2035. That is why greenhouse gas emissions should be reduced by 60 per cent by 2030. Finnish energy companies have already started the measures with which Finland can reach the carbon neutrality. So the share of fossil fuels used in district heating has decreased significantly. In figure 24, it can be seen that the use of coal in district heat production in Finland has dropped sharply in recent years and is due to end completely by 2029. Similarly, the use of peat in the production of district heat will be greatly reduced by 2030. The use of natural gas has also decreased due to the increase in its price and availability. Oil is used only a little in the production of district heating: mainly during consumption peaks and as a backup fuel. The share of wood and other biomass fuels in district heat production has more than doubled in the 2010s and their share is already over one third. In many municipalities, district heating is produced entirely by domestic fuels. However, the increase of use of wood-based fuels is limited by Finland's forest resources. That is why for replacing fossil fuels, non-combustion-based production methods are also needed, such as different heat pump solutions utilizing various heat source for example industrial waste heat, heat from municipal wastewater or cooling heat from buildings or data centres. The share of carbon dioxide-neutral heat sources in district heat production is already almost half in Finland.

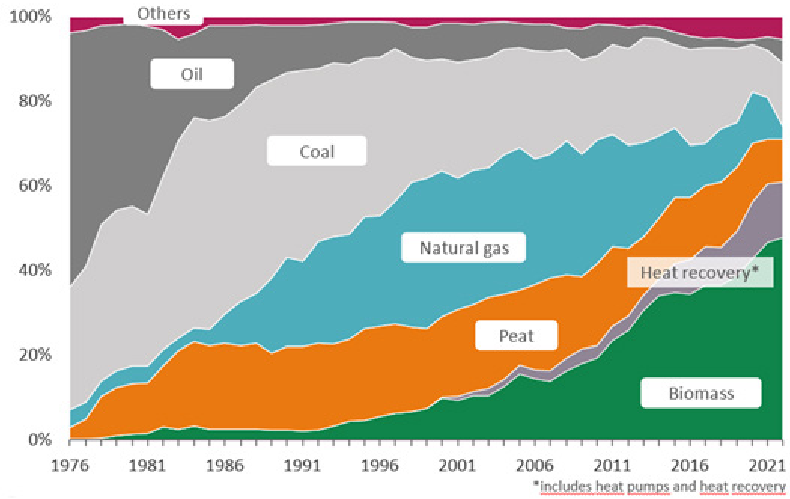


FIGURE 24. Energy sources in district heat supply in Finland (Energiateollisuus ry 2022a)

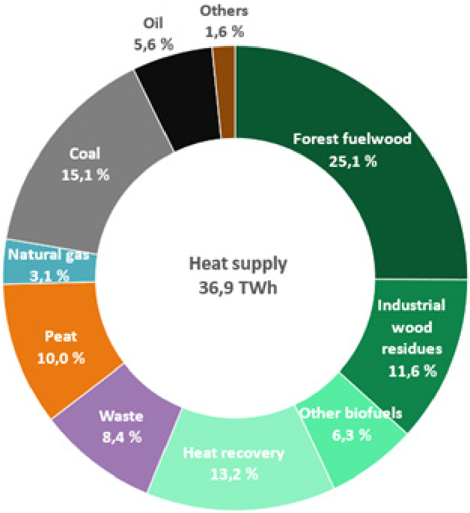


FIGURE 25. Energy sources for district heat supply in 2022 (Energiateollisuus ry 2022b)

In the figure above, the heat recovery includes heat produced either with heat exchangers from warm waste heat sources or heat produced with heat pumps from colder heat sources. The share of these two alternative ways (heat exchanger or heat pump) is:

- heat exchangers 9.5 % 3.5 TWh
- heat pumps 3.8 % 1.42 TWh (with COP 3.3 share of electricity is 0.4 TWh)
- altogether 13.2 % 4.9 TWh

In Finland, the installed capacity of large heat pumps (over 1 MW) connected to district heat network is over 300 MW according to the same statistic.

4.5 Overview of district heating and share of large heat pumps in Norway

Norway has had in use huge hydropower resources for cheap electricity production as can be seen from the figure below. In 2020, it was produced 152 TWh of electricity of which 90 % was produced with hydro power plants. Recently, they have started to install also wind turbines for electricity production. In Norway, it is produced by hydro power plants over two times more electricity than electricity is produced totally in Finland with different alternatives combined.

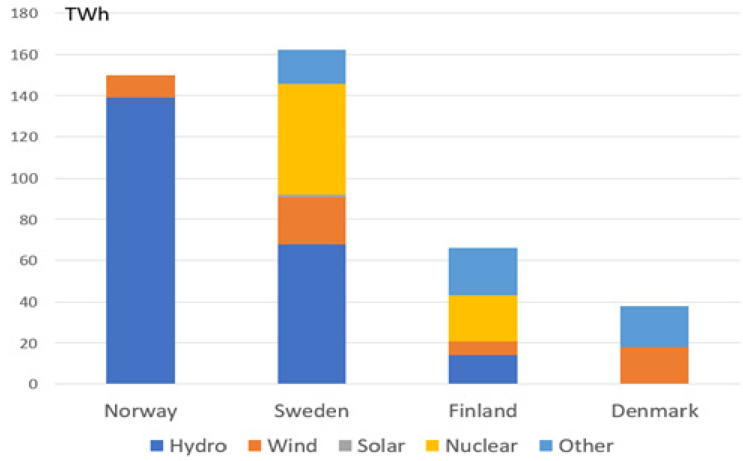


FIGURE 26. Distribution of electricity generation in the Nordic countries in 2020, by source (data from Statnett)

Because of available cheap electricity in Norway, there has not been a need to invest in district heating systems. Houses have been heated mainly with electricity (direct or with heat pumps) or with wood, and a very small amount with oil and other energy sources.

The first district heating systems in Norway were built as late as in the 1980s. But it was not until the 2010s that district heating expanded significantly, when waste dumping to landfills was prohibited, and waste incineration plants were built. The energy they produced was used for district heat production. The share of district heating in heat sector has been nowadays 10 %.

In the figure below, the energy sources in district heat production can be seen. The main sources are municipal and wood waste, but electricity, waste heat and heat pumps also have a notable role. The share of heat pumps is 9 %.

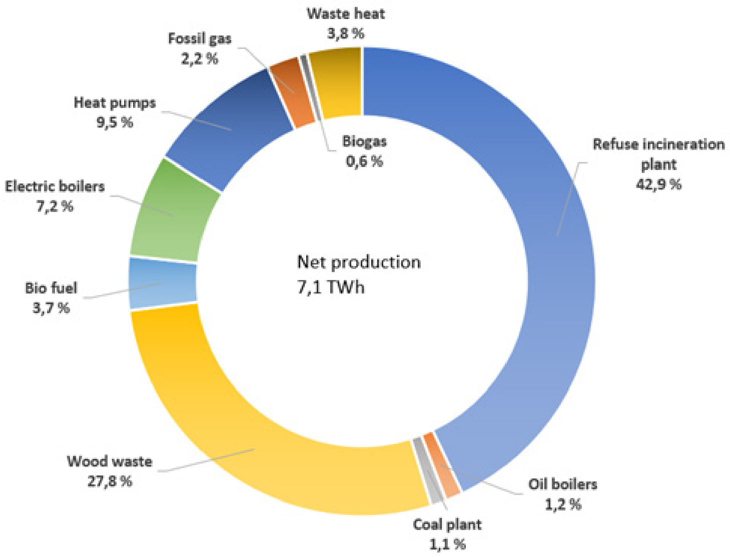


FIGURE 27. Net production of district heating, by type of heat central (GWh) 2022 (Statistics Norway 2023)

4.6 Summary

The figure below summarizes the results of this chapter. The present market share of large heat pumps in district heating systems in Nordic countries varies from 1.2 to 9.0 %.

The biggest percentage share of heat pumps in district heat production 9.0 % is in Norway. In Norway, also electricity boilers are used to produce district heat. Norway is an example of energy system largely based on electricity. Cheap electricity is produced with renewable sources (90 % with hydro power plants and 10 % with wind turbines). Houses are mainly heated with electricity (either directly or with heat pumps) and the share of district heating is very small only 10 %.

Sweden has been a forerunner in using large heat pumps in district heating production. But the main boom for their installation was the 1980s when the installed heat pump capacity for district heat production was 1,400 MW, and the share of heat pump produced district heat was almost 20 %. Since then, the share has declined. In the 1980s, in Sweden, electricity was produced mainly either with hydro power plants or with new installed nuclear power plants, and cheap surplus electricity was available to produce district heat with heat pumps.

In Finland, we have only started to invest in large district heating heat pumps some years ago, when Finland set a goal to be carbon neutral by 2035, and the target is to get rid of use of fossil fuels (coal and peat) in district heat production. It is not possible to replace all fossil fuels with biofuels, and that is why the use on waste heat, either directly or with heat pumps, is an attractive alternative. In a very short period, the share of large heat pumps in district heat production has increased to 3.8 %.

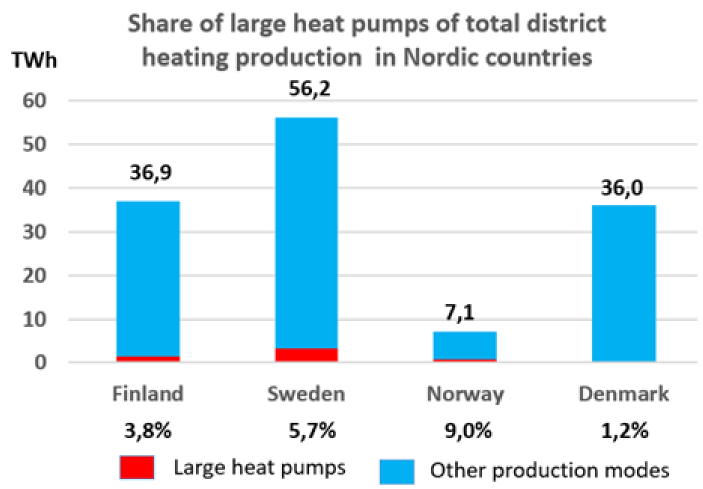


FIGURE 28. Share of large heat pumps of total district heating production in Nordic countries (data from each country’s statistic 2022)

In the following chapter, realized heat pump cases in Nordic countries are presented.

5 CASE STUDIES OF REALIZED DISTRICT HEATING HEAT PUMPS IN NORDIC COUNTRIES

Raquel Mier González

The Nordic countries, including Denmark, Finland, Iceland, Norway, and Sweden, experience cold climates, making heating a crucial aspect of their energy markets. To address this, they have adopted district heating as a key component of their sustainable energy systems. District heating offers efficient and sustainable heating solutions, helping to reduce dependence on fossil fuels, and contributing to the decarbonization and energy transition goals of these countries. (Patronen, Kaura & Torvestad 2017.)

In general, the Nordic countries have made substantial efforts to shift their district heating production towards renewable energy sources such as biomass, geothermal and hydropower. The utilization of heat pumps for district heating is prominent especially in Sweden, and in Denmark and Finland to a lesser extent. In the database of large-scale electric heat pumps with more than 1 MW thermal output in European district heating systems created by David, Vad Mathiesen, Averfalk, Werner and Lund (2017), 149 units and their main properties are listed. Most of the data for the heat pumps below have been gathered from the mentioned database, which is recommended for a more detailed information.

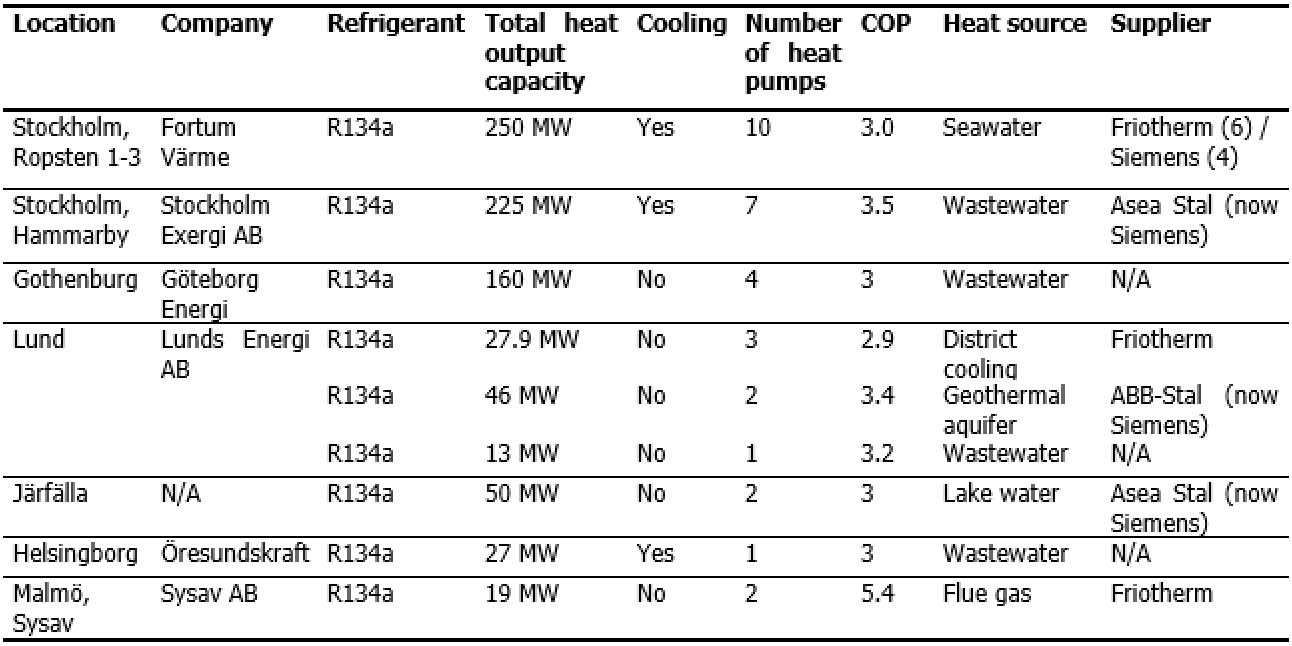
5.1 Sweden

In Sweden, industrial-scale heat pump plants have covered a significant part of the country's district heating since the 1980s; the share has varied between 7 – 30 % (Averfalk 2016, 1275-1284). In fact, Sweden is the leading Nordic country in terms of installed capacity of large-scale heat pumps in district heating systems with more than 1,200 MW installed (Euroheat & Power 2022). Table 17 shows several noteworthy examples of large-scale heat pumps integrated into Sweden's district heating systems.

The largest heat pump plant in Sweden is Ropsten plant, which is part of the Värtaverket district heating plant in Stockholm. Värtaverket is one of biggest plants for production of district heating, district cooling and electricity in Europe. Ropsten plant comprises 10 large heat pumps of over 20 MW each, that use seawater as a heat source to provide a total of 250 MW of heat. The plant also provides district cooling. Originally, the heat pumps were operating with refrigerant R22, but it was replaced by the more sustainable energy efficient refrigerant R134a. (Friotherm 2005b; David et al. 2017.)

Another example of successfully implemented large-scale heat pumps in Sweden is the case of Bahnhof Data Centres in Stockholm. Two large-scale heat pumps by Carrier are employed to provide chilled water for cooling the data centre and, at the same time, to provide hot water and heating to the buildings connected to the network. To achieve this, the heat pumps recover heat from the data centre that would otherwise be released to the atmosphere. (European Heat Pump Association 2020a.)

TABLE 17. Examples of large heat pumps in Swedish district heat production (Friotherm 2005a; Friotherm 2005b; Euroheat & Power 2017; David et al. 2017)

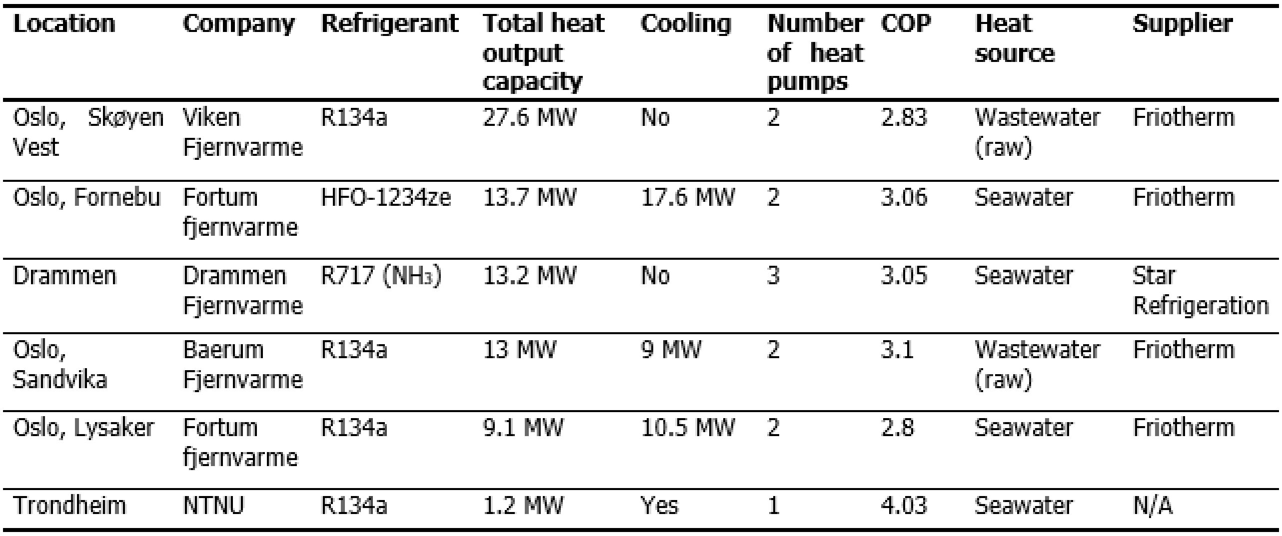


Location	Company	Refrigerant	Total heat output capacity	Cooling	Number of heat pumps	COP	Heat source	Supplier
Stockholm, Ropsten 1-3	Fortum Värme	R134a	250 MW	Yes	10	3.0	Seawater	Friotherm (6) / Siemens (4)
Stockholm, Hammarby	Stockholm Exergi AB	R134a	225 MW	Yes	7	3.5	Wastewater	Asea Stal (now Siemens)
Gothenburg	Göteborg Energi	R134a	160 MW	No	4	3	Wastewater	N/A
Lund	Lunds Energi AB	R134a	27.9 MW	No	3	2.9	District cooling	Friotherm
		R134a	46 MW	No	2	3.4	Geothermal aquifer	ABB-Stal (now Siemens)
		R134a	13 MW	No	1	3.2	Wastewater	N/A
Järfälla	N/A	R134a	50 MW	No	2	3	Lake water	Asea Stal (now Siemens)
Helsingborg	Öresundskraft	R134a	27 MW	Yes	1	3	Wastewater	N/A
Malmö, Sysav	Sysav AB	R134a	19 MW	No	2	5.4	Flue gas	Friotherm

5.2 Norway

In Norway, district heating does not play such an important role as it does in other Nordic countries, mainly due to the high availability of cheap electricity coming from its vast hydropower resources. However, statistics show that district heating is rapidly increasing. (Patronen et al. 2017.) In 2021, the installed capacity accounted for by large-scale heat pumps in district heating systems in Norway was 173 MW (Euroheat & Power 2022). Table 18 shows selected examples of these HPs.

TABLE 18. Examples of large heat pumps in Norwegian district heat production (Valor Partners 2016; David et al. 2017)



Location	Company	Refrigerant	Total heat output capacity	Cooling	Number of heat pumps	COP	Heat source	Supplier
Oslo, Skøyen Vest	Viken Fjernvarme	R134a	27.6 MW	No	2	2.83	Wastewater (raw)	Friotherm
Oslo, Fornebu	Fortum fjernvarme	HFO-1234ze	13.7 MW	17.6 MW	2	3.06	Seawater	Friotherm
Drammen	Drammen Fjernvarme	R717 (NH_3)	13.2 MW	No	3	3.05	Seawater	Star Refrigeration
Oslo, Sandvika	Baerum Fjernvarme	R134a	13 MW	9 MW	2	3.1	Wastewater (raw)	Friotherm
Oslo, Lysaker	Fortum fjernvarme	R134a	9.1 MW	10.5 MW	2	2.8	Seawater	Friotherm
Trondheim	NTNU	R134a	1.2 MW	Yes	1	4.03	Seawater	N/A

The largest heat pump plant in Norway is Skøyen Vest, located in Oslo. The plant comprises two large-scale heat pumps by Friotherm with a heating capacity of 18.4 MW and 9.2 MW, which have been in operation since 2005 and 2007, respectively. The heat pump units utilize raw wastewater as heat source to provide hot water for district heating at temperatures up to 90 °C. The heat pumps, which operate with R134a as refrigerant, have a total heating capacity of 27.6 MW. (David et al. 2017.)

Another good example of large heat pumps in DH in Norway is the district heating plant in Drammen. Since 2011, three large heat pumps with a total capacity of 13.5 MW provide hot water up to 90 °C for district heating using seawater from a nearby fjord as heat source. The fjord maintains a constant seawater temperature of approximately 8 °C at a depth of 18 metres throughout the year. The heat pumps generate about 67 GWh of heating annually, which covers the heating demand of about 6,000 homes. Currently, these heat pumps are covering 63 % of the municipality's district heating needs. However, a few years ago, when the heat demand was lower, the heat pumps covered up to 85 % of the district heating needs. (Sitra 2019a.)

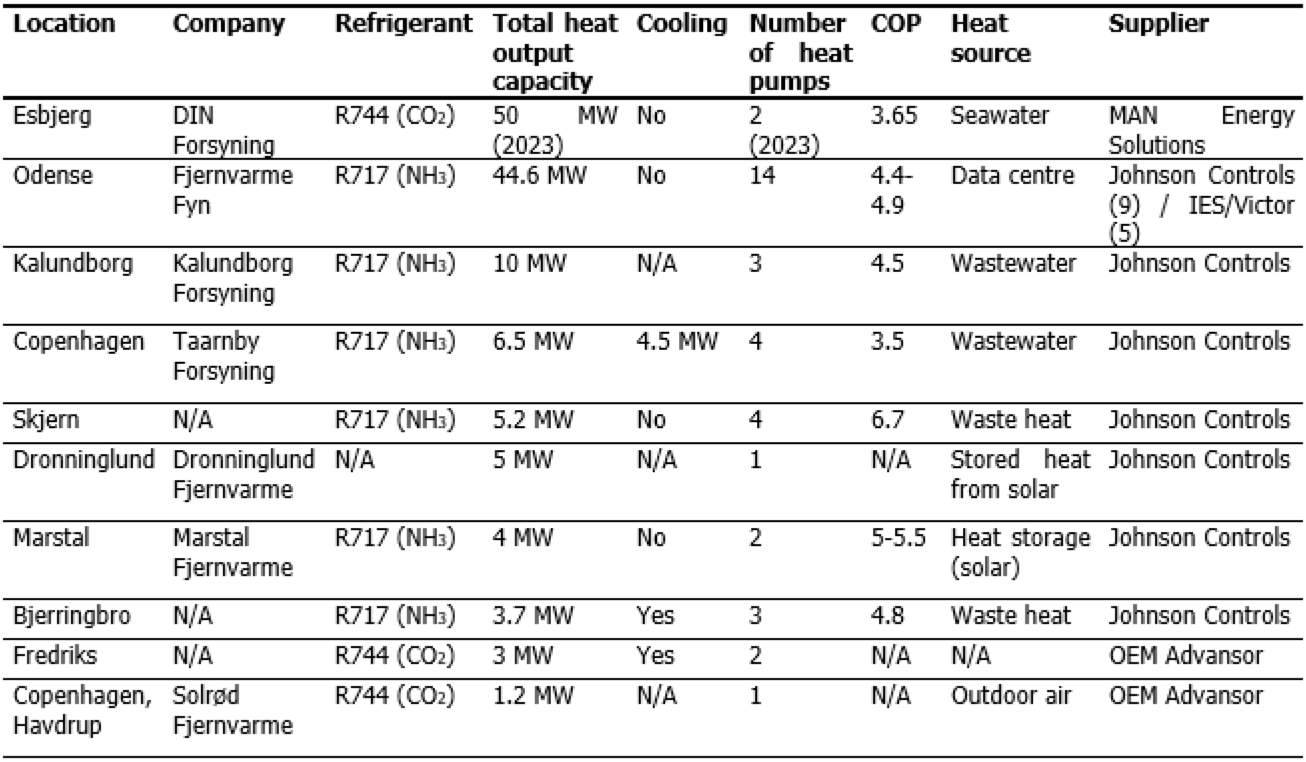
5.3 Denmark

Denmark is a global forerunner in district heating, with more than 60 % of the country's homes being heated with district heating systems. The energy sources for DH in Denmark include, among others, biomass, natural gas, waste, and coal. The heat pump share in Danish district heating systems has increased in recent years and is expected to continue growing as natural gas networks and coal are phased out. In 2021, the installed capacity accounted for by large-scale heat pumps in district heating systems in Denmark was about 440 MW (Euroheat & Power 2022). Table 19 shows several examples of these HPs. A more detailed overview of large heat pumps supplying heat to the Danish district heating is offered by the company PlanEnergi (2020).

Expected to be commissioned during 2023, the 50-MW electrothermal energy storage (ETES) heat pump system supplied by MAN ES in Esbjerg will be the largest heat pump plant in Denmark. The heat pumps, together with a 60 MW wood chip boiler and a 40 MW electric boiler for peak and backup load, will ensure an efficient and sustainable heat supply for about 25,000 households. The HP system works with CO2 as refrigerant and uses seawater to provide hot water at 50 – 90 °C for district heating. Additionally, the system is able to store the generated heat for later use. (Grøn Energi 2022.)

Another of the largest heat pump installations in Denmark is located within Fjernvarme Fyn district heating plant in Odense. It harnesses waste heat from Facebook's data centre to produce district heating water up to 75 °C in Tietgenbyen's heating centre (TBV). TBV-1, commissioned in 2019, comprises 9 screw compressor heat pumps with a total heating capacity of 23.9 MW and a COP of 4.4. TBV-2, commissioned in 2020, comprises 3 screw compressor heat pumps and 2 piston compressor heat pumps, with a total heating capacity of 20.7 MW and a COP of 4.9. All the heat pumps work with ammonia as refrigerant. The heat production of TBV covers about 11,000 households' consumption. (Grøn Energi 2022.)

TABLE 19. Examples of large heat pumps in Danish district heat production (David et al. 2017; Ammonia21 2021; Grøn Energi 2022.)



Location	Company	Refrigerant	Total heat output capacity	Cooling	Number of heat pumps	COP	Heat source	Supplier
Esbjerg	DIN Forsyning	R744 (CO_2)	50 MW (2023)	No	2 (2023)	3.65	Seawater	MAN Energy Solutions
Odense	Fjernvarme Fyn	R717 (NH_3)	44.6 MW	No	14	4.4-4.9	Data centre	Johnson Controls (9) / IES/Victor (5)
Kalundborg	Kalundborg Forsyning	R717 (NH_3)	10 MW	N/A	3	4.5	Wastewater	Johnson Controls
Copenhagen	Taarnby Forsyning	R717 (NH_3)	6.5 MW	4.5 MW	4	3.5	Wastewater	Johnson Controls
Skjern	N/A	R717 (NH_3)	5.2 MW	No	4	6.7	Waste heat	Johnson Controls
Dronninglund	Dronninglund Fjernvarme	N/A	5 MW	N/A	1	N/A	Stored heat from solar	Johnson Controls
Marstal	Marstal Fjernvarme	R717 (NH_3)	4 MW	No	2	5-5.5	Heat storage (solar)	Johnson Controls
Bjerringbro	N/A	R717 (NH_3)	3.7 MW	Yes	3	4.8	Waste heat	Johnson Controls
Fredriks	N/A	R744 (CO_2)	3 MW	Yes	2	N/A	N/A	OEM Advansor
Copenhagen, Havdrup	Solrød Fjernvarme	R744 (CO_2)	1.2 MW	N/A	1	N/A	Outdoor air	OEM Advansor

Another good example of heat pumps in DH in Denmark is Taarnby combined heating and cooling plant in Copenhagen. The plant comprises a chilled water storage tank and four heat pumps by Johnson Controls with a total cooling capacity of 4.5 MW and a total heating capacity of 6.5 MW. The heat pump system recovers heat from wastewater and, in a second project stage, also groundwater. The aquifer thermal energy storage (ATES) system utilising groundwater is expected to supply an additional 2.8 MW of cooling. (Ramboll 2020.)

Originally, Dronninglund solar district heating plant included a bio-oil boiler driven absorption heat pump by Danstoker with 5.2 MW of heating capacity and 2.1 MW of cooling capacity. In 2021, the absorption heat pump and bio-oil boiler were replaced by a compression air-to-water heat pump by Johnson Controls. The heat pump is able to switch over and utilize heat from the plant’s 60,000 m3 pit thermal energy storage which contains water heated by the solar panels during summer. (European Heat Pump Association 2021.)

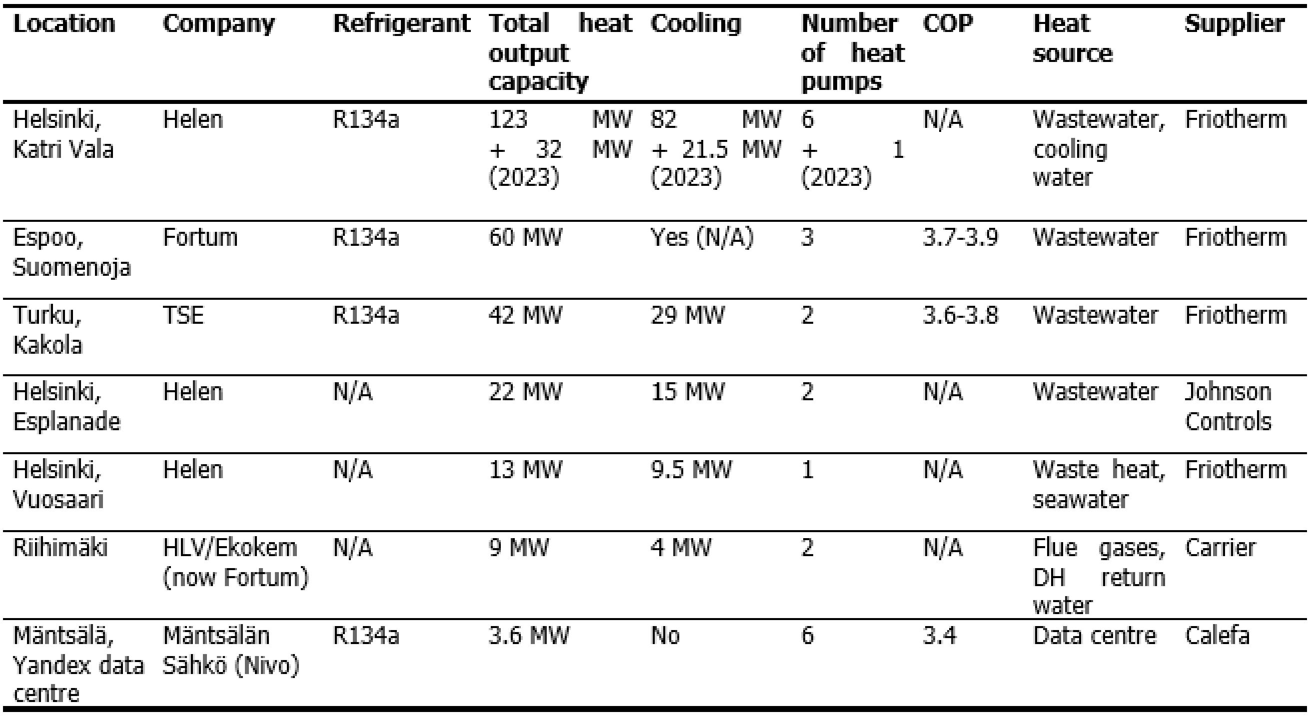
IKEA Aalborg replaced its traditional cooling system to a FENAGY H1200-AW heat pump with a chiller module for air conditioning. The new system supplies both climate-friendly district cooling to the warehouse itself and district heating to the citizens of Aalborg. The unit operates with CO2 as the refrigerant. (European Heat Pump Association 2022a.) At Danfoss's headquarters in Nordborg, oil-free water-to-water heat pumps by Danfoss are used to recover excess heat from the data centres to provide heating for the building. In 2024, the recovered heat will provide 25 % of the total heat supply for the 250,000 m2 headquarters. (Danfoss 2021a.)

FIGURE 29. MAN Energy Solutions (Image: © Sebastian Vollmert / MAN Energy Solutions)

5.4 Finland

District heating is the most common heating form in Finland. In 2020, the market share of district heating was 45 %. (Energiateollisuus ry 2022a.) The energy sources for DH in Finland include, among others, biomass, peat, natural gas, waste, and coal. The heat pump share in Finnish district heating systems has increased in recent years and as of 2021, the installed capacity accounted for by large-scale heat pumps in district heating systems was 262 MW (Euroheat & Power 2022).

TABLE 20. Examples of large heat pumps in Finnish district heat production (David et al. 2017; Helen Oy 2019; Teknologiateollisuus 2019; Isohookana 2020; Turku Energia 2022; Fortum 2023)



Location	Company	Refrigerant	Total heat output capacity	Cooling	Number of heat pumps	COP	Heat source	Supplier
Helsinki, Katri Vala	Helen	R134a	123 MW + 32 MW (2023)	82 MW + 21.5 MW (2023)	6 + 1 (2023)	N/A	Wastewater, cooling water	Friotherm
Espoo, Suomenoja	Fortum	R134a	60 MW	Yes (N/A)	3	3.7-3.9	Wastewater	Friotherm
Turku, Kakola	TSE	R134a	42 MW	29 MW	2	3.6-3.8	Wastewater	Friotherm
Helsinki, Esplanade	Helen	N/A	22 MW	15 MW	2	N/A	Wastewater	Johnson Controls
Helsinki, Vuosaari	Helen	N/A	13 MW	9.5 MW	1	N/A	Waste heat, seawater	Friotherm
Riihimäki	HLV/Ekokem (now Fortum)	N/A	9 MW	4 MW	2	N/A	Flue gases, DH return water	Carrier
Mäntsälä, Yandex data centre	Mäntsälän Sähkö (Nivo)	R134a	3.6 MW	No	6	3.4	Data centre	Calefa

Finland has significant examples of heat pumps in district heating systems, largest of them utilizing waste heat from wastewater. In table 20 are listed several plants that produce district heating and cooling with large-scale heat pumps. The largest of these plants is Katri Vala, in Helsinki, which has a district heating capacity of 123 MW and a district cooling capacity of 82 MW. After the installation of the seventh heat pump in 2023, the plant will have a district heating capacity of 155 MW and a district cooling capacity of 103,5 MW. The heat pumps, supplied by Friotherm, use treated wastewater and return water from district cooling as heat sources. (Helen Oy 2020.)

At Suomenoja power plant in Espoo, the energy company Fortum has installed 3 large-scale heat pumps with a total heating capacity of about 60 MW. The heat pumps utilize the waste heat from treated wastewater and, in summer, also seawater to produce district heating. In addition to this, the facility produces district cooling. The heat pump plant produces approximately 25 % of the heat demand of the entire district heating network. The units, supplied by Friotherm, work with R134a as refrigerant and have a COP of 3.7-3.9. (Fortum 2023.)

Also in Espoo, Fortum is installing Finland’s largest air-to-water heat pump plant at the existing thermal plant in Vermo. When completed in 2023, the plant will provide zero-emission district heating to residents of Espoo, Kauniainen and Kirkkonummi, as well as cooling for the nearby area. With a capacity of 11 MW, the plant will generate heat directly from the outside air and the waste heat of various properties. The project is part of the Espoo Clean Heat program, whose goal is to get rid of coal in the production of district heat by 2025. (Sweco 2022.)

FIGURE 30. Calefa heat pumps at Yandex data centre in Mäntsälä, Finland (Picture courtesy of Calefa Oy)

In Turku, Kakola heat pump plant has been excavated in the rock in connection with the Kakolanmäki wastewater treatment plant. The facility includes two heat pumps with a total heating capacity of 42 MW and a total cooling capacity of 29 MW. The heat pumps capture heat from the treated wastewater to produce district heating water at 85 °C. The heat pumps also produce district cooling. The units, supplied by Friotherm, work with R134a as refrigerant and have a COP of 3.6-3.8. The heat pump plant generates 302 GWh of heat annually, sufficient to meet the needs of 24,000 residents. The heat produced has largely replaced the burning of fossil fuels, resulting in an estimated reduction of 80 ktCO2 in emissions. (Sitra 2019c.)

Another successful heat pump project is the Yandex data centre in Mäntsälä. In 2015, six heat pumps by Calefa with a total heating capacity of 3.6 MW were installed. The heat pump system recovers waste heat from the data centre that would otherwise be released to the atmosphere and transfers it to the district heating network. The system significantly reduces CO2 emissions, lowering them by 11,000 tons annually. (David et al. 2017.) In 2018, the waste heat from the data centre covered 20 GWh or 54 % of Mäntsälä’s heat demand (Sitra 2019b).

In Puumala, the burning of oil and wood chips in the production of district heating has been reduced significantly since a heat pump plant by Calefa was installed in 2019. Consequently, the carbon dioxide emissions have drastically decreased. The facility (see its scheme in figure 31) also includes a solar thermal field and a thermal energy storage. Most of the plant's energy (75 %) is efficiently recovered from the outdoor air by the energy collector, and the rest of the heat is recovered by the solar collectors. The heat pump plant, with a heating capacity of 400 kW, feeds water at 80 °C into the district heating network. In addition, the plant also produces district cooling. The thermal battery can be used to buffer consumption peaks. (Lehtinen 2020.)

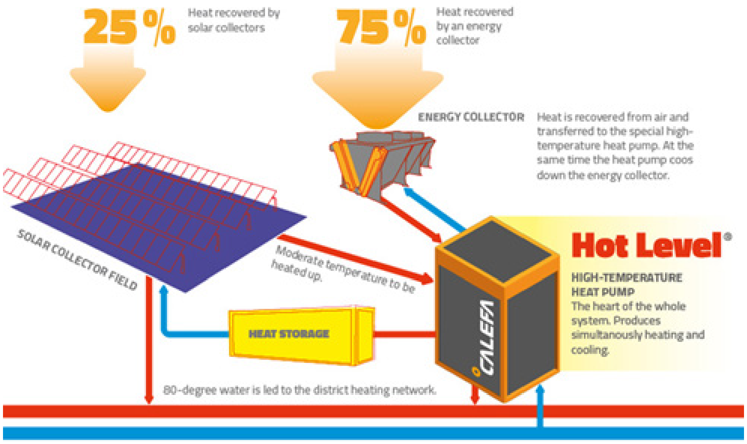


FIGURE 31. Schem of Puumala’s heat pump plant (Picture courtesy of Calefa Oy)

In Lahti, a 5 MW heat pump plant by Calefa uses excess heat from municipal wastewater to produce energy for the district heating network. The waste heat from the 9 °C wastewater at the Ali-Juhakkala wastewater treatment plant is processed into 90 °C heat for the district heating network. The solution significantly reduces the use of fossil fuels in district heat production, lowering carbon dioxide emissions by up to 1,700 tons per year. (Calefa 2023.)

An AmbiHeat heat pump plant, with a heating capacity of 3 MW, produces district heating for the 7,000 inhabitants of the district of Runosmäki in Turku since the end of 2022. By utilizing the energy of the outside air (-15 °C … +30 °C), Runosmaen Lämpö Oy will reduce its carbon dioxide emissions and significantly lower the energy prices to the residents of the area. The heat pump plant generates about 21 GWh per year. (Harmaala 2023.)

FIGURE 32. Energy collectors of Calefa heat pump system in Runosmaki, Finland (Picture courtesy of Calefa Oy)

In some cases, the heat and coolth produced by the heat pump is utilize for the customer company’s own use. For example, Calefa’s technology has been installed at Orion pharmaceutical factory in Turku for this purpose. An AmbiHeat heat pump plant, with a heating capacity of 1.5 MW, uses waste heat from Orion’s production processes in combination with energy obtained from the outdoor air, to produce heat up to 90 °C. This heat is used for the heating network of the factory as well as cooling for the cooling processes. Calefa’s solution reduces the carbon dioxide emissions of Orion up to 1,000 tons per year and decreases the need for purchased energy up to 70 %. (Calefa 2023.)

Another AmbiHeat heat pump plant was installed at the Kiilto chemical plant in Lempäälä in 2018. The system comprises two heat pumps: one recovers heat from the processes involved in glue manufacturing, wihle the other manages the geothermal energy storage and heat recovery. Initially, waste heat was exclusively utilized to heat the company’s own properties, and in wintertime natural gas served as an additional heat source. However, in 2022, Kiilto initiated a partnership with the energy company Lempäälän Lämpö. In summertime, the waste heat generated by Kiilto exceeds the factory’s demand, so the heat surplus is delivered to Lempäälä district heating network. In wintertime, Kiilto factory consumes Lempäälän Lämpö’s district heating from wood-based renewable energy sources, which reduces the factory's carbon dioxide emissions by approximately 310 tons per year. (Harmaala 2022.)

In the residential area of Postipuisto in Helsinki, an Oilon ChillHeat heat pump produces carbon-neutral heating and cooling for a new residential building. The heat pump utilizes as heat sources geothermal heat, wastewater heat recovery, condensates from refrigeration machines of grocery stores and cooling network. When the heat production exceeds the building’s demand, the surplus heat is delivered to the energy company Helen's district heating network. The geothermal system comprising 14 boreholes acts also as an energy store. Heat is extracted from the boreholes during the winter and re-charged during summer with surplus thermal energy. (European Heat Pump Association 2022b.)

5.4.1 North Savo

Markku Huhtinen, Raquel Mier González

Free Cooling Kuopion Energia

Kuopion Energia provides district heating and cooling services for the entire area of Savilahti, Kuopio. Over 70 % of the district cooling in this area is produced through a method known as “free cooling”, which utilizes cold water from a nearby lake. Free cooling method is very economical way to produce district cool compared to heat pump technology. COP for free cooling method is ~20, when it is calculated by comparing the produced district cool energy to electricity consumption needed to produce district cool i.e. to the electricity consumption of water pumps circulating lake water. The Savilahti district cooling plant, completed in 2020, has a nominal cooling capacity of approximately 30 MW, and a production capacity of 30 GWh per year. A water cooling machine and a 2.5 MW heat pump have been installed at the district cooling plant. Moreover, the plant has the option to install another 2.5 MW heat pump. (Lämpö kiertoon 2022a.)

CHC (Combined Heating and Cooling) container

To provide district cooling to an office building located within a kilometre’s proximity to the plant, a temporary solution was devised for the time that takes laying the district cooling piping there. A container was installed in close proximity to the building, accommodating a combined heating and cooling (CHC) plant consisting of two high-temperature heat pumps. The CHC plant has a heating capacity of 970 kW, a cooling capacity of 650 kW, and a combined COP of 4.8. The plant supplies cooling for the office building and transfers the excess heat from cooling to the DH network. (Oilon 2020.)

The CHC plant inside a 12-meter-long insulated container is a novel idea supplied by Oilon Oy. Its modular design enables quick delivery and easy relocation as needed. Additionally, the plant produces cooling and heating simultaneously, and it is very flexible in terms of temperatures, producing district heating water at temperatures of up to 120 °C. Moreover, the plant plays a key role in reducing CO2 emissions, making it an environmentally responsible choice. (Oilon 2020.).

FIGURE 33. The transferrable CHC plant by Oilon (Oilon 2020 & Oilon 2022c)

6 CHC (Combined Heating and Cooling) - installations in Kuopio

In areas with a district heating network, but no district cooling network, the cooling of blocks of flats and other large properties can be carried out in an energy-efficient and environmentally friendly way by CHC-technology by transferring the cooling waste heat to the district heating network with a heat pump. For example, in the Kuopio region, this has already been realized in six locations:

- Library/museum
- Valteri school
- Lumit art high school
- Niuvanniemi Hospital
- County government
- Courthouse

Oilon ChillHEAT heat pumps have been used in all sites, with a power range of 30 kW depending on the site's needs. In Kuopio, the combined cooling power of the heat pumps is 2,200 kW and the corresponding heating power is 3,295 kW. The heat pumps produce 10 °C cooling water to the cooling network of the building and 80 °C district heating water to the district heating network according to the flow chart below. The combined COP (Coefficient of Performance), when comparing the produced cooling power and district heating power to the consumed electrical power, is 5.

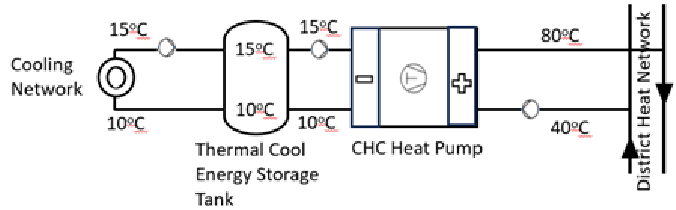


FIGURE 34. Flow chart of CHC (Combined Heat and Cooling) – heat pump

Several district heating companies all over in Finland offer this kind of service to their customers. It is possible to receive an offer from them including the connection fee, which covers the construction costs of the heat pump installation as well as the monthly power and energy fees, which are determined by taking into account the district heating energy recovered from the cooling produced in the district heating network.

Savon Voima Iisalmi power plant CHC-installation

At Savon Voima's power plant in Iisalmi, heat is produced with two fluidized bed boilers of 45 MW and 15 MW. In the spring of 2021, the operation of the plant was enhanced by the AmbiHeat heat pump plant. This industrial-scale heat pump system recovers the power plant’s heat from power plant cooling system and supplies it to the district heating network. Examples of devices in power plant process need to be cooled are generator, ash and sand conveyors from boiler, pressurised air producing compressors etc. The heat pump system has a heating capacity of 823 kW, a cooling capacity of 579 kW, and a COP of 3.37. During the summer, the system can be used as an air-to-water heat pump, with the former cooling fans working as energy collectors in the process. Thereby, 10 % of Iisalmi’s district heating is produced by the heat pump system from the energy of the outdoor air. (Lämpö kiertoon 2022b.)

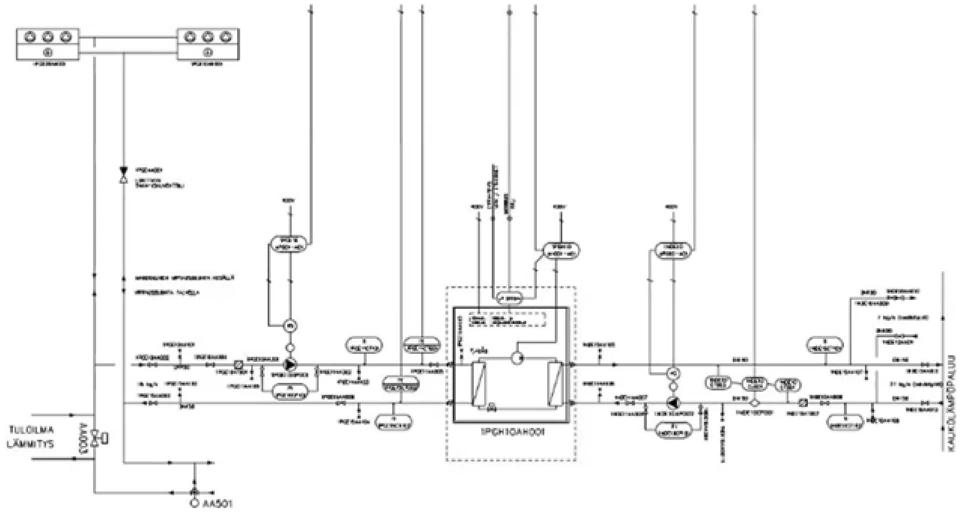


FIGURE 35. PID of the heat pump connection at Savon Voima’s power plant in Iisalmi (Picture courtesy of Calefa Oy)

Calefa Oy is the supplier of this complete heat pump system to Savon Voima’s power plant in Iisalmi. With this solution, temperatures of 90 °C suitable for the district heating network can be produced with good efficiency. This advanced heat pump technology allows the incorporation of low-grade heat sources and the reduction of CO2 emissions. The heat pump system reduces the power plant’s carbon dioxide emissions by 800,000 kg per year, which is a significant step towards Savon Voima's goal of producing carbon-neutral district heating by 2030. The value of the heat pump investment is 360,000€. (Lämpö kiertoon 2022b.)

The piping and instrumentation diagram of this case if presented in figure 35. The heat pump is installed in the power plant’s closed cooling circuit downstream of the flue gas scrubber. The district heating return water passes through the flue gas scrubber and then a small flow is directed to the heat pump. After being heated, this flow is returned before the power plant’s district heat transfer system. Additionally, some heat is recovered from the circulating oil within the two-phase compressor. The cooling circuit return water temperature is approximately 13 °C and is cooled down to 5 °C in the heat pump. (Huotari et al. 2022.)

Savon Voima Leppävirta ski arena and ice rink CHC- installation

Savon Voima has implemented an energy solution for the municipality of Leppävirta, which supports the municipality's goal of carbon negativity. The condensation heat obtained from the refrigeration equipment of the ski arena and the ice rink located in the Vokkola area will cover almost all the heat needs of the sports and accommodation facilities at Sport & Spa Hotel Vesileppis. Surplus heat is led to Savon Voima's district heating network, especially in summer. The whole CHC-installation has been implemented by Suomen Tekojää Oy. It is estimated that annual savings will be around €120,000 and accumulated savings during the entire life cycle according to the contract will be approximately €1.2 million. The municipality of Leppävirta invested about €1.5 million in equipment and has received about €250,000 in energy subsidy from Business Finland. About 10 % of the heating needs of the Leppävirta agglomeration area will be covered thanks to this project, which will reduce the amount of fuel to be burned from Savon Voima's district heating plant. (Lämpö kiertoon 2022c.)

FIGURE 36. Moomin Ice Cave in Vesileppis, Leppävirta (picture: Markku Huhtinen)

Timber drying with heat pumps

At UPM Korkeakoski sawmill, Calefa has implemented a solution to recover a large amount of heat from the timber channel drying kilns that was initially wasted. An AmbiHeat heat pump plant processes the waste heat from the exhaust ventilation air of timber drying process at approximately 55 °C into heat for the factory network at over 100 °C (max. 120 °C). The heat pump plant has a COP of 3.1, and a total heating capacity of 1 MW that can be expanded to 2 MW in the future. The solution provides significant additional power for the needs of the sawmill. Alternatively, the burning of wood chips for heat production can be reduced. In addition, during winter frosts, the drying capacity can be increased. (Calefa 2023.)

Timber drying with condensing heat pump

Condensing heat pump used for timber drying is the most common industrial heat pump application in the world (U.S. In the Department of Energy's publication Industrial heat pumps for steam and fuel savings). In Finland a representer of this technology is Kuopio-based company Tehoilma Oy, whose condensing dryers belonging to DRY-AIR brand have been used in Finland in small, so-called timber chamber dryers, where 30 – 80 m3 of timber are batch-dried. DRY-AIR drying products have been used not only in timber drying applications but also in various needs, from small dehumidifiers for laundry drying rooms to dehumidifiers for indoor ski halls and ice rinks.

Operating principle of the condenser dryer (see figure below):

As the warm air flows through the loads of lumber to be dried, it gets wet and cools. In a conventional dryer, the air is dried by leading moist air out and replacing it with a corresponding amount of dry outdoor air through heat recovery. In the condensing dryer, the moist, cooled air is led to the evaporator of the heat pump, where the air dries from condensing when the moisture in the air condenses on the cold surface of evaporator of heat pump. In the evaporator the heat released from condensing moisture is transferred to the refrigerant that evaporates at low pressure and temperature. The compressor of the heat pump raises the refrigerant pressure to the pressure of the condenser, and in the condenser the refrigerant condenses because of high pressure at a high temperature and the condensation heat is transferred to the air, which will be used to dry timber in channel kiln.

In the picture below, the condensing heat pump is placed in the channel kiln next to the existing heat production and air exchange. In this case, in an overheat situation (when the heat pump unit possibly produces too much heat into the drying kiln), part of the moisture removal can be carried out through ventilation, and on the other hand, when a new wet and cold timber pile is loaded to the drying kiln, the heating up of the drying channel kiln can be accelerated through the existing heat production.

Typically, the heating capacity demand of this kind of channel kiln, drying the timber from 50 – 60 % humidity to 15 % humidity, is 1 – 1.2 MW. It was calculated in HCIP-NS (Heat Circulation Innovation Platform – North Savo) – project case study that for the investment needed less than 5 years payback time is possible to reach.

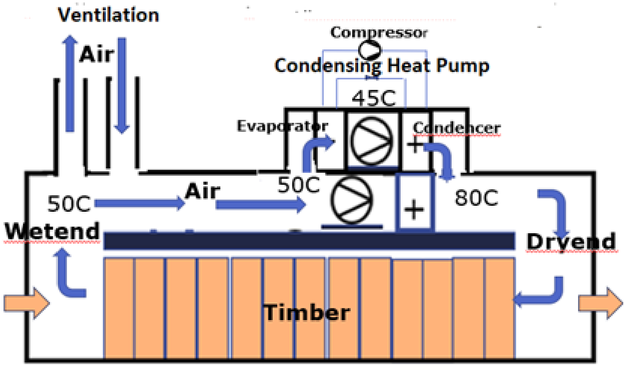


FIGURE 37. Condensing heat pump based in channel kiln of timber

SuomiValimo casting sand cooling and ventilation heat recovery

Within Heat Circulation Innovation Platform -project, a study was carried out at SuomiValimo foundry business. The main objective of this study was to identify potential waste heat sources within SuomiValimo's production facilities and explore feasible ways to harness this heat effectively. The company is connected to the local district heating network, consuming about 8,940 MWh yearly (as of 2021). Through waste heat recovery from ventilation and heating systems, an estimated 2,800 MWh per year could be recuperated. Considering the average district heat price, this would result in savings of €140,000 in heating costs per year. Regarding the casting sand cooling system, modifying the cooling system to a closed circuit, and recovering heat from the cooling water with a heat pump could add 1,100 MWh of heat power to the heating system. Also, it would reduce water costs. The projected payback time for the heat pump system with 210 kW cooling capacity is estimated to be 5 years. The total estimated savings would be 200,000€ per year. (Taskinen & Welin 2022.)

Savon Voima Oy produces district heating from the waste heat of Pakkasmarja Oy's cooling processess in Suonenjoki

Pakkasmarja Oy is a farmer-owned berry company that employs 250 contract farmer families in the area of Suonenjoki. Pakkasmarja Oy manufactures products from domestic cultivated and forest berries, which are available frozen all year round and fresh during harvest time in the frozen and fresh departments of stores and wholesalers. To produce cool creates a lot of waste heat. A small part of it can be used by Pakkasmarja Oy in its process for water heating but the main part of it is sold to Savon Voima Oy, who installed in 2022 a 200-kW heat pump for recovering the waste heat and to transfer it into the district network at a temperature of 75 °C.

6 HEAT PUMPS IN 5TH GENERATION OF DISTRICT HEATING AND COOLING

Raquel Mier González

Modern district heating systems started to emerge in the late 19th and early 20th centuries and have been evolving since then. District heating systems have been developing towards lower distribution temperature, thus, lower heat losses and higher efficiency. This development can be divided into generations, as can be seen in figure 38, from the first generation of district heating (1GDH) in 1880 to the fourth generation of district heating (4GDH) in 2020.

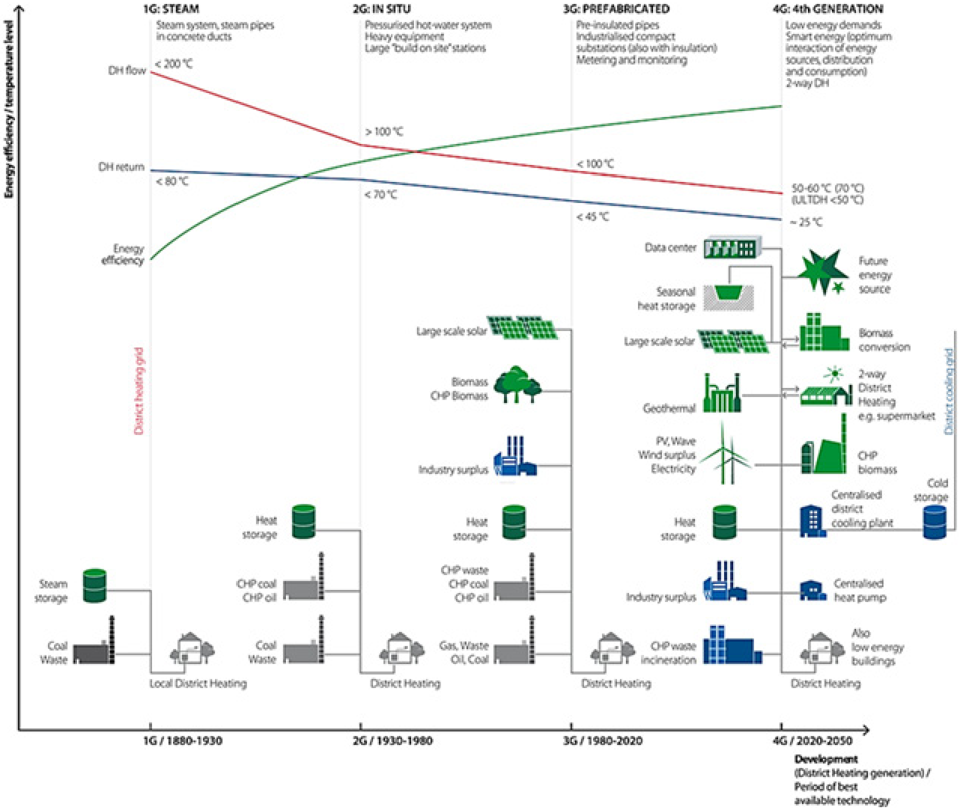


FIGURE 38. District heating generations (Lund et al. 2021), used under CC BY 4.0

The first generation of district heating networks were based on steam systems with temperatures between 100 – 200 °C. The first DH network of this type was established in New York in 1877. The second generation emerged in the 1930s with pressurized hot water at temperatures above 100 °C as heat carrier medium and the development of CHP plants. (Lund et al. 2014.)

The third generation, which was developed in the 1980s, was based on hot water systems with temperatures below 100 °C. The most significant difference regarding the previous generation is that the parts of the system were not built on site but were prefabricated and pre-insulated at the factory instead. Also, greener and renewable sources for DH generation were introduced. As a result of all these changes, the energy efficiency of the whole system increased. The fourth generation, which is currently being developed, aims to lower the distribution temperature at about 50 – 60 °C and increase the share of renewable sources. Also, centralized large-scale heat pumps are used for district heating production. These changes, together with the use of smart technology, make possible to obtain systems of even higher efficiency. (Lund et al. 2014.)

A novel district heating technology that operates at even lower temperatures than 4GDH, typically under 30 °C, is emerging. In the literature, different definitions and terms are applied to refer to the same concept, but the term 5GDHC is the most used in publications by different authors. It is expected that the development of this fifth generation of district heating and cooling (5GDHC) will be parallel to that of the fourth generation, i.e., the 5GDHC will not replace but complement the 4GDH (Lund et al. 2021).

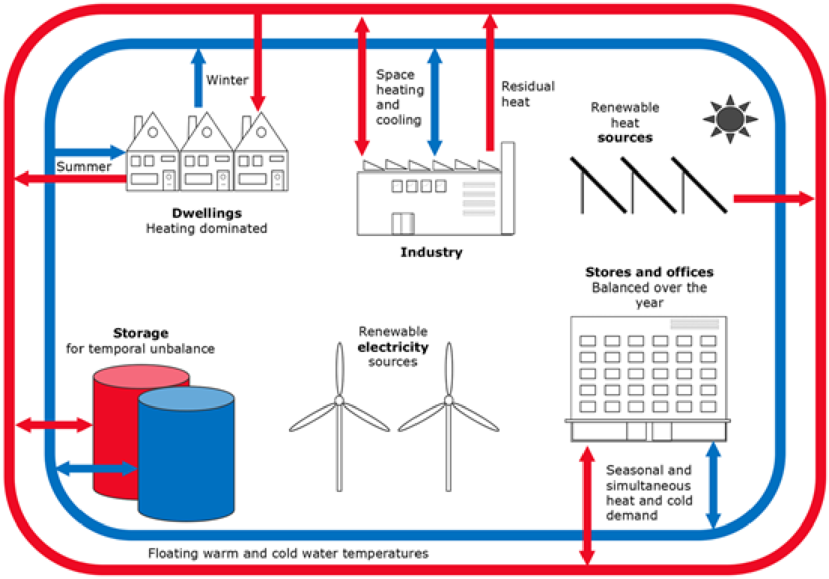


FIGURE 39. Diagram of a typical 5GDHC system (Boesten, Ivens, Dekker & Eijdems 2019), used under CC BY 4.0

Generally, the 5GDHC systems consist of a decentralized, bidirectional, low-temperature network. In principle, each customer connected to the network can operate as either consumer or producer of thermal energy and, therefore, is called a "prosumer". Thus, in 5GDHC networks there is a continuous exchange of energy flows within the own building and between the buildings connected to the network. For this to be possible, all the customers/buildings that are connected to the network use an own heat pump that raises the flow temperature to the required level for the building. This type of systems is suitable for places with similar heating and cooling demands. (Buffa, Cozzini, D'Antoni, Baratieri & Fedrizzi 2019.)

Within a 5GDHC system, different temperature levels can be distinguished: district level, building or block level, and individual level. As can be seen in figure 40, the temperature is upgraded as close to the end-user as possible to minimize heat losses. The district level comprises the pipe network, the long-term energy storage, and the energy sources. A heat pump and a buffer storage are located at the building station. Lastly, at the consumer level an optional booster heat pump can provide the necessary additional heating capacity to achieve sufficiently high temperatures for the domestic hot water (DHW) supply. (Boesten et al. 2019.)

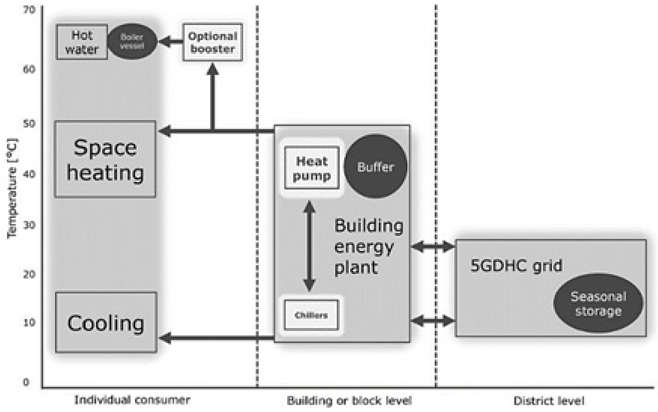


FIGURE 40. Levels of a 5GDHC system (Boesten et al. 2019), used under CC BY 4.0

Fifth-generation district heating and cooling systems include different designs and technical solutions. For instance, depending on the method for the heat extraction/rejection from/towards the thermal source they can be classified in open-loop systems or closed-loop systems. The networks can also be classified according to the number of pipelines in 1, 2, 3 or 4-pipe systems, with 2-pipe layout being the most common (figure 39). Another classification criterion is the energy flow direction and medium flow direction. (Buffa et al. 2019.) Nonetheless, the key elements of a typical fifth-generation district heating and cooling system can be summarized in (D2Grids s.a.; Buffa et al. 2019):

1. Ultra-low-temperature demand-driven two-pipe grid.

2. Distributed heat pumps.

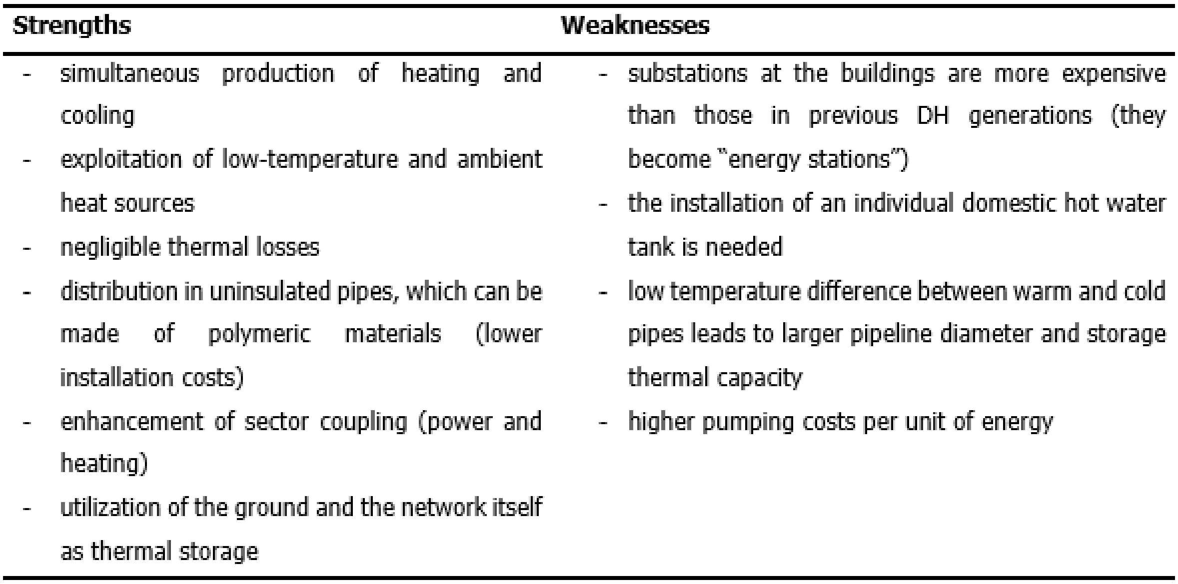
3. Storage of heat and cold.

A typical 5GDHC network operates at ultra-low-temperature that allows the incorporation of low-grade waste heat and low-temperature heat sources. The grid is demand-driven and comprises two thermal energy loops or pipes with warm and cold water designed to exchange energy. These pipes substitute the supply and return lines in the traditional district heating networks. The temperatures of the warm and cold water in the pipes are allowed to fluctuate freely, unlike in traditional DH networks, where supply temperature control is applied.

Instead of centralized heat pumps like in previous district heating generations, in 5GDHC systems decentralised reversible water source heat pumps (WSHP) are installed at the end-users. Typically, they are electrical driven heat pumps, and their size can vary depending on several factors, including the heating and cooling demands of the end-users, local climate conditions, and the available energy sources.

Both long-term and short-term storage are suitable for 5GDHC systems at district and building level, respectively, to balance the mismatch between supply and demand of heat and coolth. Small and distributed storage close to the end-users is also necessary in 5GDHC systems. Usually, a domestic hot water thermal energy storage is used to store the thermal energy at the energy station of the building. On the other hand, large and centralized storage, such as water tank thermal energy storage (TTES), aquifer thermal energy storage (ATES), borehole thermal energy storage (BTES) and pit thermal energy storage (PTES) are promising thermal energy storage (TES) technologies for 5GDHC systems. TTES systems are usually hydraulically connected to the grid directly or alternatively indirectly via heat exchangers. The separation of the warm and cold volumes within the tank is achieved by thermal stratification. The storage temperatures are the same as the warm and cold pipes of the network. The size of the TES depends on the temperature difference; the smaller the temperature difference, the larger volume is required to store the same amount of energy. (nPro s.a.)

TABLE 21. Strengths and weaknesses of 5GDHC (Buffa et al. 2019)



Strengths	Weaknesses
- simultaneous production of heating and cooling - exploitation of low-temperature and ambient heat sources - negligible thermal losses - distribution in uninsulated pipes, which can be made of polymeric materials (lower installation costs) - enhancement of sector coupling (power and heating) - utilization of the ground and the network itself as thermal storage	- substations at the buildings are more expensive than those in previous DH generations (they become "energy stations") - the installation of an individual domestic hot water tank is needed - low temperature difference between warm and cold pipes leads to larger pipeline diameter and storage thermal capacity - higher pumping costs per unit of energy

Although 5GDHC is at its early stages of development, Buffa et al. (2019) have already identified several advantages and disadvantages of these systems respect to traditional DH systems (table 21). The advantages include the possibility of producing heating and cooling simultaneously, the distribution in uninsulated pipes with negligible thermal losses, and the exploitation of low-temperature and ambient heat sources. Among the disadvantages stands out the higher costs of substations at the buildings, larger pipe diameters and higher pumping costs. (Buffa et al. 2019)

According to recent articles, the installation of 5GDHC systems has increased in the last years in Europe, especially in Switzerland and Germany, considered pioneer countries in this technology. It is estimated that in Europe there are more than 100 districts with a 5GDHC network, most of them pilot projects. A review of 40 existing cases of 5GDHC systems in Europe is presented in the article by Buffa et al. (2019). In this study, it was found that all the reviewed systems include electrically driven compression heat pumps installed at the substations.

The surveyed 5GDHC systems make use of a large variety of heat sources, with ground or groundwater serving as at least one of the heat sources in approximately 60 % of the systems. The temperature range of the sources varies from -5 °C to 35 °C. In cases where the temperature falls below the required threshold during certain periods of the year, centralized backup units have been installed. These backup units typically consist of gas boilers, water-source heat pumps, or air-source heat pumps. Many of these surveyed 5GDHC systems consist of two-pipe systems. The preferred long-term storage in these networks is a borehole field with vertical heat exchangers, where heat is stored at a low temperature. Despite the common features, each network can be considered unique in terms of loads and solution adopted. (Buffa et al. 2019.)

One of the largest and most advanced examples of a fifth-generation heating and cooling grid is Mijnwater in Heerlen, the Netherlands. Mijnwater operates at low temperatures of 18 – 28 °C and provides heating and cooling to 250,000 m2 of floor space including large office buildings, supermarkets, industry, and dwellings. This 5GDHC network operates 100 high performance heat pumps of 200 kW, and 100 booster heat pumps for domestic hot water. The network uses water in the abandoned mines under Heerlen for seasonal thermal energy storage. For short-term storage, thermal energy is stored in the buildings and hot water boilers. The heat is also stored in the water of the grid. (Mijnwater 2019.)

Heat pumps will play a key role in the district heating systems of the future, either as centralized heat pumps in 4GDH systems or as decentralized heat pumps in 5GDHC systems. As commented before, both 4GDH and 5GDHC are expected to coexist in the near future. The choice between these configurations depends on each specific project. Several factors need to be taken into account, such as the number of connections and their geographical distribution, the types of buildings connected and their heating and cooling demands, the amount of heat losses, the costs associated with installing heat pumps and heat exchangers, the costs associated with the distribution network, and the availability of heat sources (Peeters & Troch 2019).

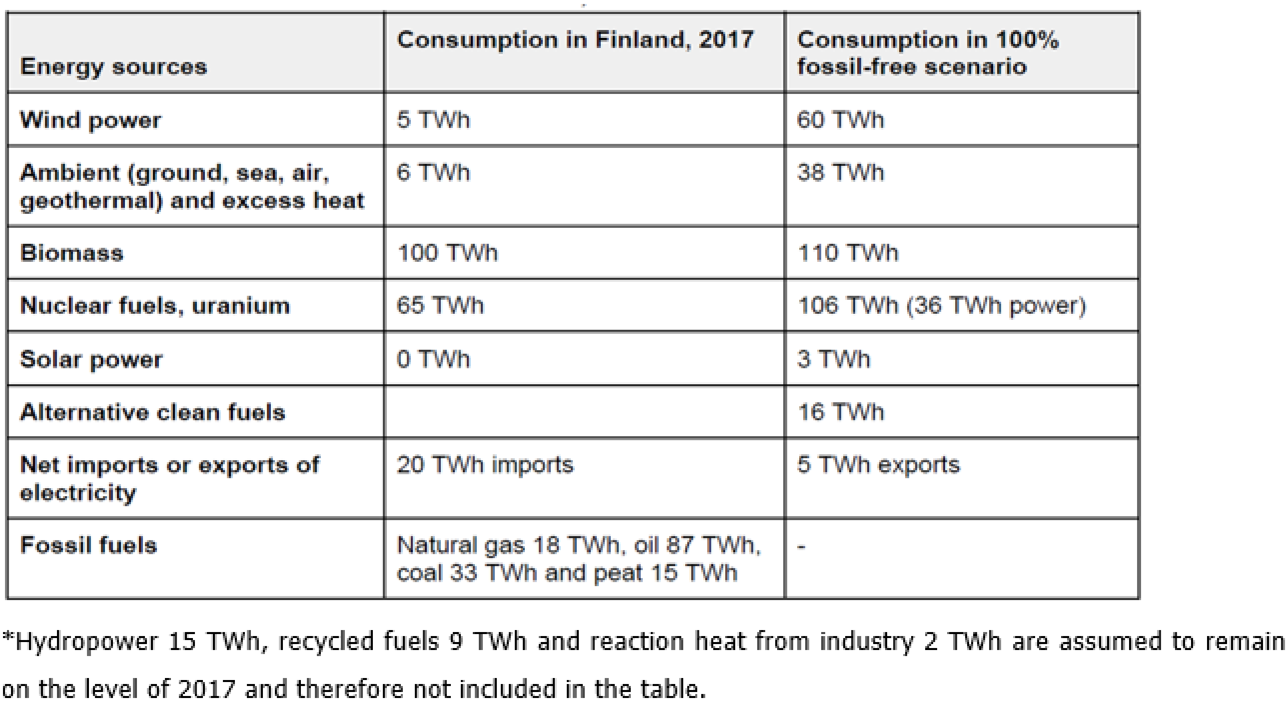
7 FUTURE POTENTIAL OF LARGE HEAT PUMPS IN DISTRICT HEATING

Markku Huhtinen

7.1 Fossil free scenario

Finland is committed to the goal of being carbon neutral by 2035 and the target is to get rid of use of fossil fuels (coal and peat) in electricity and district heat production. Aalto University has developed a fossil free scenario for Finland which was adopted as guiding scenario for HCIP-NS-project. The scenario is presented in the table below.

TABLE 22. The primary energy sources in Finland 2017 and in 100% fossil free scenario for comparison (Rinne et al. 2018.)



Energy sources	Consumption in Finland, 2017	Consumption in 100% fossil-free scenario
Wind power	5 TWh	60 TWh
Ambient (ground, sea, air, geothermal) and excess heat	6 TWh	38 TWh
Biomass	100 TWh	110 TWh
Nuclear fuels, uranium	65 TWh	106 TWh (36 TWh power)
Solar power	0 TWh	3 TWh
Alternative clean fuels		16 TWh
Net imports or exports of electricity	20 TWh imports	5 TWh exports
Fossil fuels	Natural gas 18 TWh, oil 87 TWh, coal 33 TWh and peat 15 TWh	-

*Hydropower 15 TWh, recycled fuels 9 TWh and reaction heat from industry 2 TWh are assumed to remain on the level of 2017 and therefore not included in the table.

In the fossil free scenario, all fossil fuels are replaced with other energy sources by:

- Increasing remarkably electricity production with wind turbine.
- Increasing remarkably use of ambient and excess heat.
- Increasing moderately use of biomass fuels.
- Increasing electricity production with nuclear power plant (compared to situation 2017).

- Increasing remarkably solar electricity production.

- Increasing remarkably production and use of alternative clean fuels.

As a side result, Finland will change its role from net importer of electricity to net exporter. In the following these items are examined more closely.

Wind energy production

Finland has already increased wind energy production with built wind turbines (the capacity of which was 7,000 MW at the end of 2023) to 14.5 TWh. By the year 2030, it is planned to increase wind turbine capacity to 18,000 MW as shown in figure 41. In 2030, wind turbines will produce 63 TWh with 3,500 h annual peak operation time, which is slightly exceeding the requirement in the fossil-free scenario.

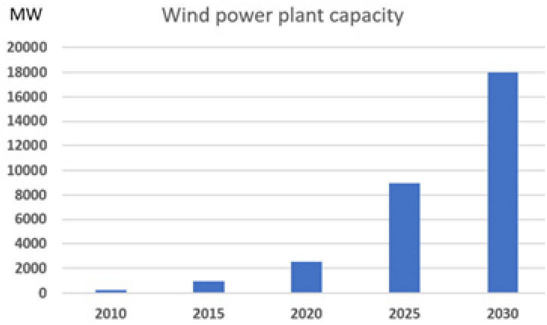


FIGURE 41. Increase of wind turbine capacity in Finland 2010 - 2030 (data from Suomen tuulivoimayhdistys)

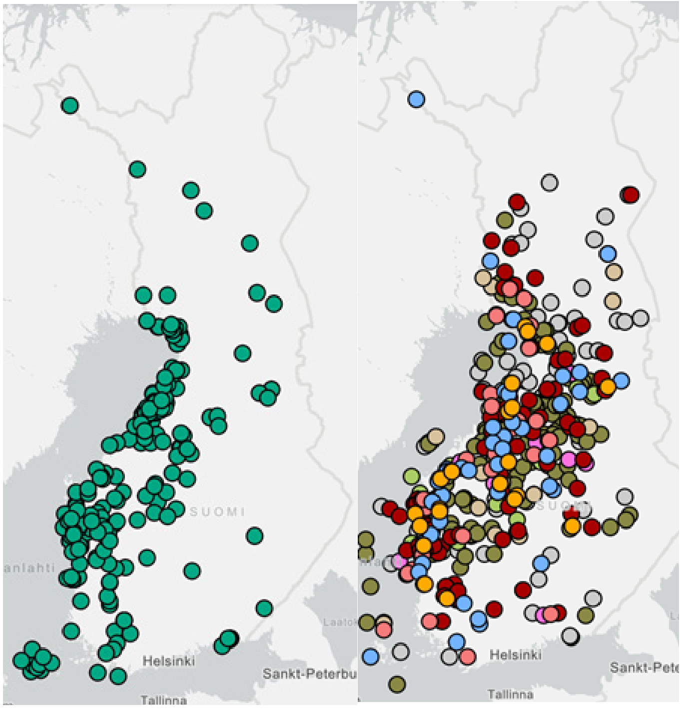


FIGURE 42. Installed wind turbines by 31.12.2023 altogether 7,000 MW (left) and projects in preparation (right) (Suomen tuulivoimayhdistys (STY))

Biomass

Biomass is an ideal fuel to be used in fossil free scenario. However, the increase of biofuels in fossil free scenario is only 10 TWh. This is due to concerns that the increasing use of wood in energy sector could make it difficult to obtain wood as raw material for industry. That is why the higher usage volume could lead to growing import, which is quite difficult in present situation, as wood imports have taken place mainly from Russia. In the future, wood will also be needed as raw material for liquid biofuel production processes. When the demand of biomass energy is increasing, there is also threat of increase of its price. (Afry 2021.)

Ambient and excess heat

In the fossil free scenario, it was presented that the use of ambient and excess heat should increase by 32 TWh from 6 TWh in 2017 to 38 TWh. It is estimated that about 130 TWh of waste heat is generated in Finland. The potential of technically reasonably utilized waste heat is estimated to be around 35 TWh (TEM s.a.). In the future, there will be even more waste heat available due to the increasing of the electrolytic production of hydrogen and data centers. So excess heat will be available even more than needed in fossil free scenario.

Nowadays, 4.5 TWh of excess heat is used, of which 3.5 TWh is so warm that it can be utilized with heat exchangers and 1 TWh is recovered by heat pumps. In the future, heat pumps will play a more significant role, when the temperature of waste heat sources is mainly colder than what is needed for heating purposes.

Future electricity consumption and production in Finland

In figure 43 is presented how electricity consumption is predicted to develop from 2020 to 2030.

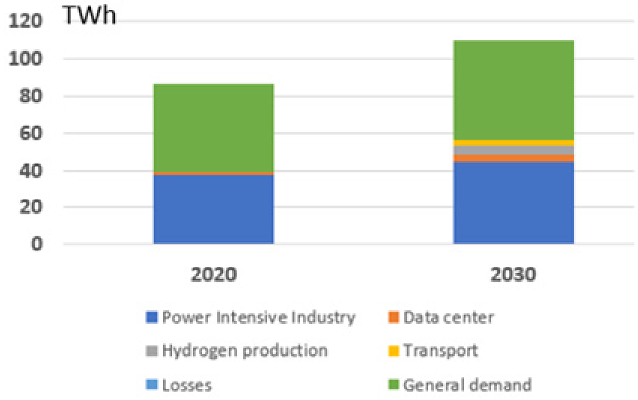


FIGURE 43. Electricity consumption in Finland in 2020 and 2030 (data from Statnett)

In year 2030, the main consumption sectors (power intensive industry and general demand (household, service and public sectors including heating) with 80 % of consumption remain the same as in 2020. But in 2030, there are also new consumption sectors transportation, data centers, and hydrogen production with the share of 9 %.

In figure 44 is shown how electricity production is expected to develop from 2020 to 2030.

- Hydro power production is estimated to remain at same level (14 TWh).

- Solar electricity is estimated to rise from almost zero to 1 %.

- Electricity production with nuclear power plants is calculated to increase with the production of Olkiluoto 3 unit.

- Wind energy production is estimated to grow to 63 TWh, as explain earlier.

- Other production, mainly district heating and industrial CHP-power plants, is expected to remain about same (so that the production of DH CHP-plant will decrease a little bit and the production of industrial CHP-plant will raise by the same amount).

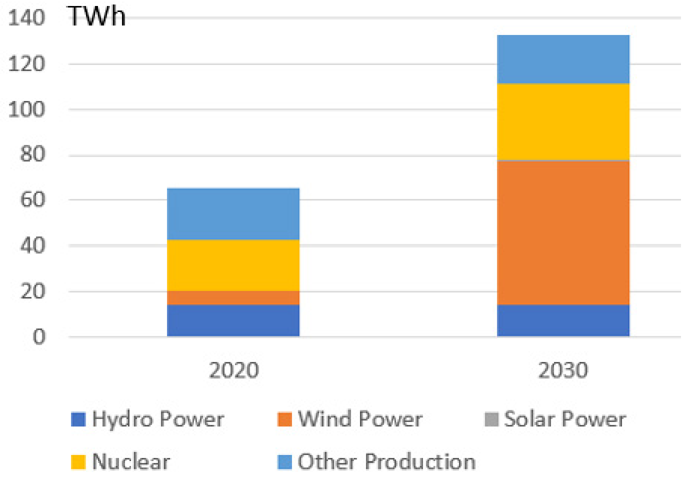


FIGURE 44. Electricity production in Finland now 2020 and 2030 in fossil free scenario

Figure 45 presents a summary of figures 43 and 44 of how electricity demand and production will change between the years 2020 and 2030. In 2020, Finland needed to import 21 TWh to satisfy the electricity need, but by the year 2030, the situation will change so that in Finland it is produced more electricity than is needed and 25 TWh can be exported abroad.

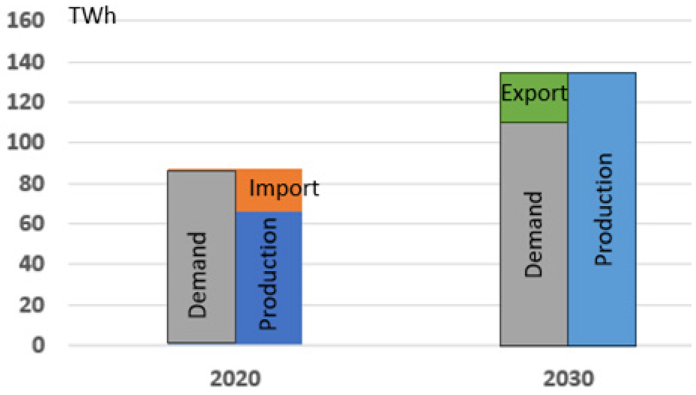


FIGURE 45. Development of electricity balance (import/export) in Finland 2020 to 2030

7.2 Changes in district heating sector

The district heating sector has already experienced a massive change when the use of coal, natural gas and oil, as well as peat, has been reduced. Biofuels and waste heat recovery with both heat exchangers and heat pumps have been increased. This trend will continue, but even bigger changes are expected.

Finnish combined heat and power generation (CHP) has been an efficient way to produce electricity and heat. However, the low electricity price has made joint production less profitable. That is why no new CHP-investments have been done during last years.

It is expected that the demand of district heat will not grow, and it is also assumed that the majority of district heating cogeneration plants will be replaced at the end of their service life with separate heat production, and partly with non-combustion-based heat production, as well as a wider utilization of flue gases and other waste heat.

When there is a high wind energy production and the electricity price is therefore low, the district heating sector’s electric boilers and heat pumps can produce heat that can either be used immediately or directed to thermal storage and used for later heating. The district heating system can thus be seen as a huge energy storage system where "overpro¬duction" of electricity can be stored. On the other hand, when the electricity price is high, the district heating sector can turn off its electricity-consuming units and produce electricity at thermal CHP plants. In this way, district heating can contribute to solving the challenges in the electricity market.

Figure 46 presents a prediction for energy sources for district heat supply in 2030. The prediction is based on the following assumptions:

- The total amount of produced district heat is 38 TWh (TEM).
- District heat produced with heat pumps is 5 TWh (Afry 2021).
- The use of direct waste heat remains at the same level as in 2022.
- The use on municipal waste remains at same level as in 2022.
- Electricity boilers produce 5 % of district heat.
- The rest of fossil fuels is replaced with biofuels.

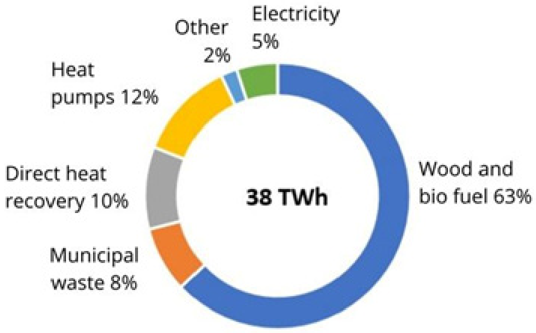


FIGURE 46. Prediction for energy sources for district heat supply in 2030

According to figure 46, 4.6 TWh of district heat would be produced with heat pumps in 2030, which is three times more than at present. The total capacity of heat pumps would raise from the present value 300 MW to 1,000 MW.

8 CONCLUSIONS

Markku Huhtinen, Raquel Mier González

Large heat pumps, when combined with heating and cooling networks, offer a critical solution for decarbonizing the European heating market. Their integration with district heating systems allows the efficient utilization of renewable electricity, balancing energy production, and tapping into sustainable heat resources. These systems allow the harnessing of renewable heating resources, including geothermal, solar thermal and ambient energy, as well as recovered waste heat from various sources such as urban environments, industrial processes, and sewage water treatment facilities. (Euroheat & Power 2022.)

Presently, large heat pumps represent around 1 % of the total capacity in heating and cooling networks in the EU, primarily located in countries with high electrification rates like Sweden and Denmark. Based on investment plans, the installed capacity for large heat pumps is expected to increase by at least 80% by 2030. (Euroheat & Power 2022.)

In Nordic countries, the share of heat pumps used in district heat production is much larger than in Europe generally. For example, in Finland the share of heat pumps in district heat production in 2022 was 3.8 % and in Sweden 5.7 %.

In 4th generation district heating system, which is currently being developed, the aim is to lower the distribution temperature and increase share of renewables and waste heat either directly or with heat pumps in district heat production. Expanding district cooling networks, increasing number of data centres and in near future also PtX-plants increase amount of available waste heat.

District heating systems with increasing amount of electricity boilers, heat pumps and large thermal energy storage systems and with existing CHP-plants can efficiently balance the electricity production alternations of wind and solar electricity.

According to the fossil free scenario used in HCIP-NS-project, it was estimated that all fossil fuels used 2022 in Finland to produce district heat could be replaced either with biofuels or with electricity boilers or heat pumps using surplus electricity produced with wind turbines. The share of large heat pumps in district heat production would be in fossil free scenario in Finland in 2030 12 %, and the installed capacity of heat pumps in district heat production would rise from 300 MW (2022) to 1,000 MW (2030).

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Appendix 1. Denmark's heat supply