Inspirational catalogue

for large heat pumps

October 2022

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Preface

This inspiration catalog is a supplement to the inspiration catalog which was published in 2017 on behalf of the Danish Energy Agency. The inspiration catalog contains descriptions of specific applications of heat pumps in Danish district heating systems. The focus of the inspiration catalog is to show the various possible uses for heat pumps, as well as to focus on the many different heat sources a heat pump can use. In this supplement, detailed descriptions of three new cases have been added.

- Kalundborg forsyning, waste water
- Fjernvarme Fyn, excess heat data center
- DIN Forsyning, seawater

The inspiration catalog comes with a handbook. The handbook and inspiration catalog can be read as separate documents.

The target group for the handbook and inspiration catalog are primarily district heating plants (operating managers, directors and boards) and heating planners in the municipalities. They will also be able to function as a useful tool for advisers, suppliers of energy systems as well as people and companies interested in heat pumps.

A decisive parameter in relation to heat pumps is which heat sources are available. That is why the inspiration catalog focuses on including different heat sources. The different types of heat sources are also described in **chapter 2** of the handbook.

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1. Introduction

This inspirational catalogue supplements the "Inspirational catalogue for large heat pump projects in the district heating system". The inspirational catalogue describes commissioned heat pumps in Danish district heating systems with the aim of making experiences with heat pumps more accessible to the industry and thereby contributing to an increased spread of heat pumps in the district heating system. The inspirational catalogue contains detailed descriptions of some Danish heat pump projects. The descriptions follow the same template to make the descriptions clear and easy to compare. The detailed descriptions include:

- Background
- Information about the system
- Operating experiences
- Organization/ownership
- Technology and specifications
- Budget and finances

The examples are described as briefly as possible, focusing on technical and economic conditions in each case. In order for the examples to best describe the economic conditions in a comparable way, standardized electricity and fuel prices have been used as far as possible. These prerequisites are shared with the assumptions used in the corresponding “Handbook”. In reality, electricity and fuel prices vary in individual cases, and the examples therefore do not show the exact economy of the solutions, but give an image of how the economy will be under the given assumptions.

In addition, emphasis has been placed on describing some of the most important experiences from the implementation of the heat pump projects. This provides an exchange of experience which can be valuable for future heat pump projects.

The inspirational catalogue covers a wide range of heat sources and heat pump types, and it focuses on the concrete figures and experiences from the descri-bed cases. Table 1.1 gives an overview of the heat pump systems which are described in detail in the inspiration catalogue.

Case	Size [MW]	Heat source	COP	Heat production price [DKK/MWh]	Investment [mio. DKK]	Simple repayment period [years]
Fjernvarme Fyn	19	Surplus heat	4,4		215	
Kalundborg Forsyning	10	Sewage	4,5	156		2,7
DIN Forsyning	50	Seawater	3,7	Not disclosed	Not disclosed	Not disclosed

2. Cases

2.1 Fjernvarme Fyn – Surplus heat pump

2.1.1 Background

Fjernvarme Fyn works purposefully to phase out fossil fuels used for district heating production and thereby reduce CO_2, and it has been decided to phase out the coal-fired plant by the end of the first quarter of 2023.

With Facebook establishing its data center in Odense, Fjernvarme Fyn had the opportunity to produce district heating on a heat pump system based on excess heat from cooling the servers at Facebook's data center.

The dialogue on the utilization of excess heat from Facebook was initiated in 2015 and the agreement signed in mid-2017, after which the construction of Tietgenbyen's heating center (TBV) began in 2018.

District heating plant	Tietgenbyen's heating center, TBV-1
Contact Person	Kenneth Jensen - Fjernvarme Fyn
Adviser	Rambøll
Heat pump supplier	Johnson Controls
Type	9 pcs. screw compressors on ammonia, fabr. Frick/JCI
Installation year	2019
Annual number of full load hours	5.000-7.000
Heat source	Surplus heat from data center
Nominel heat output	23,9 MW
Nominel COP	4,4
District heating is heated from-to	40-75°C
Heat source cools from-to	27-15 °C

District heating plant	Tietgenbyen's heating center, TBV-2
Contact Person	Kenneth Jensen - Fjernvarme Fyn
Adviser	Rambøll
Heat pump supplier	IES/Victor
Type	3 pcs. screw compressors + 2 pcs. piston compressor on ammonia. Factory Mayekawa MYCOM
Installation year	2020
Annual number of full load hours	5.000-7.000
Heat source	Surplus heat from data center
Nominel heat output	20,7 MW
Nominel COP	4,9
District heating is heated from-to	40-75°C

Tietgenbyens's heating center (TBV).

2.1.2 Systems

Fjernvarme Fyn supplies heat to more than 100,000 homes, industrial companies and institutions in Odense and the surrounding area. The production from Tietgenbyen's heating center covers approx. 11,000 households' consumption.

The annual heat production at Fjernvarme Fyn is approx. 160,000 MWh, of which Tietgenbyen's heating center supplies approx. 7%. Fjernvarme Fyn is responsible for the day-to-day operation of Tietgenbyen's heating center.

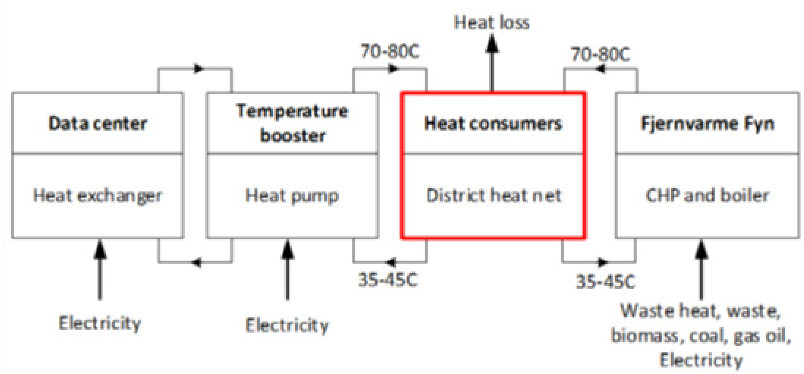


Figure 1: The structure of the heat pump plant and interaction with other production plants.

Fjernvarme Fyn produces, in addition to heat from TBV district heating, the following facilities:

- Gas boilers:
    Decentralized gas and oil boilers at heating centers within the supply area
- KV-system:
    - Coal: FYV 7 (Fynsværket block 7): Heat 490/610 MW + electricity 322/376 MW
    - Halm: FYV 8 (Fynsværket block 8): Heat 88/120 MW + electricity 32 MW
    - Waste: FFA: Heat 105 MW + electricity 20 MW
- Wood chips: DKV (Dalum Kraftvarme): Heat approx. 42 MW + electricity approx. 7 MW
- Electric boilers: 100 MW
- Heat pumps: Approx. 95 MW
- Surplus heat: From several smaller suppliers
- Accumulation capacity: 75,000 m³

Varmecentralen har egen 60 kV forsyning fra Fraugde med følgende transformeranlæg:

- 1 transformer for 60/10 kV
- 5 transformere for 10 kV for 400 V and 690 V respectively

TBV is directly connected directly to the distribution network and they are primarily consumers who are connected to this part of the district heating network which is supplied with waste heat from Facebook.

During periods when the heat pumps are not in operation, they are supplemented with heat from the other production facilities which are connected to the district heating system.

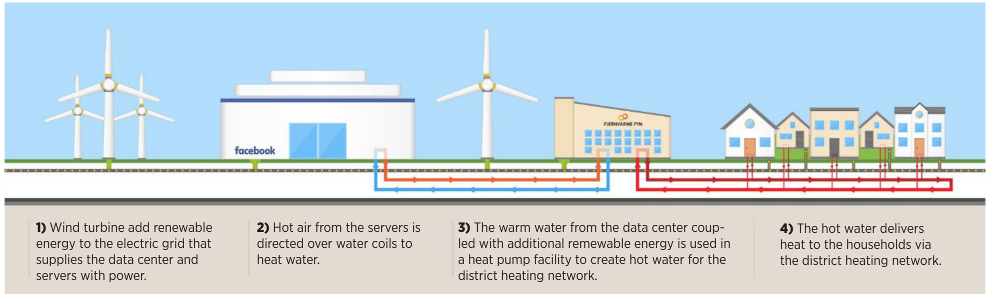


Figure 2: Principle for Tietgenbyen's Heating Center's recovery of surplus heat from Facebook.

2.2.3 Operating experience

- • The plant is largely available for operation all the time, but there have been quite long periods when capacity has been reduced as a result of the heat pumps being out of service.

- Occasionally the heat pumps fail due to technical problems, but they can usually be restarted quickly.
- The operational stoppages have been in connection with the start-up and running in of the plants caused by liquid impact in compressors, dirt in the ammonia system, leaking packing boxes in the oil system due to high ammonia pressure, faults in couplings. These startup problems are being solved. The heat pump system is relatively sensitive to changes in the temperature of the heat source from Facebook (the cooling water) and this is due to the fact that demands have been made on the flow temperature of the cooling water after the heat pump.
- Cooling water as a heat source can cause condensation at certain times of the year on cold pipes, which was solved by insulating them from condensation.
- Over the spring/summer of 2022, the high electricity prices have played a large role in relation to how much district heating the heat pumps must produce in relation to choosing other and cheaper units instead.
- Below is the average excess heat output (MW) that has been run on TBV from 2020 onwards. The district heating produced is approx. 30 percent higher than the values in the figure.
- The average COP for 2021 and 2022 has been 4.2 as a total calculation including circulation and distribution pumps.

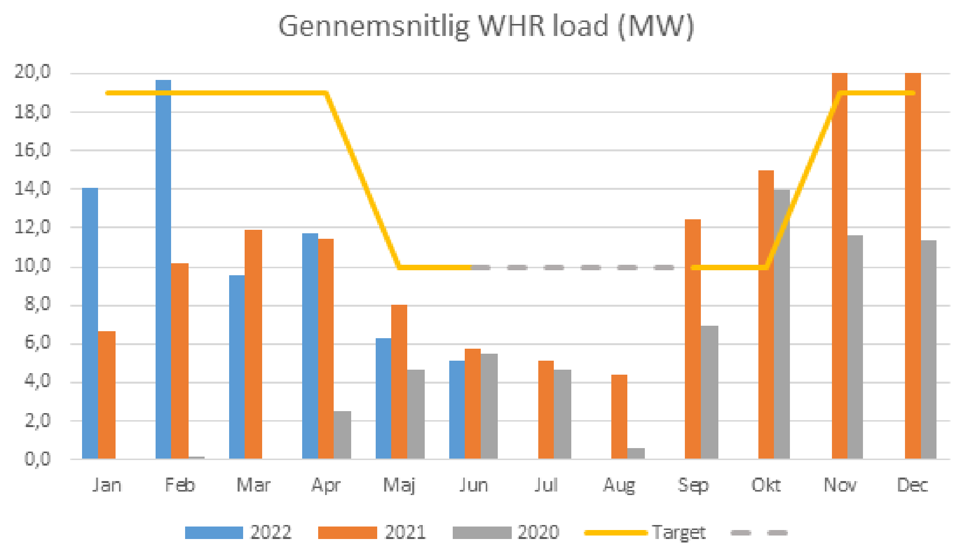


Figure 3: Average excess heat output from Facebooke before the heat pumps' temperature utilization.

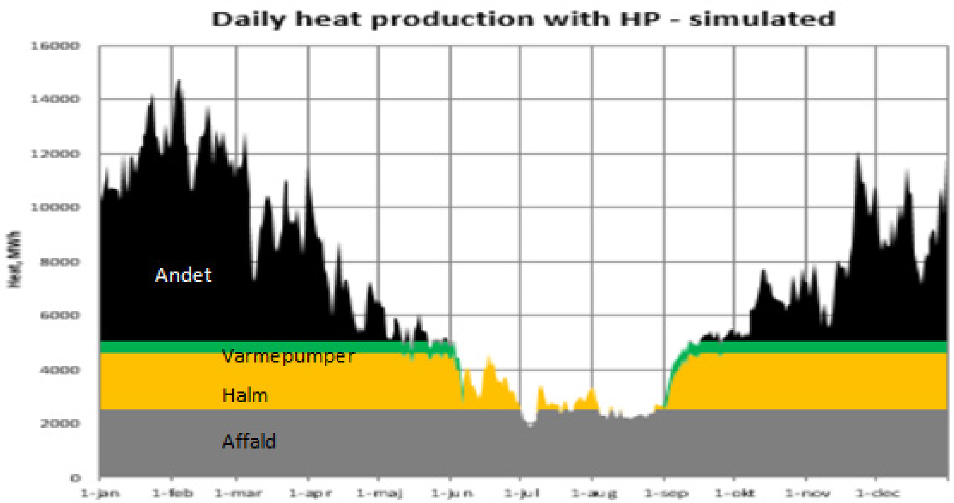


Figure 4: Annual operational profile with the distribution of heat production (MWh) on a daily basis/ fuels.

JCI compressors on TBV1.

MYCOM compressors on TBV2.

- Estimates for a future operating profile are difficult to predict, and District heating Funen currently works on the basis of the assumptions outlined in the green area in the graph below.

- Factors such as climate, electricity and fuel prices, revisions/availability of the other facilities will also have an impact on the operating profile.

2.1.4 Organization/ownership
The data center is owned by Facebook.

Tietgenbyen's heating center is owned and operated by Fjernvarme Fyn.

2.1.5 Budget and finances
Total capital investment for the two heat pump systems amounts to DKK 215 million. (TBV1 and TBV2).

2.2 Kalundborg Forsyning – Waste water heat pump

Due to the large concentration of industrial companies in Kalundborg, the waste water in the area is warmer than normal and therefore particularly interesting in relation to heat pumps.

In connection with Asnæsværket being rebuilt and converted to biomass, Kalundborg Forsyning has installed Denmark's largest heat pump plant at the time with an output of 10 MW heat. The plant utilizes the energy in the city's waste water.

Heat sourceeating plant / Contact person	Kalundborg Forsyning / Charlotta Værnstrøm
Supplier	Johnson Controls
Type	3 parallel sets of 2 pcs. serially connected DualPac ammonia heat pumps with 4 compressors each and 12 compressors in total.
Year of installation / annual number of operating hours	2017 / approx. 8,000 full-load hours/year (until Asnæsværket is completely rebuilt).
Varmekilde	Purified waste water
Nominel heat output	10 MW
Nominel COP	4,5
District heating is heated from to	57-72 °C
Heat source cools from-to	25-15 °C

2.2.1 Background

Kalundborg Forsyning has needed a replacement and upgrade of the network's peak load capacity, which previously consisted of a number of older oil boilers. Since Asnæsværket had to be rebuilt at the same time and the capacity from here will therefore be limited, it was chosen to invest in the heat pump system. This increases the peak load capacity, and the plant will, until the biomass conversion is completed, get a large number of operating hours. The heat pump acted as a base load unit until Asnæsværket was finished converting to wood chips, which was completed at the end of 2020. During this transition period, the heat pump provided significant operating savings. Therefore, the plant was established in about 6 months, which was very fast for this type of plant.

Due to the large concentration of industrial companies, Kalundborg has an annual waste water volume of 6 million. m3, and at the same time the waste water is approx. 10 °C warmer than in typical sewage treatment plants. In Kalundborg, the waste water is on average 25 °C, but varies throughout the year from approx. 15 °C in the winter period and up to 30 °C in the summer months. The higher temperature makes utilization of the heat source particularly relevant in Kalundborg.

2.2.2 Systems

supplies district heating to around 5,000 households and around 10 large consumers. The total heat production amounts to around 250,000 MWh. Until the conversion of Asnæsværket was completed, the heat pump produced around 80,000 MWh. After this, heat production at the heat pump plant fell to approx. 25,000-60,000 MWh depending on the electricity price.

The heat pump is connected to the transmission system in Kalundborg, which is why the temperature levels are relatively high. Special efforts are being made to reduce the return temperature, and it is expected that the inlet to the heat pump may eventually fall below 45 °C. After the rebuilding of Asnæsværket, the load distribution has changed and is dependent on current fuel and electricity prices. In hours when there is co-production at Asnæsværket and the heat pump, the heat pump's supply temperature can be reduced, as the production from the heat pump can be mixed with district heating from the cogeneration plant.

Kalundborg Forsyning

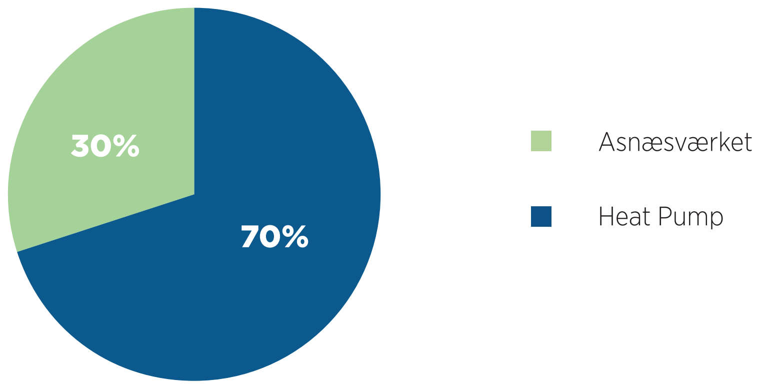


Figure 5: Heat production distribution at Kalundborg Forsyning.

The heat pump's evaporators are of the "shell and plate" type and therefore cannot be separated and cleaned mechanically. Therefore, the plant is equipped with an intermediate circuit, so that the waste water is cooled in traditional plate heat exchangers, which can be separated and cleaned if necessary.

The overall system consists of three parallel heat pump units, each with its own plate heat exchanger for the waste water. In this way, one heat exchanger can be cleaned, while operation is maintained on the other two units.

Before the plant was put into operation, simple tests were carried out with CIP liquid, where it was demonstrated that precipitation in the waste water can be removed.

The heat pump

The system is dimensioned according to the district heating system's summer load of approx. 10 MW, so that a high number of annual operating hours is achieved. The plant consists of three identical parallel sets, each made up of two serial 2-stage plants with reciprocating compressors to achieve a high COP value in a wide temperature range. Each "set" has a

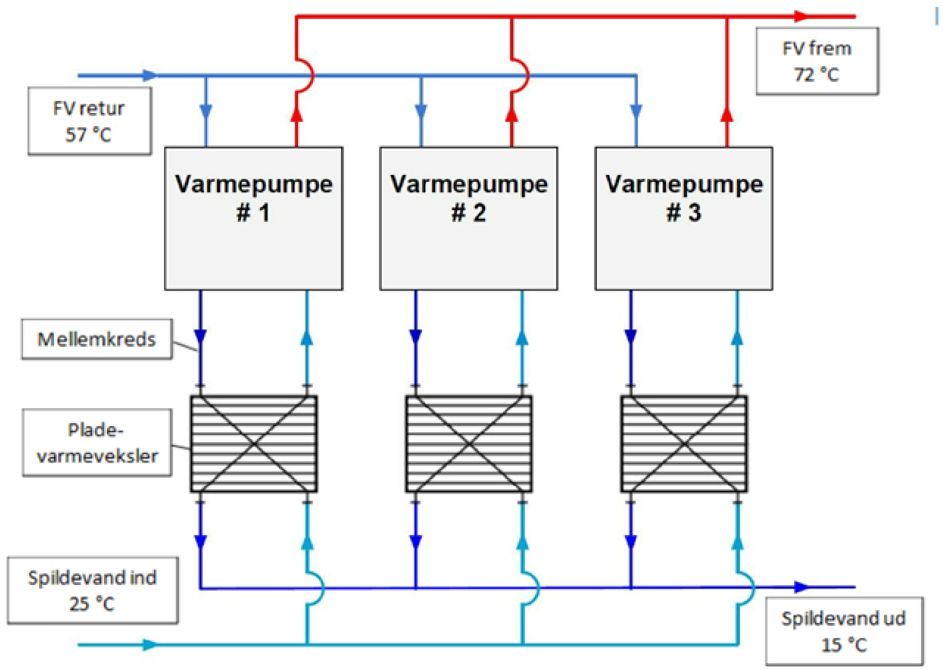


Figure 6: Plant construction in Kalundborg. The three parallel heat pumps are seen at the top, where the district heating water enters from the left and is delivered to the inlet on the right. Below the heat pumps are the plate heat exchangers, which separate the waste water from the intermediate circuit.

capacity of 3.33 MW heat at the waste water temperature of 15 °C. And the total plant can thus also produce around 10 MW in a winter situation. Each 2-stage system consists of a 16-cylinder low-pressure compressor and a smaller high-pressure compressor, which raises the pressure further to the desired district heating temperature. The low-pressure compressors are all the same, while the two high-pressure compressors in each "set" are different. Here, the high-pressure compressor in the first 2- stage

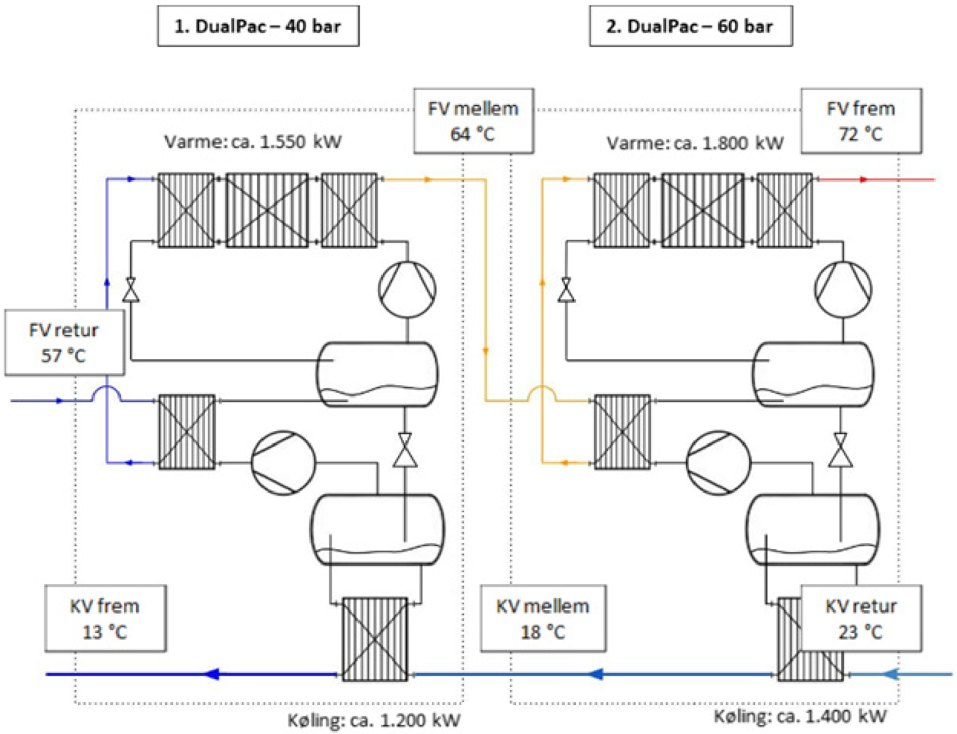


Figure 7: Principle sketch of the heat pump system in Kalundborg. The figure shows one out of three identical sets.

system is designed for 40 bar, while the compressor in the second 2-stage system is designed for 60 bar. With the high pressure stage in the last part of the heat pump system, it is possible to reach supply temperatures of approx. 85 °C.

The two high-pressure compressors have roughly the same displacement, but the second 2-stage system has a slightly higher performance, as the waste water enters this system first. Here, the waste water temperature is approx. 5 °C higher, which gives a higher performance on the low-pressure compressor. Each low-pressure compressor is equipped with a superheater, so that part of the energy is already utilized at the low pressure stage. The high-pressure compressors are equipped with an integrated heat exchanger set, which consists of a superheater, a condenser and a subcooler. Building the three heat exchangers together ensures a more compact system. The three heat pump sets are connected in parallel and are therefore operated at identical conditions. The total power for the three sets is 10 MW at a discharge water temperature of 15 °C.

Since the plant must be able to be used both independently as base load and as a supplement to Asnæsværket, emphasis has been placed on high performance and good efficiency at several different operating points. The plant is designed to operate with supply temperatures between 70 and 80 °C, and the supplier has guaranteed a maximum supply temperature of 82 °C.

The heat pump's evaporators are of the "shell and plate" type and therefore cannot be separated and cleaned mechanically. Therefore, the plant is equipped with an intermediate circuit, so that the waste water is cooled in traditional plate heat exchangers, which can be separated and cleaned if necessary. Before the plant was put into operation, simple experiments

The heat pump system in Kalundborg, the unit at the front of the picture with the two electrical cabinets, forms one half of a "heat pump set". The total facility consists of a total of 6 similar units.

were carried out with CIP liquid, where it was demonstrated that precipitation in the waste water can be removed.

2.2.3 Operating experience

At the time of writing (2022), the heat pump system has been in operation for approx. 6 years, and the plant is producing as intended. The performance of the plate heat exchangers is constantly monitored, and after the first two months of operation, the performance dropped relatively drastically, after which the heat exchangers were cleaned with the installed CIP system, which is the interval that Kalundborg Forsyning now uses as a starting point. However, it has been shown that bell-shaped animals in particular in the waste water in the summer period mean that the exchangers have to be cleaned ten times. The experience is that the performance is largely not affected for a relatively long time, but that it suddenly drops quickly.

That is why it is important to have a good monitoring system. In connection with a heavy downpour, there has been contaminated water in the system, and then a rapid loss of performance was experienced.

2020		2021	
MWh	COP	MWh	COP
44.000	3,7	6.300	3,9

Historical production and COP - production in 2021 was limited due to the high electricity prices.

2.2.4 Organization/ownership

It is Kalundborg Spildevandsanlæg that has purchased and installed the heat pump. In this way, the facility's energy savings could be reported in 2016, which significantly reduces the investment cost. The operations department from Kalundborg Forsyning, which includes both the Kalundborg Spildevandsanlæg and Kalundborg Varmeforsyning, is responsible for the day-to-day operation of the plant.

2.2.5 Technology and specifications

- Cold side (evaporator)

  The heat pumps are supplied with standard fully welded "shell-and-plate" evaporators. The evaporators on the two hot pumps in each set are connected in series and cool a secondary circuit, which then cools the waste water through a traditional plate heat exchanger.
- Hot side (condenser)

  Each of the two heat pumps is equipped with an overheating remover on the low- pressure stage, as well as an integrated heat exchanger on the high-pressure stage, which both contains an overheating remover, condenser and subcooler. All the heat exchangers are of the "shell-and-plate" type.
- Heat pump

  6 pcs. DualPac 2-stage heat pumps which are connected in series two and two. Each DualPac is equipped with two piston compressors, and the maximum supply temperature is approx. 85 °C.
- Electricity supply

  The facility is connected to the 10 kV grid with full connection.
- CO_2

  After the complete conversion of the Asnæsværket and the operation of the heat pump, the reduction of CO_2 has gone from 62,700 tons/year to 1,400 tons/year.

2.2.6 Budget and finances

As long as the heat pump is running as a base load unit, it produces about 30 percent of the heat demand in Kalundborg. This heat production would otherwise take place on temporary oil boilers/electric boilers. It is always chosen to produce the district heating on the heat pump before the electric boiler, because the heat pump has a better COP value. In this way, a very high saving was achieved in the first years of the heat pump's life.

Investment:
The key figures for the investment:
The facility has triggered an energy saving that can be capitalized to around DKK 31 million. This brings the total capital investment to DKK 38.6 million. DKK.

Varmepumpeanlæg	33,2 mio. DKK
Electrical work and SRO	6,6 mio. DKK
Transformer station and power cables	4,8 mio. DKK
Building and ventilation	7,4 mio. DKK
Waste water and construction work	3,2 mio. DKK
Transmission line	6,8 mio. DKK
Project planning	2,1 mio. DKK
Preliminary investigations	3,9 mio. DKK
Various	1,6 mio. DKK
Total	**69,6 mio. DKK**

Operating economics (2020):
There are costs for maintenance and the purchase of electricity. These amount to approximately:

- Maintenance 20 DKK/MWh-varme
- Purchase of electricity:

Spot	228 DKK/MWh-el
Transport local	39 DKK/MWh-el
Transport overall PSO tariff	83 DKK/MWh-el
PSO-tariff	0 DKK./MWh-el
Electricity tax	305 DKK/MWh-el
Total	**655 DKK/MWh-el**

Depending on the current spot price, the heat production price will be around DKK 156/MWh heat including service costs. In relation to the heat supply from Asnæsværket, the saving with the heat pump is around DKK 220 per produced MWh of heat.

Overall economy
The overall economy varies with the production margin and the number of operating hours from year to year. In the following, the following assumptions are taken into account:

- Heat price from Asnæsværket = DKK 376/MWh
- Total heat pump electricity price = DKK 383/MWh electricity
- Maintenance = DKK 20/MWh heat
- Annual number of operating hours = 8,000

With these assumptions, the total economy can be seen in the table below:

Varmepumpe på spildevand - 10.000 kW		
Investment	69.000.00	DKK
Annual number of operating hours	8.000	Hours
Annual heat production	66.00	MWh
Savings per MWh	220	Kr./MWh
Total value energy savings	31.000.00	DKK
Annual savings	14.500.00	DKK
Simple payback period	2,7	Years

2.3 DIN Forsyning – Seawater heat pump (under construction)

2.3.1 Background

DIN Forsyning works purposefully to phase out fossil fuels, which are used for district heating production and thereby reduce CO_2. It has been decided to phase out the coal-fired plant at the end of March 2023.

In phase 1, a 50 MW seawater heat pump, 60 MW wood chip boiler and 40 MW electric boiler will be established.

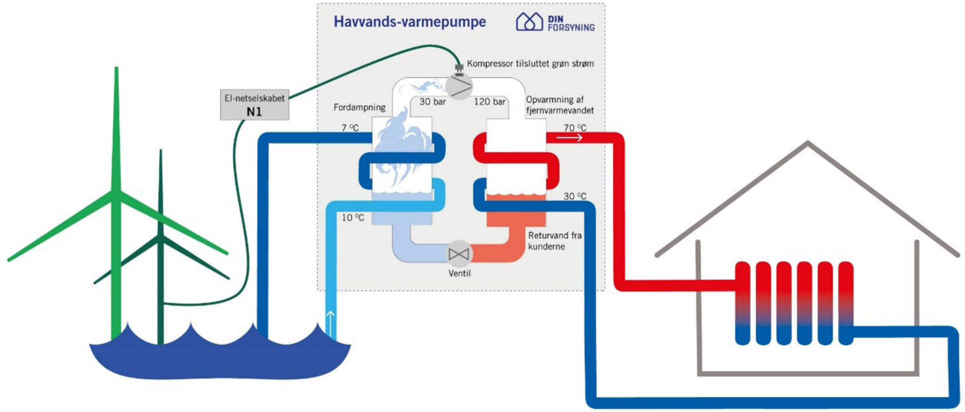
The project is under construction and is expected to be operational before 1 April 2023.

District heating plant	DIN Forsyning
Contact person	Claus Nielsen
Adviser	Added Values, Rambøll, Ingeniør Huse, Picca, COWI
Heat pump supplier	MAN Energy Solutions
Type	2 turbo compressors on CO_2
Installation year	2022-23
Annual number of full load hours	3.000-6.000
Varmekilde	Seawater
Nominel heat output	50 MW
Nominel COP	3,65
District heating is heated from-to	Return water approx. 38°C is heated to 50-90°C
Heat source cools from-to	From the temperature of the sea water (normally 3-20°C), it cools down 2-4°C

2.3.2. Systems

DIN Forsyning system supplies heat to more than 25,000 homes, industrial companies, institutions etc. in Esbjerg, Varde and surrounding areas. The annual heat sales are approx. 1,200,000 MWh.

In 2021, DIN Forsyning bought approx. 50 percent waste heat, approx. 50 percent coal heat, as well as a smaller proportion of excess heat. In the system there is an accumulation tank of 45,000 m³.



DIN Forsyning has several peak and emergency load centers scattered across the supply area. The plants are based on natural gas, gas oil and bio-oil.

Phase 1 (expected to be commissioned during 2023) of the conversion, which will replace the coal heating:

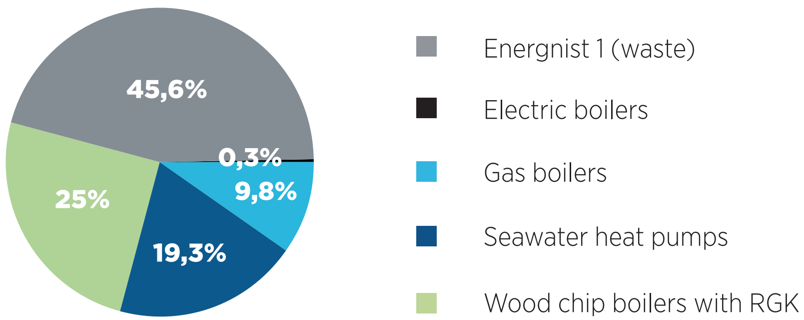
- Seawater heat pump 50 MW
- Wood chip unit 60 MW
- Electric boiler 40 MW

The heating center has its own 60 kV supply with the following transformers:

- 1 transformer for 60/10 kV
- 5 transformers for 10 kV to 400 V and 690 V respectively

2.3.3 Operating experience
The facility is under construction and therefore has no operation yet.

The expected production distribution cf. the project application is:



2.3.4 Organization/ownership
The production unit is owned by DIN Forsyning

3. Electrical connection

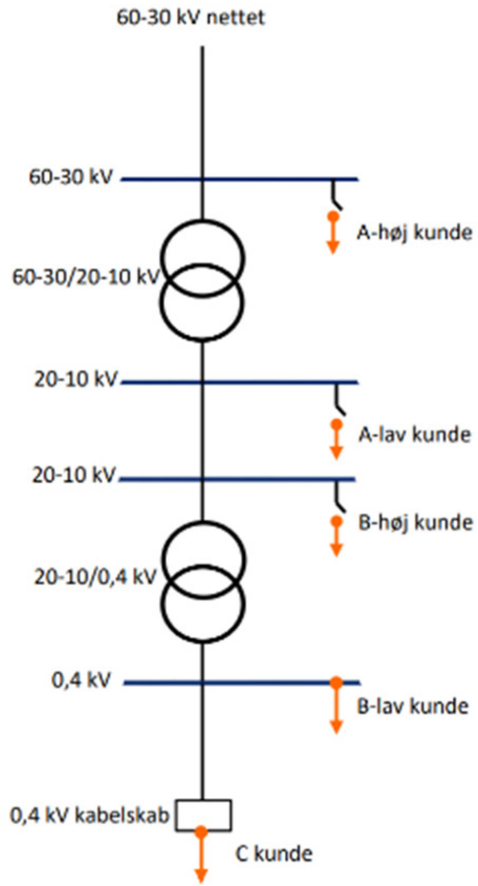
3.1 General information on connection level
In order to connect a heat pump or an electric boiler, an connection fee on the installed power to the local grid company. The connection fee is a one-off payment that is paid for a scope of delivery per new connection to the existing collective network. The connection fee finances the expansion of the existing collective network to the connected capacity requirement.

The size of the connection fee depends on where in the collective electricity grid the plant is to be connected. The purpose is that the connection fee reflects the average cost of the capacity increase that is at the connection levels below.

A-høj: Here the plant is connected at 60/50 kV level in a 60/50 kV station. (large capacity)
A-lav: Here the plant is connected at 10 kV level in a 60 kV station. (medium capacity)
B-høj: Here the plant is connected at 10 kV level in a 10 kV station. (low capacity)

What the connection points A-high, A-low and B-high have in common is that the customer himself establishes the electricity grid from the station to the consumption plant, including additional - drain plant. Typically, this will consist of cable systems, transformers, control and protection. Metering is normally established on the power delivery side.

The applicable connection fees, the general connection regulations and tariffs, can be downloaded from the network companies' website.



3.2 The three connection methods

In addition to the previously mentioned connection fee, the connection costs will depend on whether full power entitlement is desired for the consumption facility, or whether a network connection with limited network access is desired. It is possible to combine the two mentioned solutions, so that part of the connection gets full power rights and the rest is connected with limited network access.

A connection with full rights means that the above-mentioned connection contributions must be used.

If the customer can accept a reduced security of supply, the utility can be connected with limited grid access. Concretely, this means that the connection payment is reduced compared to the payment for connection on the general terms. The customer pays the actual costs associated with the connection. The principle in the scheme for grid connection with limited grid access is that the grid company has the option of automatic or manual disconnection during periods of high load on the local electricity grid/downregulation of the given consumption plant. For the network companies, this is a flexibility product for better utilization of the distribution network's capacity.

The network connection will include a restriction in network access, which can either be relevant at the time of network connection or will become current in the future. The network company can typically provide an estimate for how many hours of consumption the system can be switched off/downregulated. This estimate will be based on historical load data, as well as expected development in electricity consumption. Unforeseen connections of new large customers, expansion of power take-off by existing consumers or remodeling of the electricity grid can, however, mean that the limitation of the plant increases beyond what was foreseen.

In some cases, the restriction can also become permanent. Such changes are notified by the grid company in advance, while breakdowns in the electricity grid and the resulting temporary conversions or rearrangements in the electricity grid cannot be notified.

For further information, please refer to Green Power Denmark's home page:
www.danskenergi.dk/vejledning/nettilslutning/aftaler-vedroerende-tilslutning-til-elnettet

Please note that connection with limited network access is only offered to customers connected to the 10 kV power grid and above.

3.3 Out-of-hours

Out-of-hours or restriction occurs in the following circumstances:

- Power consumption by existing customers is increased.
- There is an operational disturbance/breakdown in the power grid with abnormal switching in the power grid as a result.
- Revision/maintenance of the power grid components.
  60/50 kV transformers are taken out for inspection at fixed intervals of approx. a week's duration. In addition, there is also an audit of 60/50 kV and 10 kV circuit breakers at 60/50 kV stations as well as associated protective equipment.

3.4 Planning phase

In order for the network company to assess the optimal connection level, the following information is necessary:

- How large an effect is desired to be connected
- Want a connection with full power rights or with limited ones grid

access.
- Map or drawing of the location of the consumption facility.

When the above conditions have been determined, the grid company prepares a grid connection agreement signed by the parties.

The delivery times for a connection partly depend on the level of connection, as there are often longer delivery times for 60/50 kV plant parts than for 10 kV plant parts and partly on how busy the grid company's plant department is. Delivery times are currently between 18-24 months for 60/50 kV components and up to 12 months for 10 kV plant parts.

3.5 Network tariffs

Grid tariffs are divided into price groups according to when the electricity is drawn off and from where in the grid the electricity is drawn off, 1.1.2.1.

Of the two price groups, the main group is based on connection level. Tariffs are generally higher the lower the voltage connected at. After the connection level is defined, the tariff is divided according to which hours the use is taken. Billing is done after three periods, which are defined as low load, high load and peak load. The periods they cover appear in Figure 8 and Figure 9 shows an example of the charges.

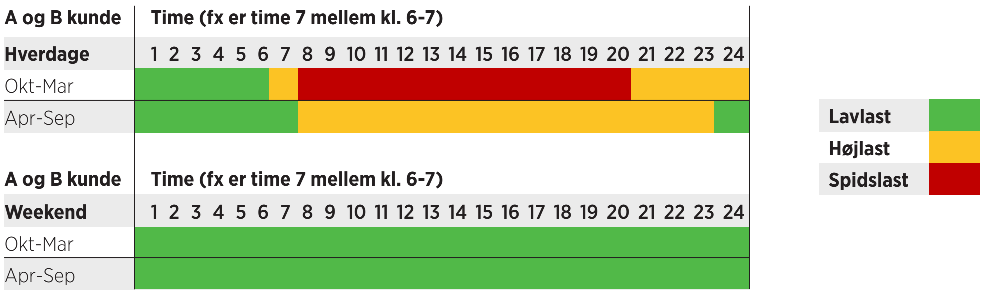


Figure 8: Time-divided load periods for grid tariff.

Tarifferne er gældende fra den 1. april 2022

C

B-lav

B-høj

A-lav

A-høj

AO

Midlertidig tilslutning

Aktuelle priser (øre/kWh)	Lavlast	Højlast	Spidslast
Transport af el (Nettarif)	2,13	3,98	5,88
Elafgift*	90,30	90,30	90,30
Pris/kWh ekskl. moms	92,43	94,28	96,18
Pris/kWh inkl. moms	115,54	117,85	120,23

A-lav anvendes, hvor aftagepunktet er på 10 kV siden af hovedstation.

Abonnement kr./md.	Ekskl. moms	inkl. moms
Netabonnement uden moms	223,00	278,75
Netabonnement egenproducenter	297,00	371,25
Netabonnement producenter	223,00	278,75

* Elopvarmede boliger og virksomheder har mulighed for at få reduceret deres elafgift (over 4.000 kWh for boliger) eller at opnå godtgørelse. Læs mere her

Figure 9: Extract of the tariff structure from Radius

Based on Figure 8 above, it is important when electricity is produced and under which connection conditions electricity is produced. The period can be affected through a combination of accumulation and electricity-consuming units. The period can be influenced through a combination of accumulation and electricity-consuming units. This can be seen, among other things, in Figure 9, where there is a big jump from C and B tariff to A-low tariff.

The difference between A-low and A-high is not that great, and here it will be of great importance how the investment costs are. From B-high to A-low, tariff costs fell by DKK 45 to 105/MWh, depending on the electricity company. It is therefore relevant for the individual companies to examine several connections options before a final decision is made on which technology to use, as this can contribute to expensive and fewer operating hours.

In addition to the price difference in the individual tariff, it must also be noted that there is a large difference between the companies. This is seen specifically in DK2, where Radius delivers. The price there is significantly more expensive than in DK1 where N-1 delivers. There are also price differences between the electricity companies internally in DK1 and DK2.

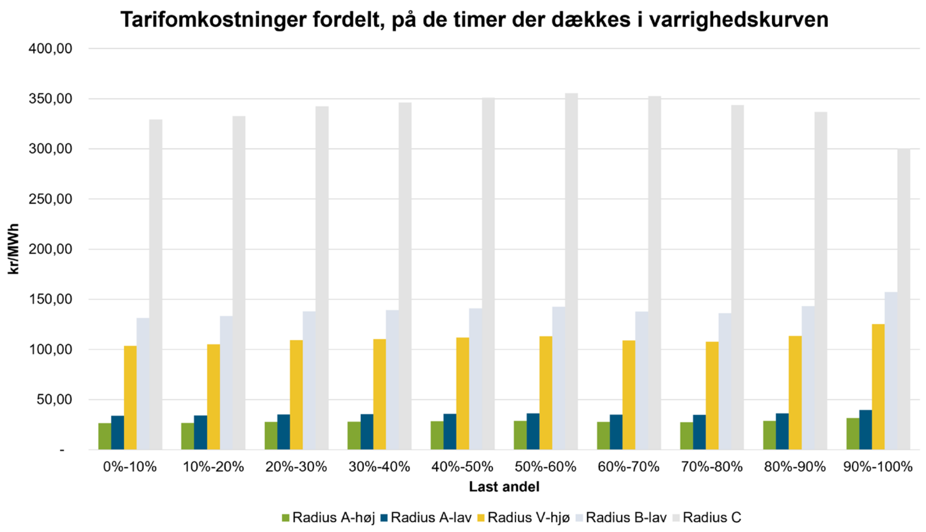
Below you can see an overview map of the various electricity companies' supply areas.

3.6 Development of charges and tariffs

The tariffs and charges are normally set annually. The electricity charges for heat (the net charge is the electricity charge minus the refund) has been steadily falling until today, where it is almost zero.

PSO was variable and dependent on the electricity price. It expired at the end of 2021.

The tariffs from Energinet have been increasing. The green transition will create major changes in the coming years and require rethinking when Danish electricity deliverance is to be secured. The expectation of the level of future tariffs is therefore associated with uncertainty. The development of the local tariffs depends on where in the country the plant is connected, as well as the voltage level at which it is connected. The expectations for the local tariffs are also linked to uncertainties due to the green transition. In addition, the local tariffs have gone from a fixed tariff



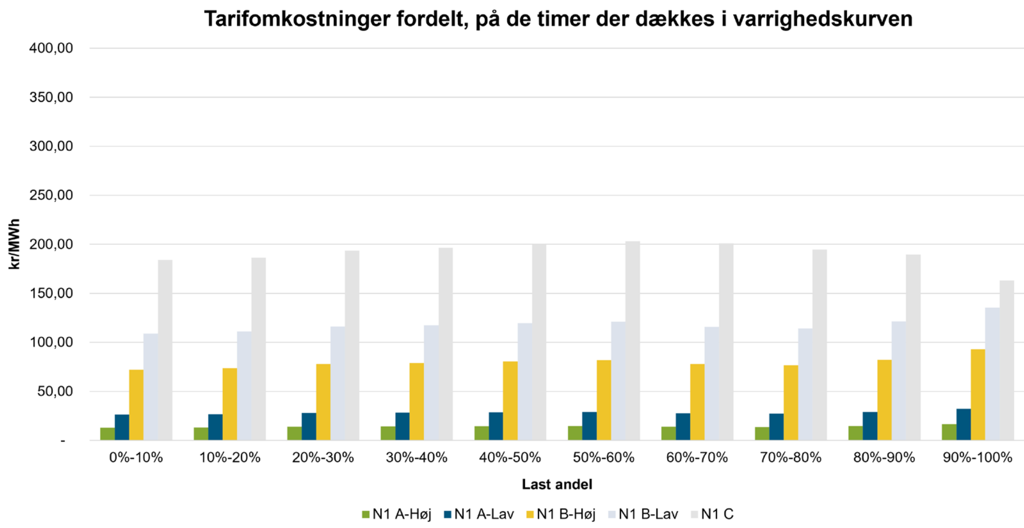
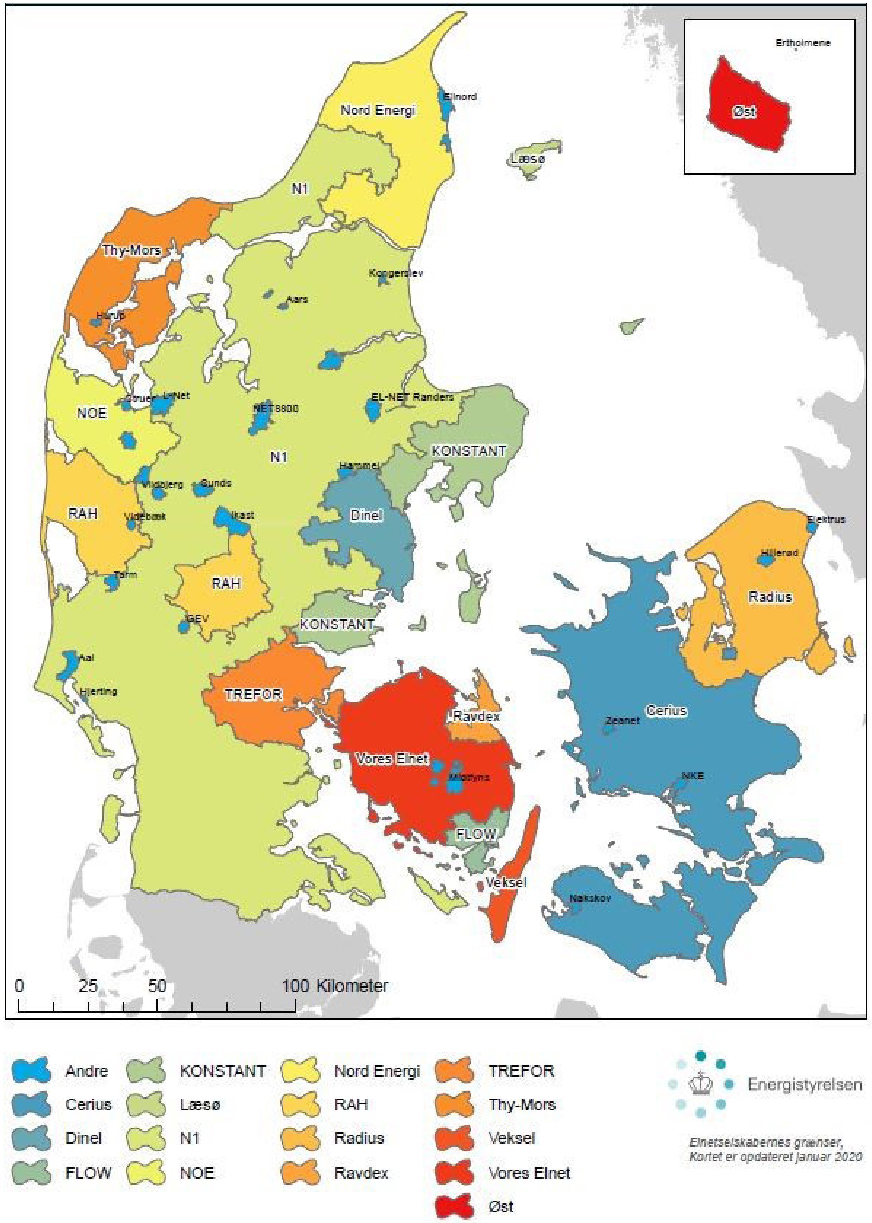


Figure 10: The tariff structure.

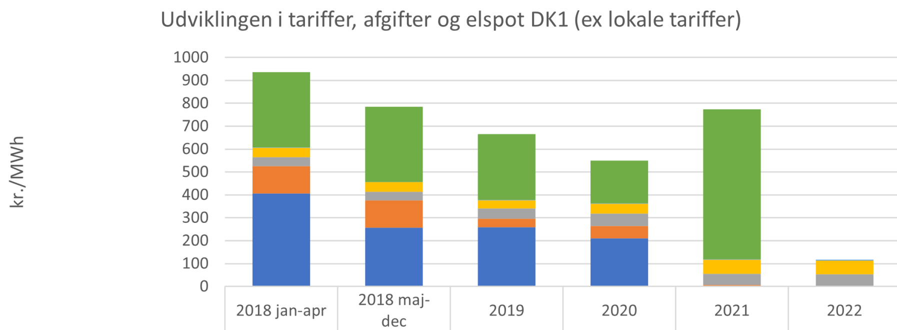


throughout the year to being variable over the year and around the clock, see if applicable. pt. 3.5.

The reduction in the net electricity heating tax is clearly visible. From being a significant factor, it is largely gone from 2021. Now the price of electricity has become absolutely the biggest factor. Note that the annual average for DK1 is used here; there is significant differences in the price for the individual days and hours.

To get the marginal heat price, the local tariffs and operation/maintenance teams must be added and divided by the COP. Please be aware that the local tariffs today are most often variable cf. 3.5

The annual average spot price of electricity has been falling until 2020. In 2021 it increased significantly, and in 2022 it looks set to increase even more. The development of the elements in the electricity price can be seen below. Please note that there are also local tariffs.



	2018 jan-apr	2018 maj-dec	2019	2020	2021	2022
Elspot DK1 årsgennemsnit	328,32	328,32	287,39	186,18	655,48	
Balance	1,44	1,44	1,63	1,87	2,29	2,29
System	42	42	36	44	61	61
Transmission	38	38	44	53	49	49
PSO	119	119	38	55	3	0
El varme afgift netto	407	257	259	210	4	4

El varme afgift netto   PSO   Transmission   System   Balance   Elspot DK1 årsgennemsnit

Figure 11: Development of charges and tariffs

4. Defrosting

Defrosting outdoor evaporators on air/water heat pumps proves to be a challenge. The formation of frost on the evaporators causes the air resistance to increase, and in addition the formation of frost acts as insulation. Where both the power consumption in fans will increase and the thermal conductivity deteriorates. To prevent this, a defrosting strategy should be chosen. There are several methods, and the most common ones will be touched upon in this section.

What influences the defrosting process (ice build-up) on evaporators is:

- The evaporation temperature
- The time
- The humidity of the air
- The temperature of the air
- The speed of the air over the evaporator

Seasonal, outdoor temperature and humidity dependent.

4.1 There are several options for defrosting
All defrosting is a trade-off between performance loss due to frost formation and performance loss due to defrosting. In order to find the right technique for the given installation, the advantages and disadvantages of the various techniques must be reviewed.

The simplest and cheapest model is to stop the fans and let the temperature of the outside air do it, but this also means that the time it takes depends a lot on the temperature of the outside air. Which can constitute a challenge in the winter.

Defrosting with hot gas, where refrigerant gas taken from the pressure side of the compressor on the heat pump, where it is superheated, is used and fed to the evaporator. This type of defrosting is suitable for systems with flooded evaporators, as there is no risk of liquid impact in the compressor..

Defrosting with hot glycol can be done by heating the glycol with the condenser heat or waste heat from the compressor. Here the glycol is heated and stored in an accumulation tank until it is used for defrosting. In order to defrost effectively with Glycol, it must be ensured that the glycol does not get too cold, as the viscosity at around -18°C becomes so high that the energy consumption for pumping is increased considerably. Defrosting with glycol should be able to reduce the energy loss during defrosting, as you lose condenser performance to a lesser extent than hot gas defrosting. However, it can be uncertain whether you can generate enough heat for the glycol before defrosting.

This can be remedied by collecting glycol heat from two parallel plants. Electric defrosting has low initial costs, but operating costs can be high depending on the price of electricity. Despite the perfect efficiency of the electric heating element, it is practically impossible not to waste heat during defrosting, as the temperature of the heating elements is usually very high.

It is important that the system is dimensioned correctly in relation to pipe sizes and circulation numbers in order to achieve the highest efficiency. Here, a needs analysis should be made to determine whether the plant will primarily run at full load or partial load, since with pipes that are too large (full load dimensioned) liquid may collect in the return pipe under partial load, while with pipes that are too small (partial load dimensioned) too high a pressure drop will occur. Both parts will affect the efficiency in the load situation for which they are not dimensioned. To alleviate this, you can make two parallel pipes, where you run on the most optimal in relation to the operating situation, otherwise a so-called hybrid evaporator can be used.

4.2 Prevention of frost formation

There are several strategies to prevent frost formation. In this section, the focus is on what is relevant for outdoor air evaporators, and air treatment is not considered to be relevant here.

The wind speed has a direct influence on frost formation, and this should be kept as high as possible. However, account must also be taken of increased noise generation and electricity consumption in the fans, whereby this method may be inappropriate. At low fan speed, problems with frost formation on or around the fan blades are often seen when the air direction is from down to up.

The fin distance is also a significant factor for frost formation, here you like to keep the distance between the fins low to both reduce production costs, space consumption and increase efficiency. However, the short distance means that the plant has an increased need for defrosting.

The same applies to the type of fin, the type of exchanger and the surface treatment of the fins, all of which are important for frost formation, defrosting and the efficiency of the plant.

4.3 Defrost control

Defrosting can be structured in several ways. The simplest and least effective are time-controlled defrosting, where the defrosting follows a predefined time schedule. This means that you will end up defrosting without it being necessary and not defrosting when it is necessary. To counteract this, you can vary the timetable based on various factors, including outside temperature, experience and season.

But to minimize energy waste, defrosting should be based on control. Here there are several options for measuring the defrosting need. The closest ones are measuring the differential pressure above the evaporator and control using the fan's power input. Both methods measure the same thing: the air resistance above the evaporator, by which it can be determined whether the fins are frosted.

In addition, it can be controlled whether defrosting is to be done actively or passively, with a defrosting system or outside temperature alone by measuring the outside temperature.

The duration of the defrost and capacity for this is very dependent on the operating situation, therefore it can be difficult to determine how long the defrost should last when it comes to time-controlled defrosting.

Here, temperature sensors together with the air resistance over the evaporator can tell when the defrosting is sufficient. The formation of frost will first defrost in the middle of the evaporators and finally in the corners. Thereby, with temperature-controlled defrosting, you should measure on the corners of the evaporator.

To avoid freezing of the evaporators, you should blow dry the evaporators after defrosting. So that there is no liquid on the evaporators that risks freezing when operation resumes.

4.4 Experiences

Defrosting of evaporators must be ahead of the frosting at all times so that icing does not occur as it can cause a self-reinforcing effect.

Liquid flow and level in splash-separators are necessary parameters to achieve efficient and optimal defrosting.

Evaporators must be blown dry before restarting the system, as the effect of the defrosting is otherwise ineffective. If you choose to blow dry, you must reverse the fans, otherwise you risk the water settling on the fans as ice.

Defrosting of evaporators or lack thereof will reduce the COP value and thereby increase production costs. The time interval between defrosting sequences is important for the plant's capacity, which decreases with increased infiltration, where a 25 percent reduction in performance is not abnormal for lack of defrosting.

The Technological Institute's experiences:

- Ice builds up a complex matter depending on the state of the air
- Ice density in excess of 200kg/m3 is likely
- Use drain-controlled defrosting for condensing defrosting
- Optimizing the defrosting is crucial for air/water heat pumps
- The traditional time-controlled method is not optimal and results in unnecessary energy consumption and sometimes in defective defrosting
- Intelligent data processing of different start and stop signals from a "master evaporator" can ensure efficient defrosting with low energy consumption

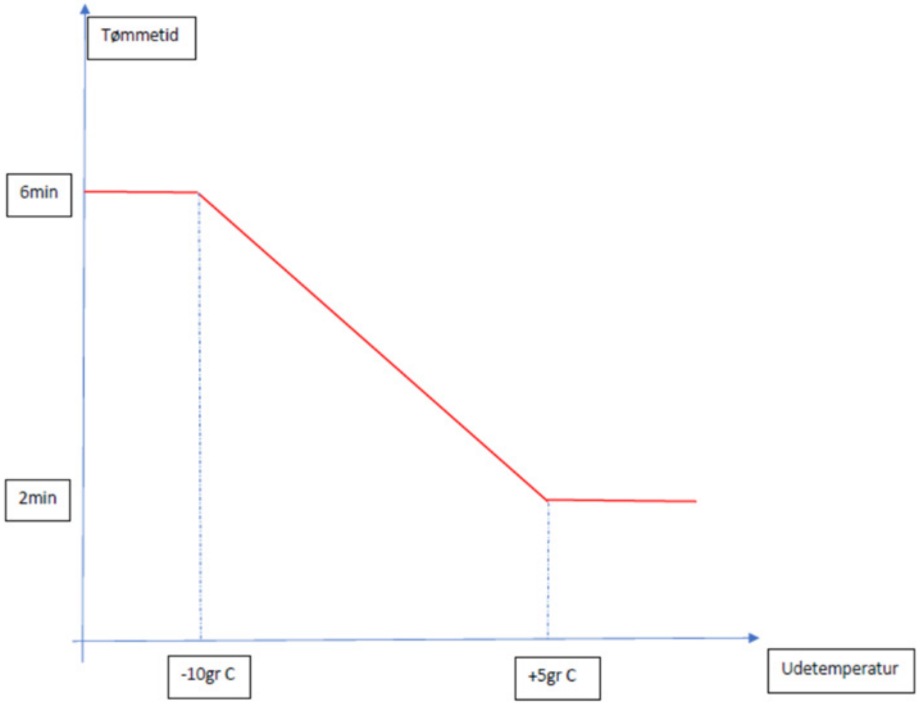
When air is used as a heat source, frosting is a problem which lowers the efficiency of the heat pump. However, it is possible to plan your way out of that by making several vaporizers associated with each compressor. Thus a single evaporator is taken out of service for defrosting while the remaining are still in service. Freezing is especially a problem in Denmark, as there are many hours with temperatures between 0-7 °C. The air is often humid at that temperature level, which creates a lot of condensation. When the temperature falls below the freezing point, the frosting is less, as the air is drier in frosty weather. The low temperatures during the heating season mean that the effectiveness of air as a heat source is lower than most other heat sources.

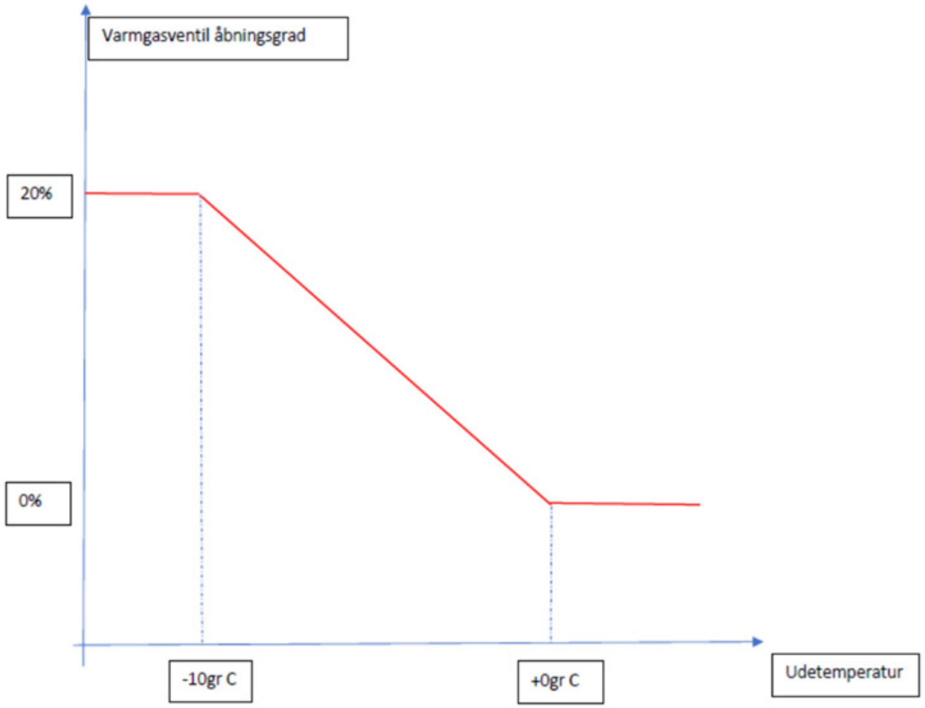
Despite the above, air can be a sufficient heat source in areas without other heat sources. The establishment costs for a heat pump solution with air as a heat source can also be significantly lower than other heat sources. This can help offset the lower efficiency in the winter months.

At the moment, there are several plants in Denmark that are being established with air as a heat source.

Emptying	The evaporator is emptied of liquid
Defrosting	Hot gas/hot liquid is supplied
Compensation	pressure is compensated
Freezing	The pressure is lowered to suction pressure so that the remaining water is frozen solid

The hot gas defrosting can be optimized using a temperature sensor at the bottom of the evaporator (liquid inlet side), whereby a set point for the defrosting is set to e.g. -2 °C, and the order of evaporator defrosting is determined based on which evaporator has the coldest temperature.





During defrosting, the emptying time will vary with the outside temperature due to the fact that the hot gas will condense in the coil where it is the lowest temperature (the bottom of the evaporator), therefore it is advantageous to use a defrosting scheme.

The hot gas can be supplied from an economiser, where it is also possible to supplement with gas from the discharge side of the compressor. Here you can also optimize to reduce redundant suction pressure.
The evaporator temperature can also be used to stop defrosting rather than running at a fixed time. In other words, when the evaporator temperature reaches, for example, 10 °C, the defrosting ends.

4.5 Advantages/disadvantages of the heat source
Advantage:

- The heat source is easy to access.
- The heat source is available everywhere.
- The technology has been tested on a large scale in smaller household installations, while larger heat pumps have only just been put into operation, so the experience are limited.
- The authority processing is simpler than for example groundwater Heat Pumps.

Disadvantages:

- The heat source has low temperatures in winter
- Requires defrosting which reduces efficiency when the temperature is below 7 °C
- Fans for the cooling surfaces are noisy, which must be dealt with in the planning phase, this can be a limitation if there is housing around the construction site
- It requires an area to set up evaporators. In Ringkøbing, approx. 255 m2 evaporators for the heat pump, which together deliver 2.5 MW (in winter), which corresponds to 102 m2/MW.

5. Refrigerants

Choice of refrigerant and its various properties in technical terms are important for the choice of a heat pump and its construction, as the refrigerants have special properties which place demands on the design and operation of the plant.

In theory, all refrigerants are equally good thermodynamically, but function differently at different temperature levels, which means that certain refrigerants are often most appropriate in a system that is adapted to this.

In addition, there are various practical considerations such as pressure level, flammability, toxicity, selection of components and more that can make certain refrigerants best suited for certain applications.

For district heating production, until now it has primarily been ammonia that is used in the heat pump systems. Here you get a tested product that provides a high degree of efficiency, while standard components from the refrigeration industry can be used, which can be designed for the specific plant and operating pattern.

The worldwide development of coolants for larger heat pumps takes place primarily through the use of natural coolants, and the selection of these will in future be larger than today.

For the larger heat pumps, it has mainly been natural cooling agents that have been used, as these do not affect efficiency and performance.

This therefore means that certain components, which have been developed especially for synthetic refrigerants, cannot be directly used in heat pumps, and therefore require adaptation.

Today, there is extensive regulation of the use of refrigerants based on the desire to reduce the climate effects from refrigerants, while at the same time meeting the needs of the market, so that there are refrigerants for all relevant targets.

GWP is the impact that one kilogram of CO_2 has on the climate
One kilogram of CO_2 has a GWP equivalent of 1
The requirements for GWP are a maximum of 5

The legislation in Denmark thus prevents refrigerants with a high GWP (Global Warming Potential) from being used in heat pump systems, thereby ensuring that these do not have a harmful effect on the environment and contribute to increasing the greenhouse effect.

In practice, the requirements in the refrigerant legislation are thus not a problem, as it does not exclude the use of synthetic refrigerants and thus hinders the spread of large heat pumps, but instead sets requirements for the GWP load of the refrigerant.

The most widely used natural refrigerants are ammonia (NH_3), carbon dioxide (CO_2), isobutane (C_4H_{10}) and propane (C_3H_8). They are all found naturally in the environment and therefore have low climate effect.

Ammonia has a GWP factor of 0, CO2 a GWP factor of 1, while isobutane and propane both have a GWP factor of 3 and thus have limited influence of the greenhouse effect.

Refrigerants that are used today in the larger heat pump systems have, as previously mentioned, primarily been ammonia, but in recent years new refrigerants have appeared on the market. New heat pump systems have been established where the refrigerant is carbon dioxide (CO_2), isobutane (C_4H_{10}) and propane (C_3H_8).

All are natural refrigerants, which have a limited impact on the environment around us and will therefore be important for the establishment of large heat pumps in the future.

For example, a CO_2 plant differs technically from an ammonia heat pump, although the working principle is the same, there are different requirements for compressors, heat exchangers, pipe systems, etc. Depending on the chosen refrigerant, the technical structure of the plants will differ from one another.

In addition to the natural refrigerants, there are synthetic refrigerants which have different thermal and chemical properties that make them suitable for plant types where natural refrigerants have their limitations.

For example, synthetic refrigerants will be able to be used at high temperatures and thus be an alternative to traditional plants that use natural refrigerants which normally cannot supply these.

In recent years, new types have appeared among synthetic refrigerants, one of them is R1234ze(E), which has a GWP factor of less than 1, which is suitable for large heat pump systems with turbo compressors from 20-150 MW and temperatures up to 95 °C.

Among the properties of the mentioned refrigerants can be mentioned:

5.1 Carbon dioxide – CO_2

CO_2 is a well-known refrigerant that requires a high working pressure and has therefore for some time only been used at low temperatures. CO_2 was used in refrigeration systems at the beginning of the 20th century, but was later out-competed by CFC refrigerants. But with the phasing out of the greenhouse-loading refrigerants (CFC and HFC refrigerants) in Denmark and other countries, as well as the technological development of compressors over the past 10-15 years, the refrigerant has found a place in supermarket refrigeration systems and is now also used in heat pump systems where there is a need for higher temperature. The range of components for heat pump use are the same components that are used for cooling systems. This means that for a heat pump system there is a need to install several similar components when a larger system is to be made in order to get the desired performance.

CO_2 has thermodynamic properties which make it particularly suitable for heating water where a large temperature rise is needed, for example from 35 to 75 °C and therefore suitable for district heating operation. When CO_2 is used as a refrigerant, in systems with CO_2 as the only refrigerant, condensation cannot occur at higher than 31 °C. For high-temperature heat pumps, gas coolers are therefore used instead of condensers. In this way, CO_2 can be used in the supercritical (transcritical) stage. This will result in a lower degree of efficiency, a loss of efficiency which can however be mitigated by the use of an 'expander' on the compressor shaft which utilizes some of the refrigerant's remaining energy as kinetic energy.

CO_2 plants are available today in sizes over 50 MW, for example the upcoming plant at DIN Forsyning in Esbjerg will be 50 MW based on 2 turbo compressors.

Advantage:
- GWP 1
- Temperatures up to and beyond 90 °C
- Non-toxic and non-flammable
- Suitable for smaller installations where a large temperature rise is needed
- Compact plants
- Can handle large temperature difference between hot and cold side

Disadvantages:
- Limited selection of certain major high-capacity components
- (due to the requirement for high pressure)
- Works poorly when the return temperature is above 40 °C
- Gives a high COP, but it requires a low return temperature
- Risk of dry ice formation at safety valves
- Low critical temperature
- Danger of suffocation at over 5% concentration

5.2 Ammonia- NH_3 - R717

Widely used for industrial cooling, but the technology has been further developed so that it is now also used in heat pumps with few large components and capacities above 1 MW. Ammonia is currently the most widely used coolant in large heat pumps.

Ammonia cooling systems typically have a maximum working pressure of 25 bar and can deliver a temperature of 50-55 °C. There are heat pumps with 40 bar components which allow you to reach a temperature of 70-75 °C. If higher temperatures are needed, new, special high-pressure components have been developed, which make it possible to reach temperatures of 90-95 °C.

Advantages:
- GWP 0
- Temperatures up to 95 °C
- Large selection of standard components that provide efficient and economical plant design
- Great availability of components
- High efficiency
- Good as a low-pressure coolant in multi-stage systems
- Low investment costs

Disadvantages:
- Toxic
- Slightly flammable
- Installation must be built in several stages when there are large temperature differences

5.3 IsoButan - C_4H_{10} - R600a

Used for medium-sized heat pumps of 4-500 kW with high temperatures. The thermodynamic properties mean that it is possible to use main components that have been developed for synthetic refrigerants.

The low operating pressure makes it possible to achieve temperatures of up to 85 °C without the pressure exceeding 20 bar.

The system is similar in structure to refrigeration systems with synthetic refrigerants.

There is still limited experience with the plant type, despite the fact that there is a large selection of suitable components. Suppliers are hesitant to provide a product guarantee on plants with isobutane rather than synthetic refrigerants.

Advantage:
- GWP 3
- Temperatures up to 85 °C
- Simple and affordable systems
- Uses standard commercial cooling components
- Can handle large temperature difference between hot and cold side

Disadvantages:
- Flammable gas
- Certain main components are not available in industrial quantities
- Component suppliers are reluctant to provide product guarantees

5.4 Propan - C_3H_8 - R290

Typically used for medium-sized heat pumps up to 4-500 kW with supply temperatures up to approx. 60 °C.

Contrary to isobutane, propane systems work at a higher pressure, which means that a smaller compressor gets greater performance, and propane systems can thus be advantageous where a high temperature is not required.

Advantage:
- GWP 3
- High heating performance compared to isobutane
- Simple and affordable systems
- Uses standard commercial refrigeration components

Disadvantages:
- Flammable gas
- Certain main components are not available in industrial sizes
- Maximum temperature is approx. 60 °C

5.5 Syntetisk kølemiddel - R1234ze (E)

Mostly used as a replacement for HFC134A and also developed with that in mind.

However, the coolant shows potential when it comes to large heat pumps, high temperatures can also be achieved. The refrigerant enables rapid up and down regulation, with examples of regulation down to 30 percent of maximum capacity.

Unlike R1234yf, R1234ze(E) is produced on an industrial scale and is therefore relatively easily available.

Advantage:
- GWP<5
- Up to 150 °C
- Non-toxic
- High efficiency
- Can handle fast regulation
- Good chemical compatibility with plastic and elastomer
- Very low TFA content
- Low working pressure

Disadvantages:
- Limited operating experience in Denmark
- Easily flammable
- Low chemical compatibility with lubricating oils