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Practical experience on tendering and contracting heat pumps for district heating

Bjarke Paaske, Niels From

PlanEnergi, A.C. Meyers Vaenge 15, Copenhagen DK-2450, Denmark

Abstract

The Danish Energy Agency has recently subsidized 10 demonstration projects to push the utilization of heat pumps for district heating. This takes the total number of heat pumps in Danish district heating to around 30. The focus is on heat pumps that utilize ambient heat sources to enable stand alone operation with output temperatures between 70-75 °C. The units must consist of commercial available components with no R&D elements as this will ensure swift installation. Sizes range from 0.8 to 4 MW thermal and the funding was pledged late 2015. The demonstration plants will be put into operation from late 2016.

The engineering company PlanEnergi is currently client advisor on 6 heat pump projects. This presentation will discuss tendering and contracting based on practical experience. As annual operating hours are high and the primary operating cost is caused by electrical consumption, high efficiencies are key for profitable plants. This has to be evaluated relative to installation cost and complexity, and must be included in the tendering documents. Small deviations in performance have a great impact on the total economy and adequate performance acceptance tests are vital. Existing test standards are not applicable as tolerances are too high and new methods have been developed to allow fair and accurate onsite performance evaluations in conditions that may differ from the tender. The developed performance test only allow small deviations from guaranteed performance as well as remedies and bonus terms for the supplier.

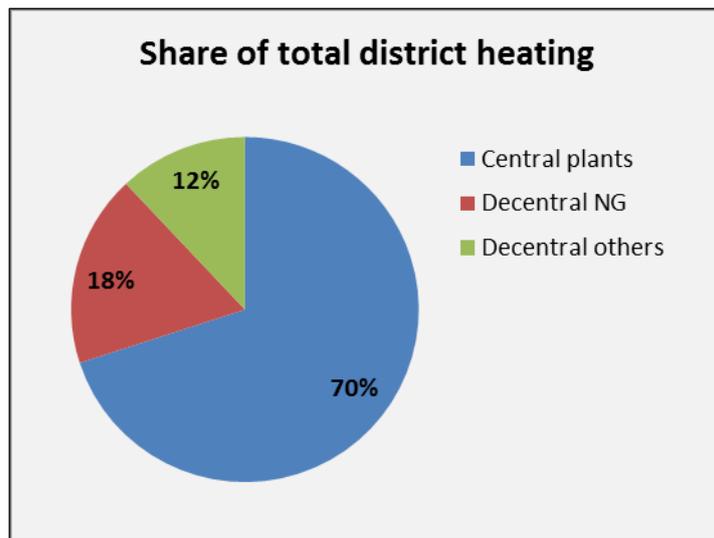
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Heat pump; district heating; tendering; performance test

1. Background

More than 65 % of the Danish households are heated through district heating. In the larger cities heating is produced through central power plants and waste incineration. These cover around 70 % of the produced district heating. The remaining 30 % regards less dense populated areas and consist of around 340 user owned cooperatives. 250 of these are combined heat and power plants based on natural gas. Figure 1 below shows the distribution of district heat production in central plants, decentral plants based on natural gas and other decentral plants. Other decentral plants are often based on biomass or waste incineration.



For the natural gas fired plants, the settlements for power production has changed dramatically since their construction in the 1990's. The market have changed from fixed tariffs to a liberalized market. Furthermore the capacity in power transmission to foreign countries have been expanded, while power production from wind turbines have increased to 42 % of the total Danish power consumption in 2015. All together this means that gas based power production is not feasible, and the 250 gas fired plants are primarily producing district heating on boilers. This is expensive and less energy efficient than individual heating, and force the plants to look into other alternatives such as solar heating or large-scale heat pumps. These plants typically supply from 200 to 5,000 households and produce 6,000 to 100,000 MWh of heating annually.

1.1. Heat pumps in Danish district heating

Due to uncertain financial frames, the implementation of large-scale heat pumps have been slow, The technology is however very suitable for the Danish energy system with low power prices and increasing wind power. All of the decentral plants has storage tanks for flexible production, which can be utilized by heat pumps as well. Furthermore the temperatures in these systems are quite low as there is no heat exchangers from the plant to the radiators in the households. Typical temperatures are 70 °C forward and 35 °C return, and the most efficient systems are at around 60 °C forward and 30 °C return. This enables high COP values while the heat pumps consist of low pressure standard components. The centralized systems in the larger cities demand much higher temperatures making heat pumps less suitable.

In order to push the utilization of heat pumps, the Danish Energy Agency has recently subsidized 10 new units that will be installed in 2016 to 2018. This will take the total number of heat pump installations to around 30. Figure 2 below shows the development in installed units from 2009.

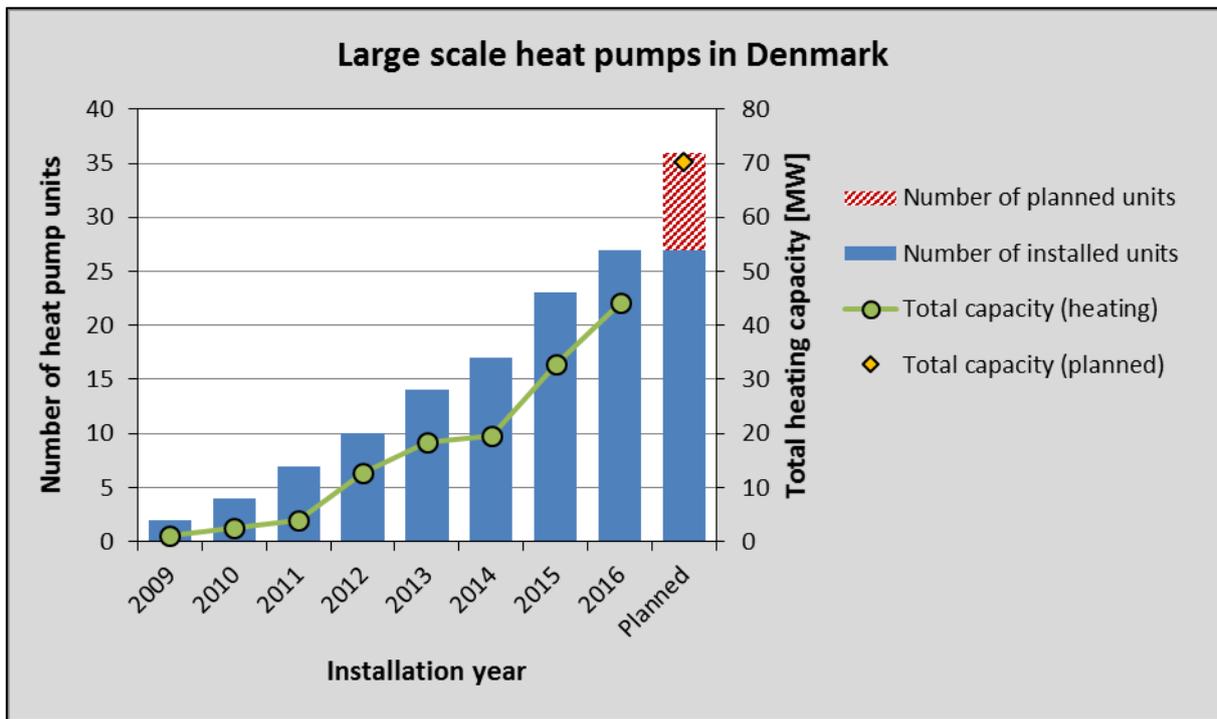


Figure 2 – Development in installed electrical heat pumps in Danish district heating systems

The current momentum in installations are primarily caused by the described subsidies while low gas prices slows the development. The main part of Danish heat pumps use ammonia as refrigerant as this allows high efficiencies. The sizes range from 300 kW for flue gas condensation on boilers up to around 7 MW in utilization of industrial waste heat and space cooling.

It is important to notice that the heat pumps are installed in existing systems alongside existing heat production units. The heat pumps are not installed in order to increase capacity but solely to replace heat production on gas boilers thus reduce production costs. This means that the installation cost of heat pumps must be covered by a reduction in the heat production cost alone. This is possible as the heating plants are user owned non profit organizations that will accept long return of investment periods as long as the risk is low.

Construction of new networks in Denmark is very rare as district heating networks already cover the main part of the country.

2. Heat pumps in gas based systems

As of November 2016 PlanEnergi is managing 6 heat pump projects for district heating. The capacities are in the range from 800 kW to 4 MW of heating and the heat sources are waste water, surface water and ground water. The source temperatures are quite low ranging from 4 °C for surface water during the winter and up to 22 °C for waste water. 4 of the projects have been subsidized meaning that 25 % of the installation cost is funded by the Danish Energy Agency.

2.1. Implementing a heat pump into an existing system

One of the current projects is a heat pump that utilize ground water in the town Broager. The heat pump is being installed at the time of writing. Broager is a small decentralized system based on natural gas. The plant produces around 25.000 MWh of heating annually and has recently installed 17,000 m² of solar heating. The plant also holds three gas fired boilers with a total capacity of 12 MW and a gas engine with a thermal output of 3,6 MW.

Due to the Danish climate, the solar thermal system will primarily produce during the summer period whereas heat production is based on gas in other periods. Figure 3 shows the duration curve of the typical production in Broager.

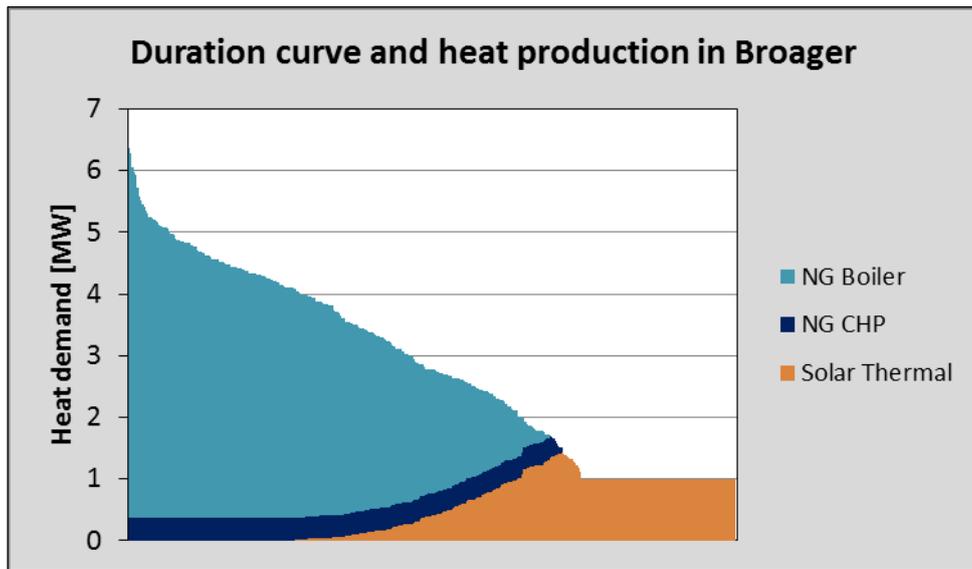


Figure 3 – Duration curve and typical heat production in Broager

Figure 3 shows that the peak heating demand is around 6,5 MW, while the summer load is around 1 MW. The solar thermal system covers the summer load as there is almost no operation dependent costs. When electricity prices are high, the gas engine will produce heat at less cost than the boilers. On average this is a few hours per day meaning that the average combined heat and power production is very low. Because of this gas boilers typically produce around 70 % of the annual heating, while the gas engine produce 10 % and the solar thermal system 20 %. When adding a heat pump into this system it is important to consider the type of heat production that is replaced as well as the amount. These two parameters are key when considering a heat pump in an existing system where increased capacity has no value.

2.2. Feasibility

A heat pump for ambient heat sources has high investment costs meaning that a combination of low production cost and a high number of annual operation hours is necessary for a feasible investment. Energy prices and operation costs are stated in Table 1 below. Investment costs are not included as the solar and gas systems already exist:

Table 1 – Energy and operation cost for heat production units in Broager

Production unit	Energy price	Transport	Taxes	O&M	Total
Solar Thermal	0 €/MWh _{th}	0 €/MWh _{th}	0 €/MWh _{th}	1 €/MWh _{th}	1 €/MWh _{th}
Gas Engine (heating)	13 €/MWh _{th}	3 €/MWh _{th}	20 €/MWh _{th}	11 €/MWh _{th}	47 €/MWh _{th}
Gas boiler	20 €/MWh _{th}	5 €/MWh _{th}	28.5 €/MWh _{th}	1.5 €/MWh _{th}	55 €/MWh _{th}
Electricity for heat pump	23 €/MWh _e	26 €/MWh _e	85 €/MWh _e	6 €/MWh _e	140 €/MWh _e

Table 1 shows how the solar thermal system has the lowest heat production cost by far. There is no energy consumption and the only cost is for operation and maintenance, which is around 1 €/MWh_{th}.

Regarding the gas engine, part of the energy turns into power that is sold. When this income is withdrawn, the resulting price for energy and transport sums up to 16 €/MWh. Danish energy taxes on gas to heat and power are lower than gas to heat and equals 20 €/MWh, while operation cost is relatively high for gas engines. The total heat production cost sums up to an average of 47 €/MWh_{th} using the gas engine. This will vary according to the hourly power prices and 47 €/MWh is a yearly average.

Using a gasboiler means higher energy costs while operation and maintenance is cheap. The gasboiler sums up to 55 €/MWh_{th}.

Electricity is more expensive than gas on the energy prices itself as well as transport and taxes. Operation costs for a heat pump is typically similar or a little higher than that of a gas boiler considering the heat output. When calculating the operation cost per electrical input the cost will be 3-5 times higher according to the COP value. This means that the total electricity and operation cost of a heat pump sums up to 140 €/MWh_e. Calculating in to thermal production prices, a heat pump with a COP of 3 will have a heat production cost of around 47 €/MWh_{th}. A heat pump with a COP of 5 will return a heat production price of 28 €/MWh_{th}.

Assuming that COP will be at least 3 the heat pump will be the most feasible heat production unit next to the solar system. This means that the heat pump will provide the base load as long as the solar system is inadequate.

2.3. Heat production including heat pump

A 3.5 MW heat pump in Broager will change the annual heat production according to the duration curve in Figure 4 below.

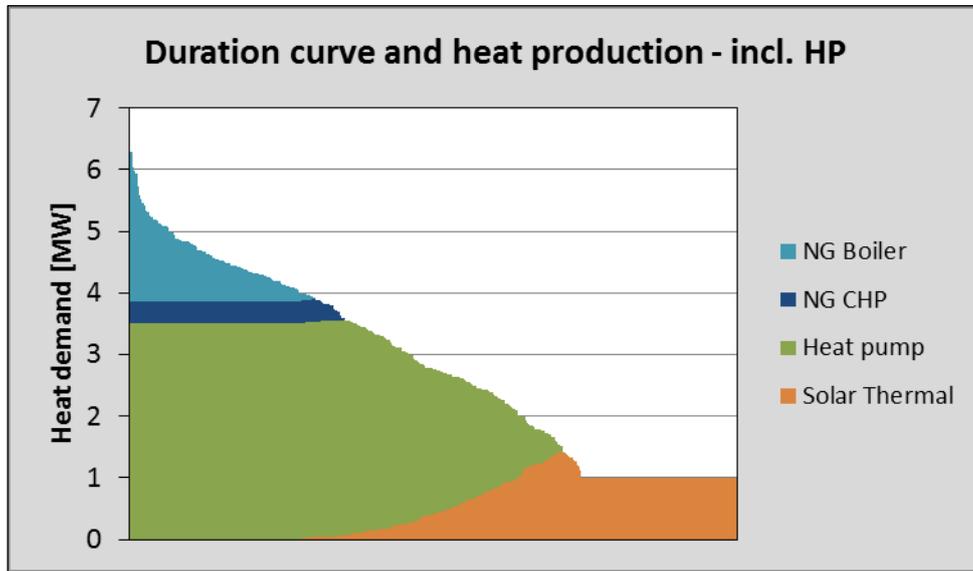


Figure 4 – Duration curve and heat production in Broager incl. 3.5 MW heat pump

Figure 4 shows how the heat pump forms the base load when solar heating is inadequate. The heat pump will produce around 17,000 MWh a year, which equals 70 % of the total heat demand. The heat pump will replace around 1,000 MWh_{th} of combined heat and power production and 16,000 MWh from the gas boilers. The annual full load equivalent operating hours is around 5,000.

3. Tendering and contracting

As stated above, a 3.5 MW_{th} heat pump will replace 16,000 MWh of heat from the boilers and 1,000 MWh of heat from the gas engine. A heat pump with a COP of 3 has a heat production cost of 47 €/MWh, while a heat pump with a COP of 5 has a production cost of 28 €/MWh. Thus giving an annual saving of:

Table 2 – Annual savings on heat production costs using heat pumps with COP values of 3 and 5

Production unit	Production cost	Amount replaced	Total cost	Annual savings
Gas Engine (heating)	47 €/MWh _{th}	1,000 MWh	€ 47,000	-
Gas boiler	55 €/MWh _{th}	16,000 MWh	€ 880,000	-
Heat pump – COP 3	47 €/MWh _{th}	17,000 MWh	€ 799,000	€ 128,000
Heat pump – COP 5	28 €/MWh _{th}	17,000 MWh	€ 476,000	€ 451,000

As the cost of electricity is quite high, the COP value has great influence on the feasibility meaning that COP must be weighted high in the tendering. Other important parameters in the quantitative evaluation are:

- Investment cost
- Performance in varying operating conditions
- Thermal capacity

3.1. Specifying dimensional data in Broager

The temperature of the groundwater in Broager is around 9 °C. In order to extract as much heat as possible, the groundwater will be cooled to the lowest permissible temperature of 2 °C before reinjected. Temperatures in the district heating network are typically 70 °C forward and 35 °C return. Regarding capacity the client wishes a heat pump of between 3.5 and 4.0 MW. This means that the basic specifications are:

- Heat source: 9 - 2 °C
- Heat sink: 35 - 70 °C
- Thermal capacity: 3.5 - 4.0 MW

It is assumed that the temperature of the groundwater can vary between 8 and 10 °C, which must be taken into account designing the heat pump. Temperatures in the district heating system are neither static as the forward temperature is adjusted according to the demand. The return temperature will also vary according to the heat demand and the forward temperature. In winter periods when the heat production is a combination of gas and heat pump, the heat pump can reduce the supply temperature for preheating or mixing to the gas units. As the thermal capacity of a heat pump will vary with temperatures of the heat source, the supply temperature and the return temperature, this leaves a lot of different operating conditions that must be taken into account.

In the project in Broager, the variations in design conditions are stated in Table 3 below:

Table 3 – Design conditions for a ground water heat pump in Broager

Parameter	Max	Min
Temperature of heat source	10 °C	8 °C
ΔT heat source	8 K	6 K
Forward temperature DH	75 °C	65 °C
Return temperature DH	40 °C	30 °C
ΔT district heating	40 K	30 K
Thermal capacity at full load	4.0 MW	3.5 MW
Operating at part load	100 %	25 %

Table 3 shows how variations in 7 different operating conditions must be considered in the tendering. As the variations in different parameters can be combined this leaves a very large number of duty points. It is not realistic to include all possible combinations in the tender and in Broager the number of duty points were narrowed down to 11 for evaluation of the incoming offers.

3.2. Quantitative evaluation of heat pump solutions for Broager

11 duty points were chosen to evaluate the performance of different heat pump solutions. These revolves around a basic duty point with 3 variations in source temperatures, 4 variations in sink temperatures and 3 variations in heat load. The suppliers were asked to state the following performance data for each of the 11 duty points:

- Cooling capacity [kW]
- Pressure loss in heat exchangers for ground water [kPa]
- Heating capacity [kW]
- Pressure loss in heat exchangers for DH water [kPa]
- Power consumption [kW]

In this case the 11 duty points were weighted equal and used to calculate an average COP value for each supplier. The suppliers were also asked to provide an offer for operation and maintenance which in combination with the COP value returns the heat production cost for each offer.

As Broager district heating will provide heat for many years ahead and they trust that a heat pump is the right solution for future heat production, a long depreciation period was used to evaluate different offers. The offered heat pump solutions are considered in a period of 15 years, meaning that the heat production cost is viable and high COP values will justify high investment costs.

In Broager the components and constructions outside of the heat pump were tendered separately. These amounts to around € 2.0 mill. Table 4 below shows how variations in COP and investment cost of the heat pump itself will balance the net present value of the project. The interest rate is set to 3 %.

Table 4 – COP values can balance investment costs

COP value	Cost heat pump	Other equipment	Total cost	NPV – 3 %, 15 yrs
3,0	€ 0.0 mill.	€ 2.0 mill.	€ 2.0 mill.	€ -0.4 mill.
3,3	€ 0.5 mill.	€ 2.0 mill.	€ 2.5 mill.	€ 0
3,6	€ 1.2 mill.	€ 2.0 mill.	€ 3.2 mill.	€ 0
3,9	€ 1.8 mill.	€ 2.0 mill.	€ 3.8 mill.	€ 0
4,2	€ 2.4 mill.	€ 2.0 mill.	€ 4.4 mill.	€ 0

Table 4 states how a heat pump with a COP of 3.0 will return a negative net present value even if the heat pump was free. The maximum investment cost of a heat pump with a COP of 3.3 is € 0.5 mill., while a heat pump with a COP of 4.2 can cost as much as € 2.4 mill. and still return the investment.

As part of the tender, each supplier received a prepared spreadsheet that would return the net present value of the project according to the performance data, cost of maintenance and price of the heat pump unit. This enables the suppliers to value their solution from the clients perspective and fine tune the solution accordingly.

Qualitative differences from supplier to supplier must be evaluated as well but is not discussed in this paper.

3.3. Contracting in Broager

The district heating company in Broager received 5 offers from 4 suppliers for the groundwater based heat pump. Two offers were very close and in the end one had a more suitable service agreement. The chosen offer was a heat pump system consisting of one single stage low pressure unit and one two stage high pressure unit, that are connected in serial. The total system consist of 2 evaporators, 7 reciprocating compressors and 7 heat exchangers for desuperheating, condensing and subcooling at the heat sink. This returns a very high COP value that was one of the reasons that this offer was chosen for contracting. Key figures from the chosen offer are:

- Heating capacity @ 9 °C source and 70 °C supply: 4.0 MW
- COP @ 9 – 2 °C source and 35 – 70 °C supply: 4.04
- Investment cost for the heat pump: € 1.6 mill.
- Investment cost other equipment: € 2.0 mill.
- Total investment cost: € 3.6 mill.
- Net present value (3 %, 15 yrs.) € 1.8 mill.

3.4. Guarantee of performance

As stated earlier, low heat production cost is the main reason that the district heating plant will invest in a heat pump. The performance is also the main reason that this particular offer was chosen for the contract, meaning that this should not deviate from the specified.

Suppliers typically refer to the EN12900 standard regarding deviations in performance. According to this standard, the lowest acceptable capacity of the unit is 95 % while the COP value must be at least 90 % of the specified. In this case it means that the client must accept a heating capacity of 3.8 MW instead of 4.0 MW and that the COP can be reduced to 3.6 from 4.04. If this was the case the net present value of the heat pump would be reduced from € 1.8 mill. to € 0.7 mill. which makes the heat pump much less attractive.

EN12900 is not suitable for these kinds of applications as the tolerances are high and can change the feasibility from good to bad. Because of this the contract in Broager holds a performance agreement in which the supplier pays a remedy if the heat pump underperforms and is entitled to a bonus if the system is better than specified. The performance test is done on site before the unit is handed over. Energy meters with known uncertainties are used and deviations beyond these uncertainties returns either a bonus or a remedy. The size of an eventual fine is calculated from the actual cost of the deviation and then halved. This means that the supplier only pays half of the total cost if the system under performs and receives half of the gain if the system over performs. So far the suppliers have accepted this procedure.

4. Conclusions

Heat pumps in Danish district heating systems will mainly be add on units to existing gas based heat production with no need for further capacity. Because of this, heat pumps must be able to return the investment solely by lowering the heat production price. With relative high cost of electricity, COP values must be high and good performance are very vital to reach the most feasible systems.

This promote complex and expensive systems with multiple stages and reciprocating compressors. In the case of Broager a single screw compressor could probably reach the same heating capacity as the 7 reciprocating compressors. However, the power consumption will increase and as shown above, a heat pump with a COP of 3 is not feasible. Not even if it was free of charge.

The complex heat pump designs demand much more from the suppliers and preparing offers become very time consuming. This as well as new frames regarding performance guarantees is however gradually being accepted by the Danish suppliers. The new procedures mean much more work but the reward is also greater.

Looking into the future, changes in gas and electricity prices could change the current framework. If the total price on power consumption is reduced, energy consumption becomes less vital and simpler heat pump systems with lower COP values could be more feasible. As apparent in Table 1 electricity is taxed quite high. It is likely that this could be lowered meaning that energy efficiency will be less important compared to investment cost.

The heat pump in Broager is scheduled to be operating early 2017 and experience from the project will be announced.