Seawater Heat Pump:

FIRST OPERATIONAL EXPERIENCE FROM A MEGA PROJECT IN ESBJERG, DK

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The mega heat pump project in Esbjerg has attracted significant attention since it was first contracted in 2021—and for good reason. As a first-of-its-kind 70 MW seawater heat pump, it marks a bold step toward fossil-free district heating. This article shares valuable insights from the plant's first five months of operation, with more in-depth reporting to come after the guarantee testing phase. And yes—many elements, including the presence of pigs in seawater, have contributed to a smooth start.

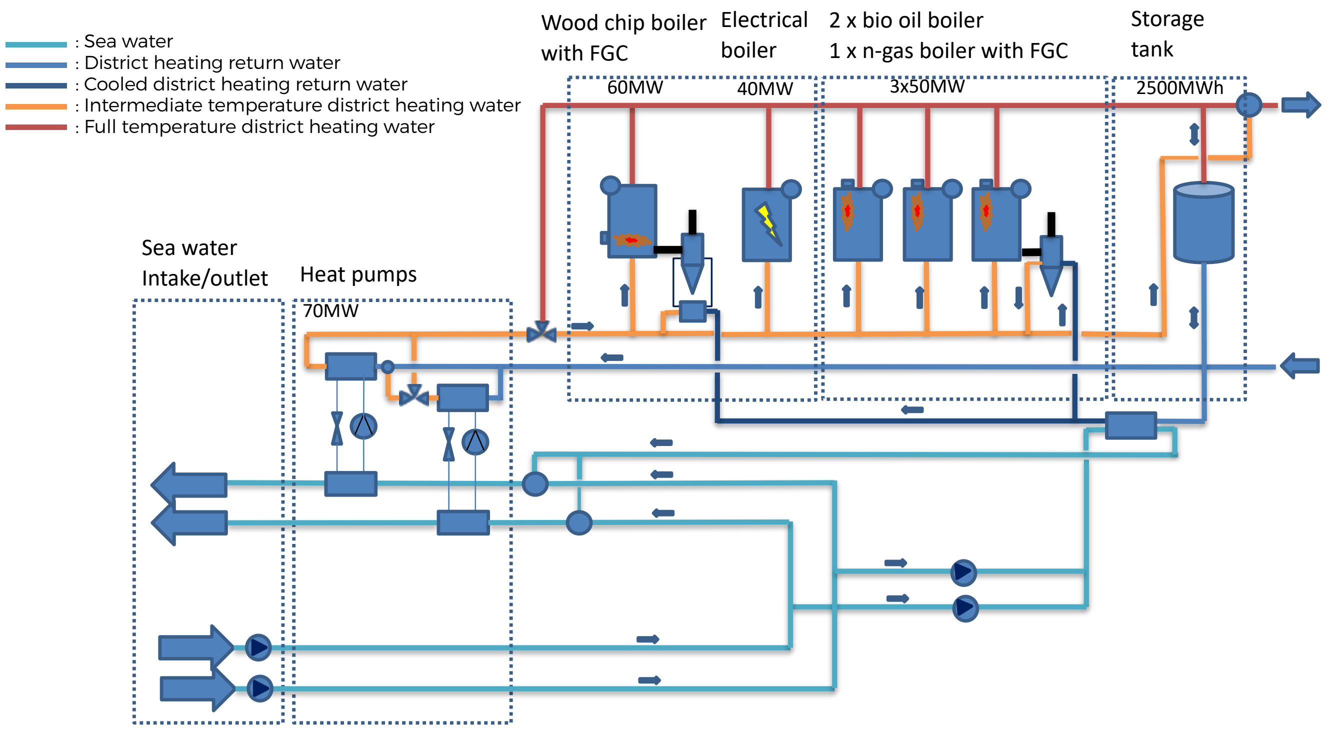

Figure 1: Illustration of the overall concept in operation at the harbor site.

Project history and ambitions

The seawater-based heat pump is part of the new district heating production capacity in Esbjerg and partly replacing a fossil-based district heating production from a 440 MWth coal-fired CHP plant (370 MWe). This Ørsted-owned[1] coal-fired plant was taken out of operation in August 2024. Until then, it had provided 50% of the district heating for consumers in the Danish cities Esbjerg, Varde, and the island of Fanø, with a total consumption of approx. 1,200 GWh/year. In 2017, the planning of the new production set-up was initiated. The result was a long-term investment roadmap in which phase 1 consisted of a 70 MWth seawater-based CO_2 heat pump, a 60 MWth woodchips-fired boiler, and a 40 MWth electrical boiler. The mixture of different technologies in the roadmap is a result of a balanced optimization of minimized investment costs, minimized operational costs, and robustness against varying fuel and power market conditions.

This roadmap was developed in close cooperation between DIN Forsyning and Added Values, and it was based on detailed techno-economical model-based analyses in which security of supply, thermal efficiency, and operational flexibility were prioritized. The techno-economical model was also an important foundation for setting up the economic and technical criteria for the heat pump tendering material, which was published in autumn 2020. At this point, it was of high priority to purchase a heat pump with operational characteristics including:

- High efficiency, i.e., high COP, especially during wintertime
- High load capacity, especially during wintertime
- High operational robustness (availability)
- High operational flexibility, incl. power load dynamics for ancillary services

A balanced evaluation of these four criteria was decisive for awarding MAN Energy Solutions the contract.

System Design and Integration

The heat pumps can produce either low intermediate forward temperature (> 55 °C) or full temperature (90 °C). In the former case, a further temperature boost can be provided by other units or condenser output can be used for a shunt at the transmission outlet. This mode allows for improved COP operation. The latter case allows for direct production to a transmission outlet or storage on the tank for later use.

In addition to these thermal synergies, the heat pump solution also includes high-performance power load flexibility. The two compressors enable up to 16 MWe continuous load flexibility for activation of ancillary services, depending on actual load and operating conditions.

Altogether, Figure 1 shows the total concept and boundaries across the different plants on the harbor site.

Figure 1 illustrates the general interactions and synergies

[1] Ørsted is a Danish energy company and global leader in offshore wind power, focused on developing renewable energy solutions including wind, solar, and green hydrogen.

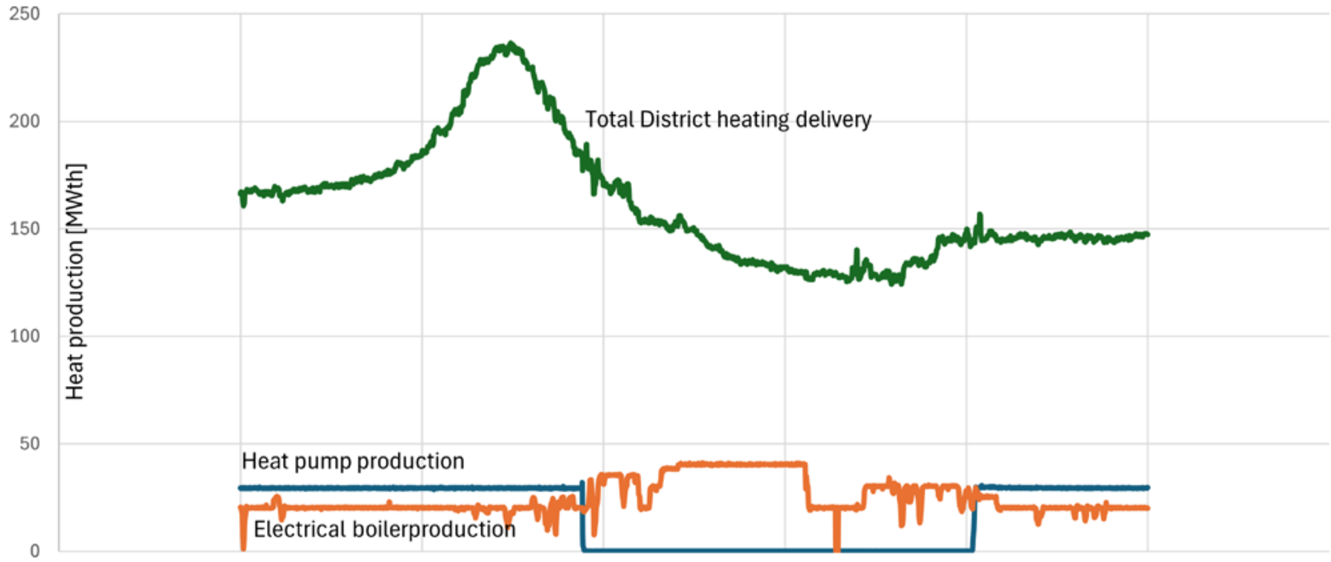

Figure 2: 24 h operation example illustrating district heating production at the harbor site.

enabled by the heat pumps and other plants. Sea water is used as a heat source through two intakes for the two evaporators, including a preheat option of seawater using district heat return. This ensures available heat pump capacity during low-temperature seawater periods, and it also enables improved efficiency on the flue gas condensers using low-temperature return water.

Promising initial operation of the mega heat pump

Since initial start-up and commissioning, the focus has mostly been on producing "flat heat" due to the lack of other low-price district heating capacity. For the same reason, heat pump operation has been primarily at 90 °C at the condenser outlet.

A 24-hour operation example is shown in Figure 2.

In this example, the heat pump 1 load is approx. 30 MWth (10 MWe) during night and morning hours and during evening hours. At midday, the heat pump was taken out of operation. This was due to the low district heating load and very low spot prices, which allowed the electrical boiler to deliver ancillary services. The other heat pump (not shown) was also in operation during the sequence, while the local storage tank and the nearby WtE CHP plant (Waste-to-Energy CHP plant) also contributed to the total production, leaving the harbor transmission lines.

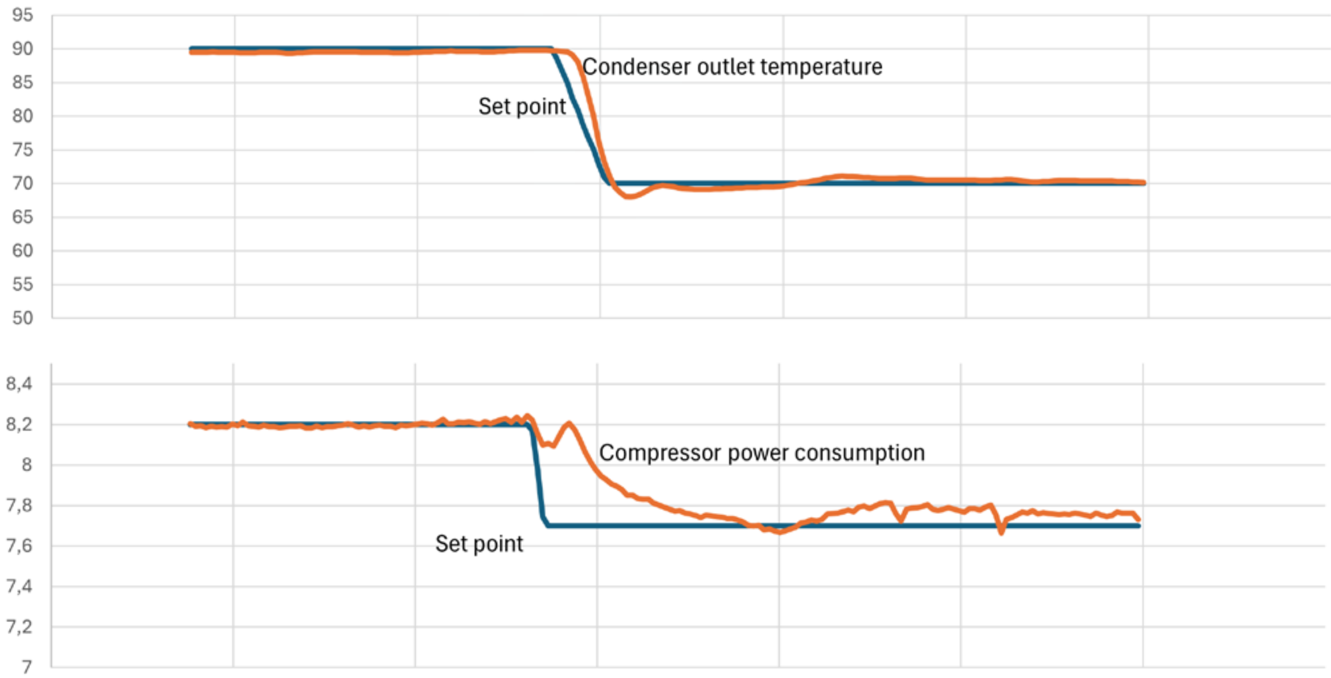

Figure 3: 15 min example illustrating the operational stability of one heat pump.

Feature	FCR	aFRR	mFRR
Also known as	Primary reserve	Secondary reserve	Tertiary reserve
Activation	Automatic	Automatic	Manual
Response time	Seconds	~30 sec – few min	~12–15 min
Duration	Short-term (up to 15 min)	Medium	Long
Purpose	Immediate frequency stabilization	Restore frequency	Restore reserves or handle imbalances

In the table above is a breakdown of the services essential for maintaining grid frequency at 50 Hz (Europe) or 60 Hz (e.g., North America). They are typically produced by Transmission System Operators (TSOs)

An important part of the tendering process was the economic and technical evaluation of the heat pumps' ability to provide ancillary services to the power grid. The heat pumps have not yet been prequalified by Energinet for ancillary services but are expected to be in the future. Prequalification requires certain dynamic characteristics of the physical heat pumps and also requires high-level control algorithms with a real-time interface to the markets.

The dynamic characteristics are illustrated in Figure 3, in which a setpoint change (and load change) test was performed. The setpoint for the condenser outlet temperature was ramped down from 90 °C to 70 °C showing a well-performing control loop on the measured value. At the same time, the power setpoint was changed from initially 8,2 MWe to 7,7 MWe, showing a quite fast response time on the measured value – in this case, 0,5 MWe change during 3 min. It is important to note that this is a preliminary test, whereas full guarantee testing still remains. As an example, during the Factory Acceptance Test at MAN Energy Solutions' in-house testbed in Zurich, the original compressors — now installed in Esbjerg — demonstrated an 8 MWe load change within just 30 seconds for one compressor, which makes it very promising for the FCR, aFRR and mFRR markets. These ancillary service markets consist of a capacity market as well as an energy activation market (EAM), and they are applied by the TSOs (Energinet in Denmark) and have been undergoing significant changes lately. Future utilization of heat pumps combined with other production plants and storage tanks in these markets is expected to make a significant contribution to the operational economy.

Measurement	Heat pump unit 1 + 2
Seawater inlet temperature	3.3 °C
Seawater outlet temperature	1.2 °C
DH return temperature	33.1 °C
DH forward temperature	90.0 °C
DH heat rate	55.2 MWth
Power consumption	19.9 MWe
COP	2.8

Figure 4: Figure 4 Performance measurement for 2 hours of operation (average values).

Full guarantee testing still remains

According to the contract, the guarantee testing program is quite comprehensive and has not been completed yet. Only some of the guaranteed characteristics have been verified so far, as utilization of full production capacity at full supply temperature has been prioritized during the high load season. However, the few performance tests carried out have shown promising results. An example of normal operation, i.e., operation at steady-state full load, is shown in Figure 4.

In Figure 4, the measured COP is lower than the guarantee values, which are up to 3.6 depending on the actual load operation point. It is important to emphasize that these numbers are preliminary performance examples.

Safe operation of the seawater system

The seawater system was an owner's delivery, i.e., different subsystems were functionally designed by DIN Forsyning and Added Values. Special attention has been paid to potential fouling issues, implementing different preventive measures, and installing different types of cleaning facilities. This includes

Figure 5: Pig and receiving station

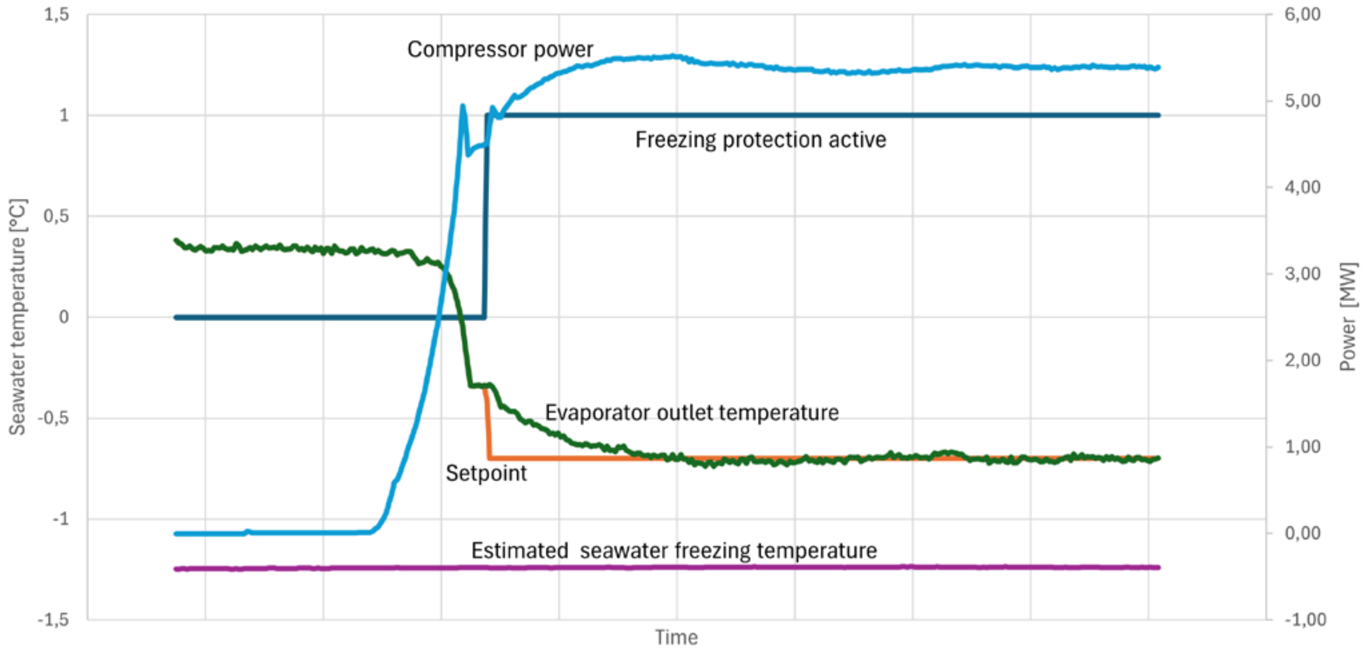

Figure 6: 1 hour operation illustrating control of seawater temperature

a pigging cleaning system for the seawater piping system. During the first 6 months of operation, these systems have worked well and according to the original plan – including the pigging system shown in Figure 5.

Another important area in focus is keeping a safe and efficient operation of the evaporators, including ensuring a frosting safety margin in the shell-and-tube exchangers. For this purpose, a load-reducing interlock is implemented in the control system in case critical conditions of seawater temperature occur.

An example of a start-up of one of the heat pumps is shown in Figure 6. During the start-up, the power consumption of the compressor increases from 0 MWe to approx. 5,5 MWe. The setpoint for the evaporator outlet is calculated as a function of seawater salinity with a safety margin of 2 °C from the estimated freezing temperature.

Further benefits still to come

In addition to the above-mentioned benefits, more are still to come.

In the short term, the new biomass-fired fluid-bed boiler will be in permanent operation. This means that utilizing temperature boosting and thus releasing an increased COP of the heat pump is possible. Furthermore, it allows for the opportunity to utilize the heat pump for ancillary services in the DK1 power market area, which is expected to be of high value.

The parties involved in the Esbjerg project are basically interested in disclosing the project and operational experience as soon as possible to benefit future projects. This article is, accordingly, very early in the plant life cycle, and further reports will be published when full guarantee testing and handover have been executed.

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