ENGINEERING
TOMORROW

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Case study | VLT® AQUA Drive FC 202

Electrification and sector coupling ensure **flexibility and optimal use of energy** for HOFOR

Copenhagen has adopted the ambitious goal of becoming a CO_2-neutral city by 2025, and district heating plays an important role. A demonstration plant at Copenhagen's Nordhavn harbor, which supplies cruise ship terminals with district heating, shows just how far you can get with electrification and sector coupling. Danfoss Drives has joined the Greater Copenhagen Utility's (HOFOR) green journey regulating the facility's heating capacity according to flexible demand, with variable speed drives ensuring optimal use of energy.

4 MWh
Energy storage

Photo: Ole Malling

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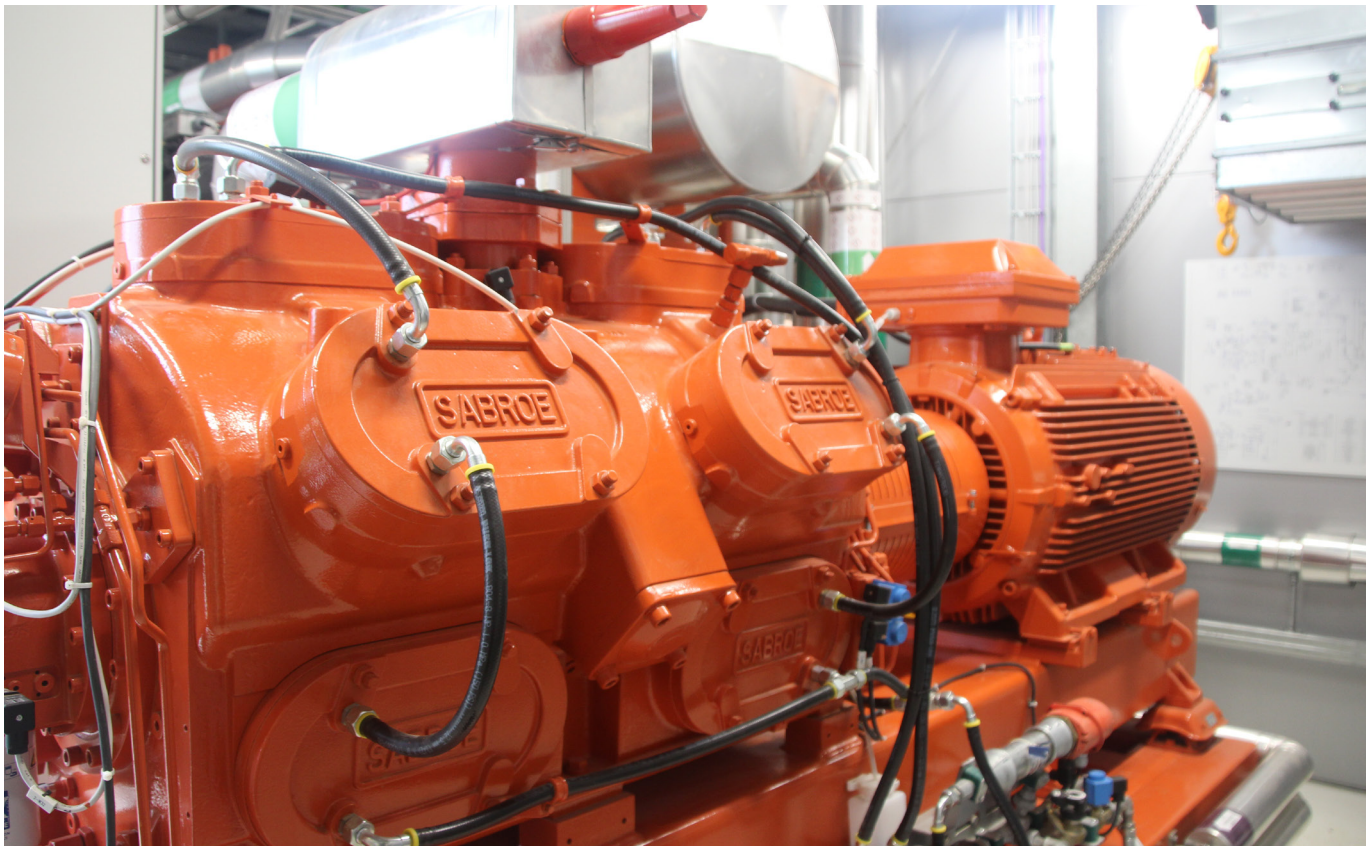
With sector coupling and sustainable energy sources, CO_2 goals are achieved

To reach global targets for CO_2 emission reductions, most of the future electricity supply will come from renewable sources such as sun and wind. Denmark already has a head start on the production of environmentally friendly electricity, and the challenge is more a matter of using the green energy when it is available. The fact is that the wind does not always blow in time with electricity demands. In fact, at certain times, wind turbines produce more energy than can be absorbed via normal consumption. That is why, in recent years, there has been more focus on increasing the demand for electricity through the electrification of more sectors, and on making electricity consumption more flexible.

One way of creating flexibility in power consumption is through sector coupling, where excess electricity is stored in other energy systems. One example of this is the district heating supply, where heat pumps with thermal storage use the power when it is plentiful and therefore inexpensive; and avoid using it in periods with peak loads in the system, for example, late afternoon, when most people come home from work and turn on lights and household appliances. HOFOR's FlexHeat project in Copenhagen's Nordhavn is a prime example of this type of sector coupling. The thermal energy storage corresponds to a "virtual battery" of 4 MWh.



The variable speed drive-controlled heat pump sends 70°C – 80°C water out into the system, and approximately 40 °C water comes back to the plant. The plant was supplied and installed by Johnson Controls Aps with consultancy from COWI A/S.

District heating based on ground water

HOFOR's district heating plant at Nordhavn was established in 2018 as a demonstration project that also supplies three cruise ship terminals and the nearby UNICEF warehouse. These buildings are all situated at Nordhavn and are too far from the city centre to warrant connecting the buildings to Copenhagen's district heating grid. Therefore, until recently they received their heat from two oil-powered heating plants, which the FlexHeat plant has now replaced. The plant is part of the large development project EnergyLab Nordhavn, which is subsidized by the Danish Energy Agency through the Energy Technology Development and Demonstration Programme (EUDP). Here, the focus is on innovative solutions for sustainable power and district heating supply. The plant satisfies both a real need for district heating, but is also a demonstration project in EnergyLab Nordhavn that can serve as inspiration for other cities in their green transformation.

The FlexHeat plant is a heat pump based on ground water that is retrieved from a 150 m deep well. The saline 10.5°C water is pumped through a heat exchanger with ammonia as a refrigerant. The temperature is raised in two steps via two compressors, and in a heat exchanger, the heat from the condensed ammonia is transferred to the district heating water, which then leads into a storage tank and is pumped out to consumers at the three cruise ship terminals and the UNICEF building. The FlexHeat plant also has two electric heaters, which are used in special circumstances to increase the temperature of the outgoing supply to the consumers. The heat pump has a heat output of 800 kW, and the two electric boilers have a total output of 200 kW. Altogether, the FlexHeat facility has a heating capacity of 1 MW.

According to the supply agreement, the water must, as a minimum, have a temperature of 65 °C when it reaches the last customer or building. As the heat loss in the system can be more or less significant depending on the outdoor temperature, the plant sends approximately 70 °C water out into the system. Approximately 40 °C water is returned to the plant, where it is then heated again.

Heat supply in different modes

The FlexHeat plant can operate in six different modes (where the sixth is not used in daily operation). Tore Gad Kjeld, who is an energy planner at HOFOR, explains that it is the intelligent switching between these modes that ensures the plant runs as effectively and economically as possible in relation to electricity prices. Modes one and three are the same, just with slightly different settings. The principle in these two modes is that the heat pump delivers heating to customers while storing excess heat in the tank. That is the mode of operation when electricity prices are low.

Mode two offers the possibility of boosting the heating water that is pumped out to customers up to a higher temperature, using an electric heater. This can be useful when the weather is particularly cold and the output temperature therefore needs to be higher.

In the fourth mode, the storage tank supplies the heat to customers. However, if the water at the top of the tank is a little too cold, the system can switch to mode five, which allows the water to be heated by means of the electric boiler instead of starting the groundwater heating pump inopportunely. This is important for the system's flexibility, as the heat pump does not respond well to being turned on and off at short intervals - and therefore needs to operate for longer stretches of time. The electric boiler allows for a small boost in temperature, so the plant can provide heat to customers from the storage tank in periods when electricity prices are highest.

The FlexHeat plant stores thermal energy corresponding to a virtual battery of 4 MWh in the 100-m³ storage tank on the left side of the image.

Smart operation ensures flexible power consumption

The heating facility operating mode is determined partly by the weather forecast, and additionally by electricity prices, which also reflect the local power supply situation. When wind turbines are harvesting at full power, prices are low and the FlexHeat facility can contribute to a higher coefficient of exploitation of green energy. The challenge is that the purchase of electricity has to be determined a day in advance, before the market closes. Tore Gad Kjeld explains:

"Smart-operation of the facility is based on electricity prices and a weather prognosis, where we take into consideration the power consumption viewed historically under similar weather conditions. Along with current operation data, these data are fed into an algorithm, which helps us work out a plan for the next day's use of electricity. The machine learns a bit every time, getting smarter and smarter because of the data that we feed into the system. This type of machine learning will make us even better in the future at operating the facility according to favourable electricity prices."

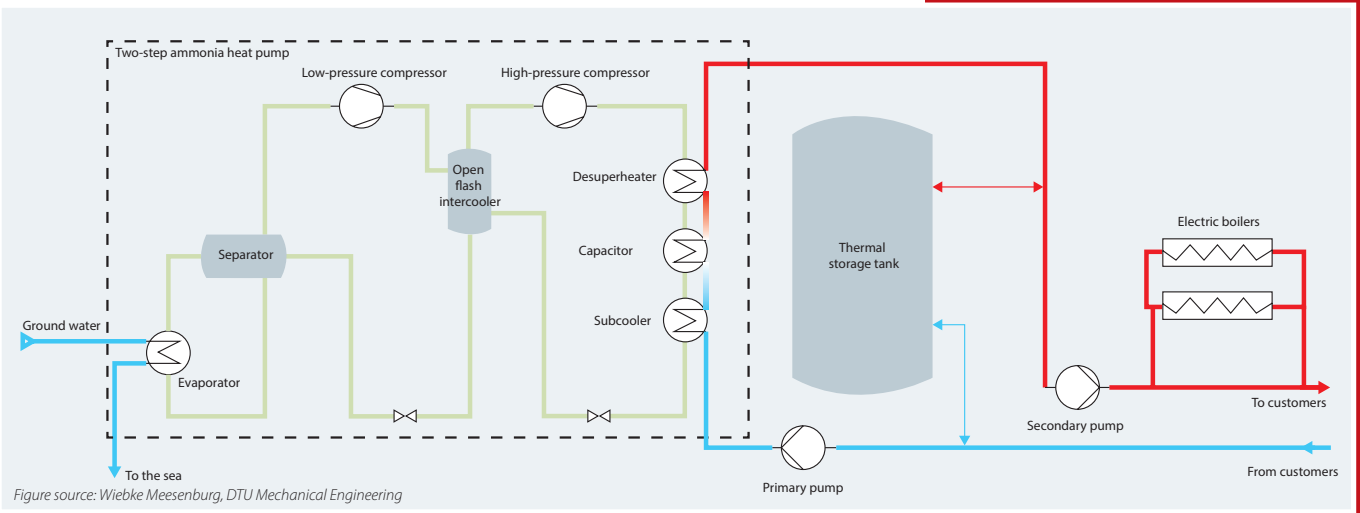


Figure source: Wiebke Meesenburg, DTU Mechanical Engineering

The FlexHeat plant can operate in six different modes, which ensures that it runs as effectively and economically as possible in relation to electricity prices.

VLT® AQUA Drive units can accelerate the heat pump from minimum to maximum performance in just a few minutes, while the electric heater can be adjusted upward in a few seconds,' explains Tore Gad Kjeld.

Savings on electricity bills and CO_2 emissions

It is difficult to say exactly just how big the savings are on the electricity bill, for operation of the district heating system in Nordhavn. HOFOR's simulations show that, with smart operation, FlexHeat will save 8.9% on the electricity bill in 2022, because the highest electricity prices can be avoided due to flexible power consumption. In the future, when a greater share of the price of electricity will consist of electricity spot prices, the savings may potentially be even greater. And how much CO_2 can the FlexHeat plant at Nordhavn save the environment? Tore Gad Kjeld estimates that the savings today are about 315 tonnes of CO_2 annually, seen in relation to LPG gas boilers, which would be the best fossil-fuel alternative to a district heating solution. And, in the future, when the electricity uptake becomes 100% green, the savings can potentially reach up to 430 tonnes of CO_2 annually.

Extensive collaboration on sector coupling

Sector coupling is a joint effort between different energy systems – in this case between the electricity supply company Radius Elnet and HOFOR's FlexHeat Nordhavn – which aims to utilize energy from electricity optimally. After taking the first successful step, the two companies are now looking into the technical potential of their systems to increase flexibility and exploit green energy to an even greater degree. You could say that, at the moment, this is only happening indirectly as HOFOR purchases electricity when it is cheapest. The next step will be when FlexHeat directly adjusts the operation of its heat pump according to the needs of the power grid to sell electricity. The two companies are now in the process of evaluating the systems' capabilities for achieving this.

On the drawing board, with the aim of extending the cooperation between FlexHeat and Radius, is a plan where the heating central offers help to the power grid in the form of a flexible demand with frequency regulation adjusted to the power grid's need to sell power. Danfoss AC drives can ramp up the heat pump from minimum to maximum capacity in just a few minutes, while the electric heater can be ramped up in just a few seconds. Therefore, it is possible to react at very short notice to the production of wind and solar power. Radius also operates a 460 kWh/630 kW grid-connected battery plant at Nordhavn, which is also able to store electricity at short notice. HOFOR's FlexHeat heat pump facility thus demonstrates how electrical and thermal power storage can be coupled, contributing to an optimization of the supply networks of both heating and electricity

HOFOR

HOFOR, the abbreviation for ***Hovedstadsområdets Forsyningsselskab*** *(capital region utility company), is a Danish utility company that supplies several municipalities in the capital region with drinking water and manages waste water. The company also supplies district heating, cooling and natural gas, and it invests in sustainable energy as part of the City of Copenhagen's climate plan which aims to make Copenhagen CO_2-neutral by 2025.*