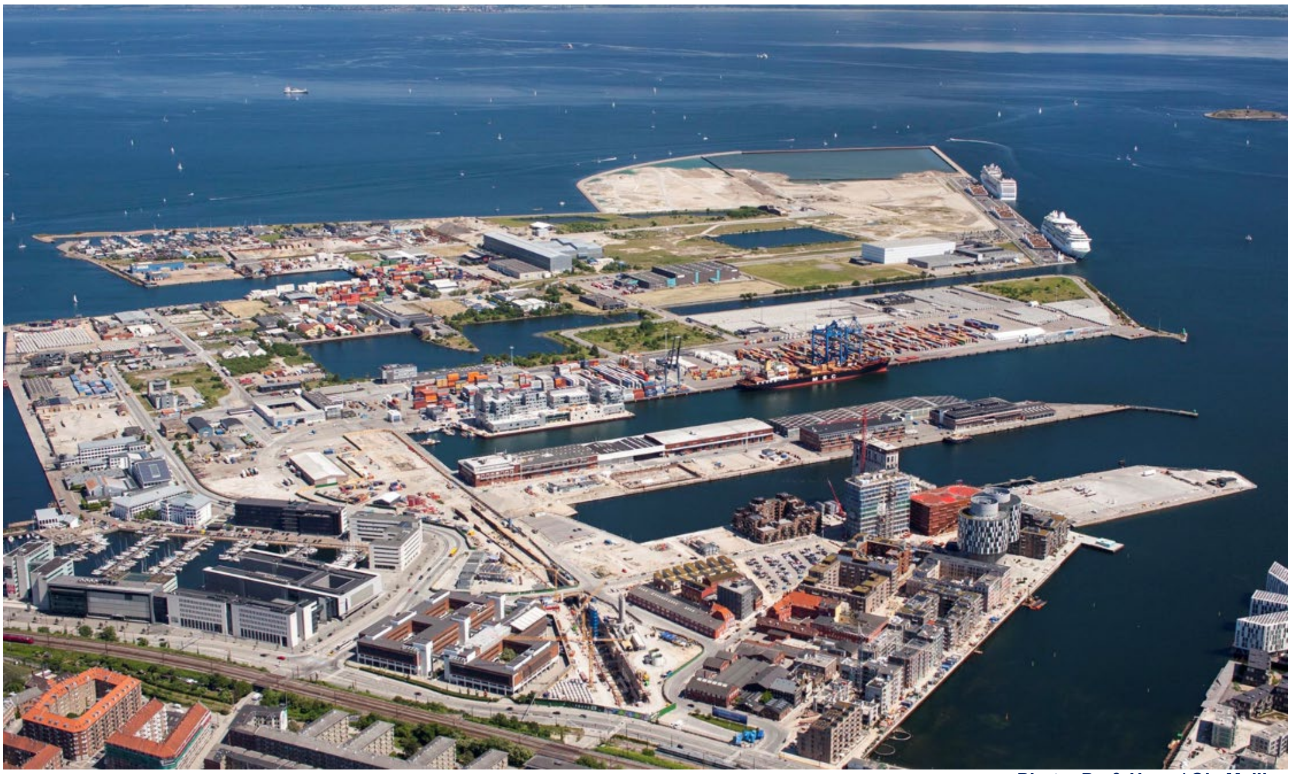
Delivery no.: D5.5a
Optimum supply of an island district heating grid by a local heat plant



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HOFOR
Author, Tore Gad Kjeld
Date 23th of May, 2019

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Preface

EnergyLab Nordhavn – New Urban Energy Infrastructures is an exciting project, which will continue until the year of 2019. The project will use Copenhagen's Nordhavn as a full-scale smart city energy lab, which main purpose is to do research and to develop and demonstrate future energy solutions of renewable energy.

The goal is to identify the most cost-effective smart energy system, which can contribute to the major climate challenges the world are facing.

Budget: The project has a total budget of DKK 143 m (€ 19 m), of this DKK84 m (€ 11 m) funded in two rounds by the Danish Energy Technology Development and Demonstration Programme (EUDP).

Forord

EnergyLab Nordhavn er et spændende projekt der løber til og med 2019. Projektet vil foregå i Københavns Nordhavn, og vil fungere som et fuldskala storbylaboratorium, der skal undersøge, udvikle og demonstrerer løsninger for fremtidens energisystem.

Målet er at finde fremtidens mest omkostningseffektive energisystem, der desuden kan bidrage til en løsning på de store klimaudfordringer verden står overfor nu og i fremtiden.

Budget: Projektets totale budget er DKK 143 mio. (EUR 19 mio.), hvoraf DKK 84 mio. (EUR 11 mio.) er blevet finansieret af Energiteknologisk Udviklings- og Demonstrationsprogram, EUDP.

Project Information

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WP Leader: Kristian Honoré
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For further information on this specific deliverable, please contact:

Tore Gad Kjeld
Energy Planner
Production – District Heating

Direct phone.: 2795 4341
E-mail: tgkj@hofor.dk

For other information regarding EnergyLab Nordhavn, please contact:

EnergyLab Nordhavn Secretariat
Center for Electric Power and Energy, DTU Electrical Engineering
Elektrovej
Building 325
DK-2800 Kgs. Lyngby
Denmark

E-mail eln@dtu.dk
Tlf. +45 45 25 35 54

www.energylabnordhavn.dk

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List of Abbreviations

- DSO: Distribution System Operator
- COP: Coefficient Of Performance
- NVP: Net Present Value
- FlexHeat: Name for the flexible heat facility installed by HOFOR A/S in Nordhavn

Executive Summary

HOFOR A/S has committed to supply at least three buildings by a local heat plant. The solution for this proposition has been to select a remote island grid in Nordhavn and supply this by a heat pump system. The existing grid consists of four buildings, which used to be supplied by two oil boilers in two separate heating grids – these heating grids are forged together and a central heat pump system supply these buildings with low-temperature district heating.

The heat pump system is a demonstration facility with a two-stage ground-water heat pump with ammonia as its refrigerant, two electric boilers and a large thermal storage tank.

In 2013, the planning of the facility started and was commissioned on the 1st of May, 2018. Tests and optimizations for the utility will be performed from 2018-2020. The facility, the island district heating grid and the costumers are utilized to test the flexibility of the district heating system. This flexibility can be used to integrate heat and electricity, as the heating system can consume electricity in an intelligent manner to relieve the electricity grids both locally and regionally – this will in turn lower the heat production costs due to lower electricity prices and flexibility payments from the electricity sector.

Version Control

Quality Assurance

Author	Reviewer	Approver
Tore Gad Kjeld	Brian Elmegaard	WPL group

Version	Date	Author	Description of Changes
[Official versions only]	[yyyy-mm-dd]		
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3	2019-05-01	Tore G. Kjeld	Revised version
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Status of deliverable		
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1. Introduction

The objective of this paper is to document the local heating solution installed by HOFOR A/S in the outer region of Nordhavn to supply four industrial constumers with sustainable heat. The following can summarize the objectives of the local heating solution:

- Selection of group of costumers, at least three, outside of the district heating grid
- Evaluation of the current heat supply in the region
- Establishment of a local heat plant facility which are economically and environment advisable
- Evaluation and perspective on the future heat supply in the region

This paper is thus an introduction to the more in-depth analysis performed in deliverable 5.5b, in which the flexible system is applied intelligently.

2. Location

2.1 District heating grid

Figure 1: Position of the district heating grid in the Nordhavn region relative to the island grid.

In Figure 1, the end of the district heating pipeline in Copenhagen going towards Nordhavn is shown in the orange-circled area and the location of the local heating solution, FlexHeat, is circled in the green area.

The closest distance to the facility is about 2,7 km, which makes it too expensive to expand the district heating grid given the low consumption in the area. Another aspect for not expanding the district heating grid is the uncertainty about future demand in the area as well as the Nordhavn expansion plans regarding metro-stations and high roads potentially crossing through its path.

The area thus fulfills the criterion of being outside of the district heating grid.

2.2 The FlexHeat location and local district heating grid

The examined flexible heating production is named FlexHeat Nordhavn, which is part of a larger island district heating grid, which can be seen in Figure 2.

Figure 2: The island heating grid of investigation

The island grid consists of four buildings. The right-hand side of the grid consists of three cruise-ship terminals, which combined hosted around 900.000 cruise-ship guests in 2018. On the left-hand side, there is a UNICEF warehouse, which ships emergency supplies globally from Nordhavn. These four buildings have an expected annual demand of 1.800 MWh, which could potentially increase to 2.200 MWh due to the expected terminal 4, which will be positioned further out next to terminal 3.

The grid before FlexHeat was divided into two sections: one for the UNICEF supply, and one for the cruise-ship terminals. The existing grid is shown with the black-lines, and the blue lines are the newly installed grids as seen in Figure 2. The existing grid in section 1 was supplied by an oil-fired boiler of 850 kJ/s and section 2 was supplied by an oil-fired boiler of 520 kJ/s. The two oil-fired boilers have been taken out of production but kept as back-up for the new system.

A new flexible heat pump system has been installed on the parking lot of UNICEF, denoted FlexHeat on Figure 2, and the grid has been reinforced to reach the existing grids. This facility is required to reach a peak demand of 0,7 MJ/s – potentially increasing upwards to 0,8-0,9 MJ/s with a new building.

2.3 Low-temperature district heating

The area of Nordhavn, which is shown on Figure 3, is planned to be converted to a low-temperature district heating grid.

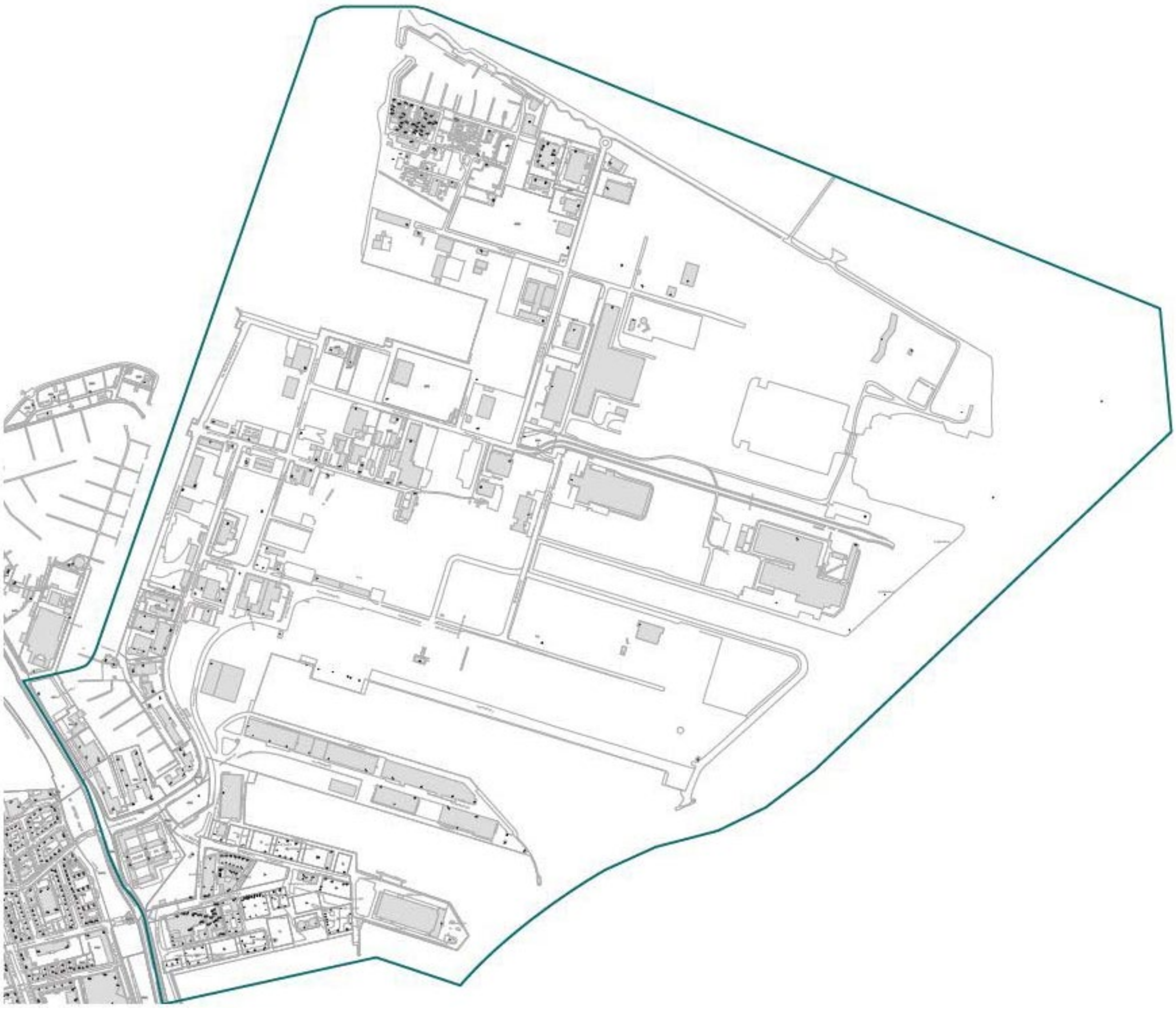

Figure 3: The area of Nordhavn, which is planned to be converted into a low-temperature district heating grid.

Here, the temperatures that the costumers need to be able to manage are the following:

Heating season (15/9-15/5)
- Forward temperature: 65 °C to 70 °C
- Return temperature: Maximum of 45 °C

Outside of the heating season (16/5-14/9)
- Forward temperature: 65 °C
- Return temperature: 30 °C

This is thus the dimension criteria for the FlexHeat facility. Furthermore, the owner of the three cruise-ship terminals, CMP, has signed a contract with HOFOR A/S, in which they allow HOFOR A/S to test different flexibility based tests with their buildings for research purposes.

2.4 The customers

The customers in the grid were mentioned earlier: three cruise-ship terminals and a UNICEF emergency warehouse. HOFOR A/S was aware of the fact that the return temperature from the customers are vital for the performance of a heat pump facility as the COP drastically reduces with a higher return-temperature. Hence, counselling of the customers on their facilities was paramount to the success of the project.

The three cruise-ship terminals were recruited as a flexible costumer, which means that the owners of the terminals, CMP, has agreed on flexible behavior of the buildings to suit the district heating grid within acceptable boundary conditions. Hence, HOFOR A/S could properly optimize the heat supply temperature and reduce the return temperatures. Here, HOFOR A/S installed the energy management system, ECL 310, to supervise and control heat supply to the main heat exchanger of each building.

An example of this system is seen on Figure 4.

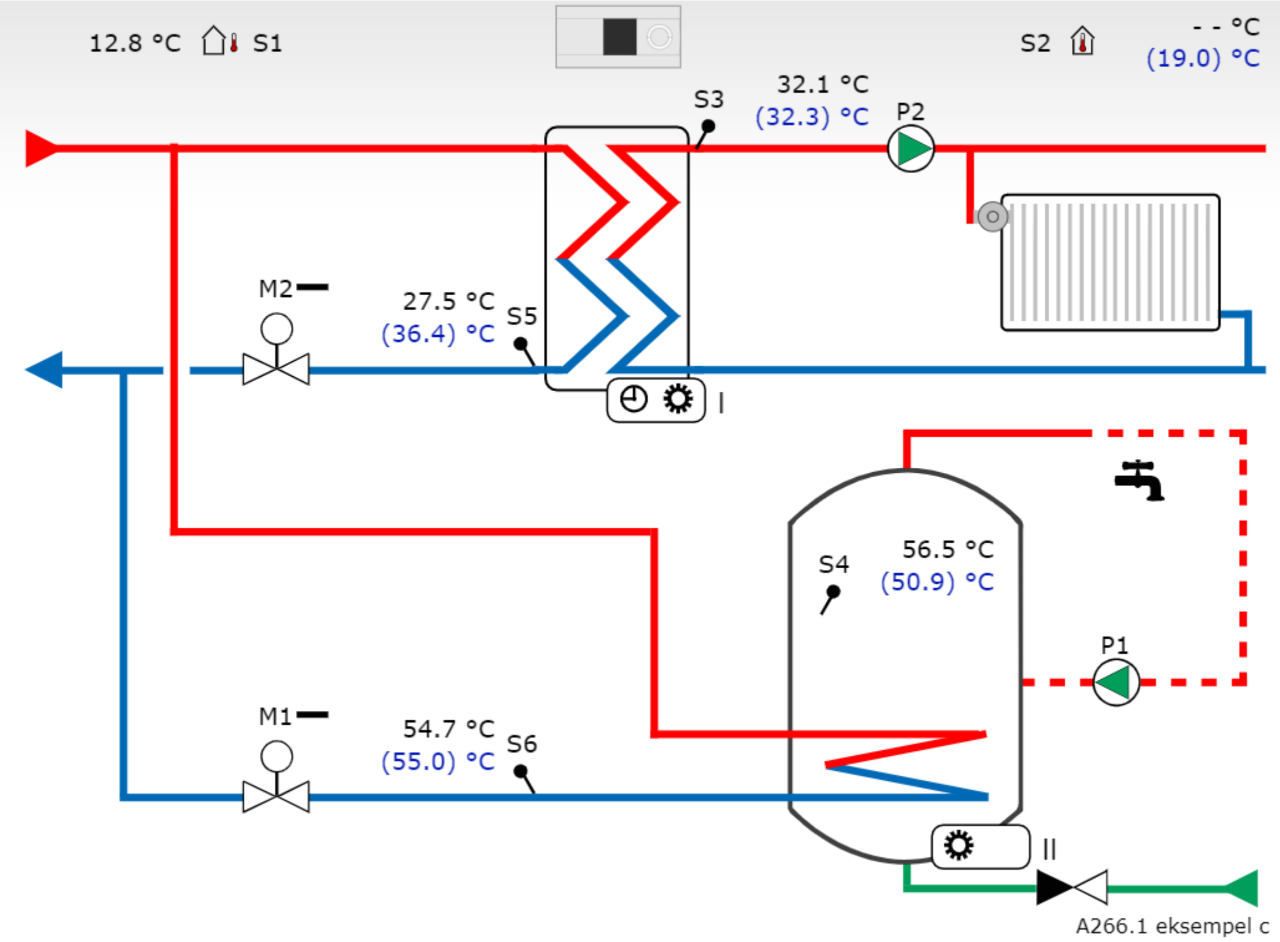

Figure 4: The ECL 310 portal from Danfoss to supervise and control the heat supply to the cruise-ship terminals.

Here, the heat supply to the building is optimized according to the outside temperature. The diagram is a simplified version of the heat system in the cruise-ship terminals, but as HOFOR A/S does not go interact with the secondary side of the costumer application, the diagram is fitting. The regulation of the secondary side is performed by CMP with counselling from HOFOR A/S. With substantial effort from HOFOR A/S, CMP and a third counselling firm, JOS-consult, the return temperature was decreased by approximately 15 °C.

The UNICEF warehouse is a more complex system, and is not a flexible costumer. However, HOFOR A/S has been counselling the property owners, By&Havn, in the aim of reducing the return temperature and hereby optimizing heat consumption. The return temperature was decreased by approximately 10 °C here.

3. Background

3.1 FlexHeat time-line

The project time-line goes from 2013-2020. Figure 5 summarizes the events.

Figure 5: Time-line for FlexHeat - from the feasibility study to its finalization of tests.

Here, the feasibility study in 2013 was looking at all the framework surrounding the installation of a heat unit in Nordhavn – some outlines are:

- The site and its potential for a heat source
- Technology catalogue for heat pumps, electric boilers, heat storages and so forth
- Reference technology of boilers fired by gas and oil

The study concluded the potential for a heat pump, and extra flexibility projected by installing a heat storage and electric boilers.

In 2015, the contracting were done for consultants on the facility, entrepreneurs for the heat pump system delivery and for the building site. COWI A/S won the consultant role, Johnson Controls Aps won the entrepreneur role on the heat pump system, and Hoffmann A/S won the entrepreneur role on the building site, the grid extension and ground-water drillings.

The installations were all initiated in quarter 3 of 2017, and finalized by quarter 2 of 2018. In 2018, the SAT-test for the facility were performed in March, and a continued facility test were performed throughout April and the facility commissioned on the 1st of May, 2018.

In the remaining period, tests for the heat pump, storage tank and electric boilers have been and are to be tested from 2018-2020.

3.2 Economic valuation

The system is installed as a demonstration facility, which is also able to provide heat at all times for the costumers. The aim for the business case has thus been to provide a sustainable solution, which will be able to reach a payback time within 20 years according to the reference of oil boilers. This has been possible with the electricity duties that were present in 2016, and it has later been compared to a gas solution in the area and provides a payback period within 20 years here also.

The system is installed for demonstration use, not commercial use – hence there are more metering units on the facility than you would do on a commercial facility, and the tank is substantially larger than what is suitable for commercial operation, as the tests require a large amount of flexibility to illustrate the potential of intelligent heat pump usage.

The business case is thus not a valid parameter for comparison when installing heat pumps, but for the area taken into consideration, it is a healthy business case after all. Also, with current tests for flexibility and lowering of electricity tariffs from 2018-2020. The comparison can be seen below compared to a gas-fired boiler in Figure 6. The discount rate was 3,5% being standard for HOFOR.

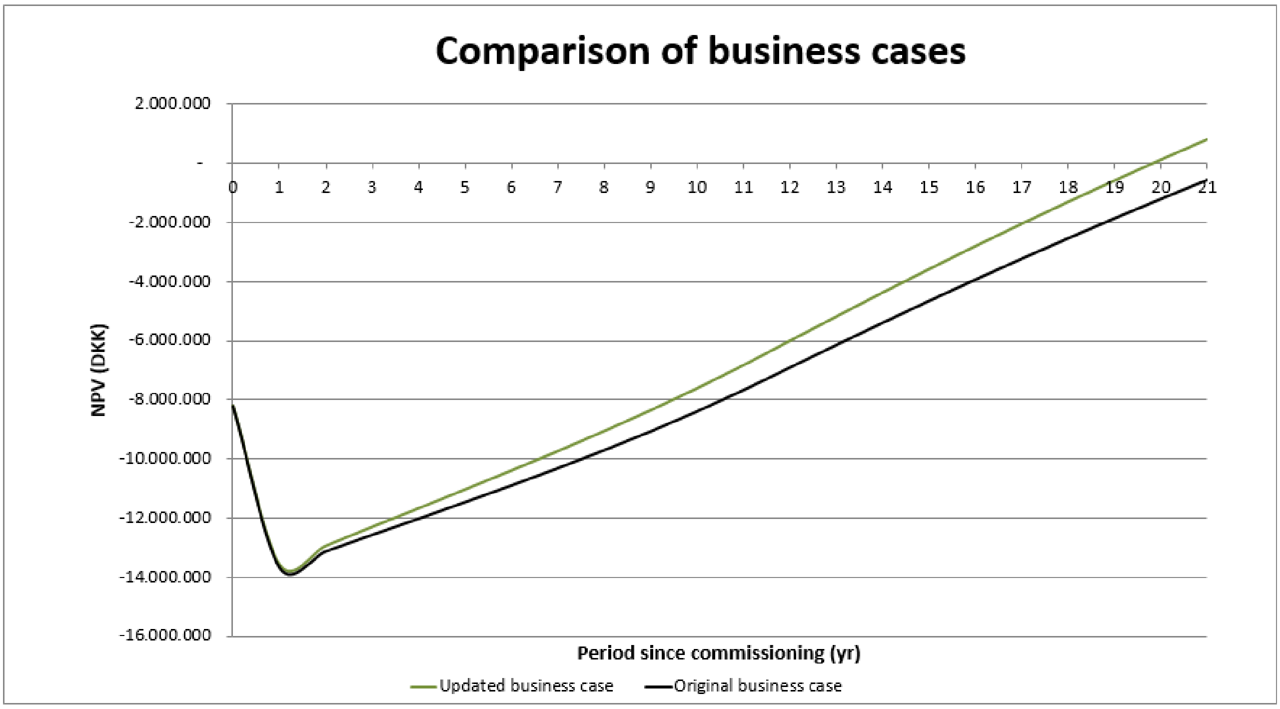

Figure 6: The business case for FlexHeat comparison between the original business case performed in 2016 with gas and an updated one for 2019.

Hence, the business case has been improved with 2,1 mio. DKK due to a change in regulations or a payback-period 3 years shorter than expected.

4. Facility description

The system consists of a heat pump, two electric boilers and a thermal storage tank. The key-values for the units are the following:

Heat pump

- Heat production of 800 kJ/s
- System COP of 3,2*
- Ground-water source at 10 °C
- District heating temperature range of 60°C to 84 °C

*System COP refers to the total heat delivered related to the electricity consumption for the compressors (low- and high-pressure), the ground-water pumps, the primary pumps and the secondary pumps.

Electric boiler

- Heat production of 200 kJ/s
- Can boost the temperature up to 90 °C

Thermal storage tank

- Volume of the tank is 100 m^3
- Heat storage potential of 4.000-5.000 kWh
- Can provide 4-14 hours of flexibility

4.1 Simple overview

A simple schematic of FlexHeat is shown in Figure 5:

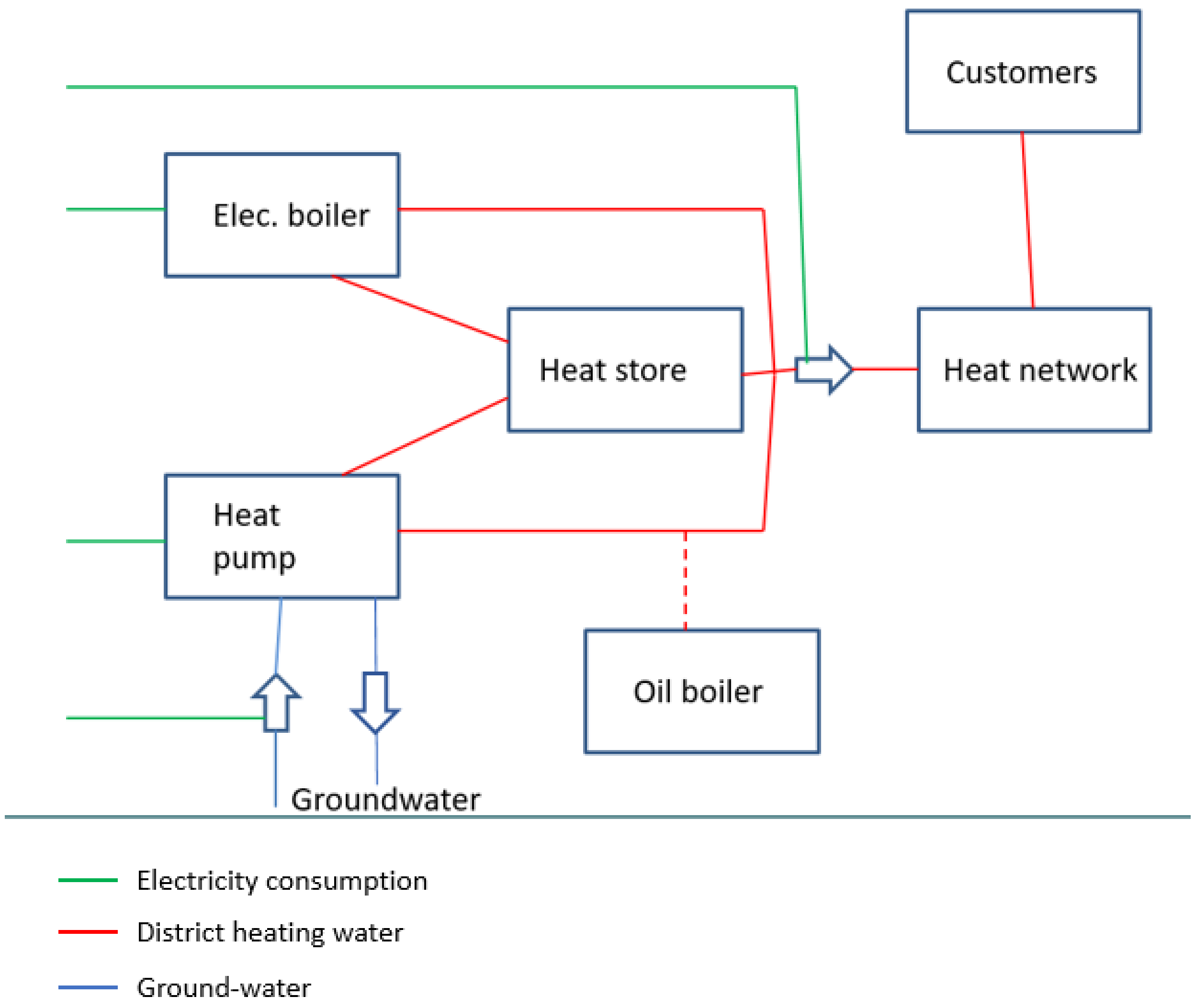

Figure 7: Simple schematic of the FlexHeat facility.

The hot water storage tank has a central position in the system as indicated in Figure 7, and the system can run in the following modes:

1. The heat pump runs at a given capacity and based on the consumption level, the remaining heat is delivered into the tank

2. The same as mode 1, but the temperature to the costumers is boosted to a higher level by the electric boilers if needed.

3. Same as in mode 1 but with different settings for the tank and heat pump. Mode 1 is used as a default mode whilst mode 3 is used for tests.

4. The heat pump is not running. The storage tank discharges heat to the costumers.

5. Same as in mode 4, but the temperature of the discharged heat from the tank is boosted by the electric boilers to a sufficient level.

6. The heat pump is not running. The return water is circulated through the electric boiler to boost the temperature in the bottom of the tank while discharging the tank.

4.2 Detailed overview

FlexHeat is presented more detailed in Figure 8:

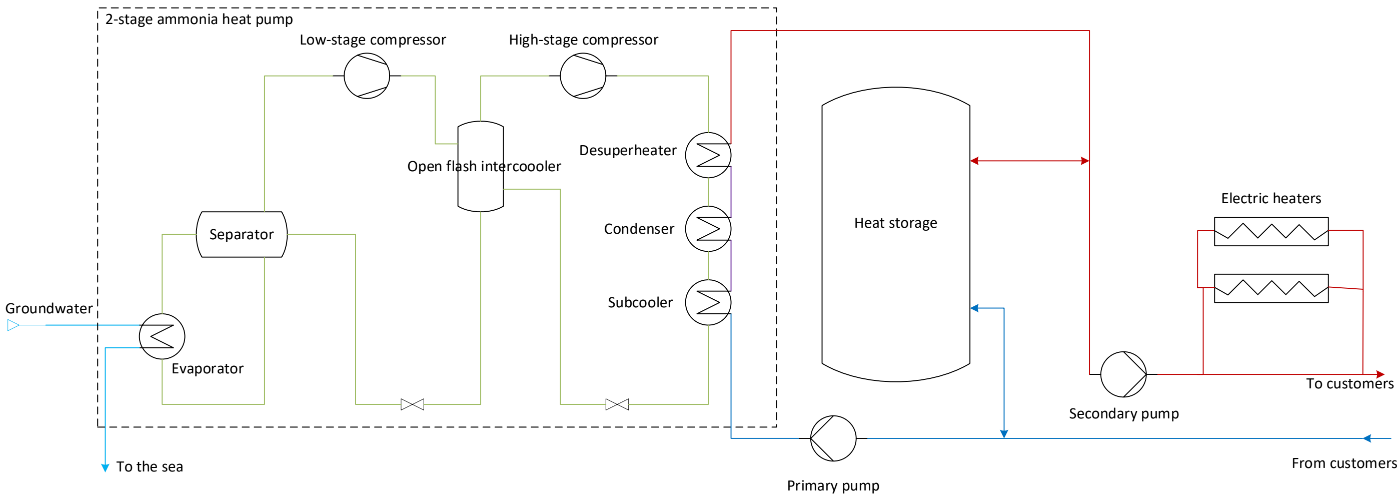

Figure 8: Detailed version of the FlexHeat system. [Source: Wiebke Meesenburg, DTU Mechanical Engineering – Presentation at DTU Køle- og Varmepumpeforum 2019 with the headline "Feasibility and limitations of flexible operation of large-scale ammonia heat pumps."]

In Figure 8, the FlexHeat system is presented in which a two-stage ground water heat pump with ammonia as the refrigerant is capable of delivering 800 kJ/s, a hot water storage tank of 100 m^3 equivalent to 4500 kWh storage capacity, with additional 200 kJ/s electric boiler capacity.

4.3 3D-drawing of the facility

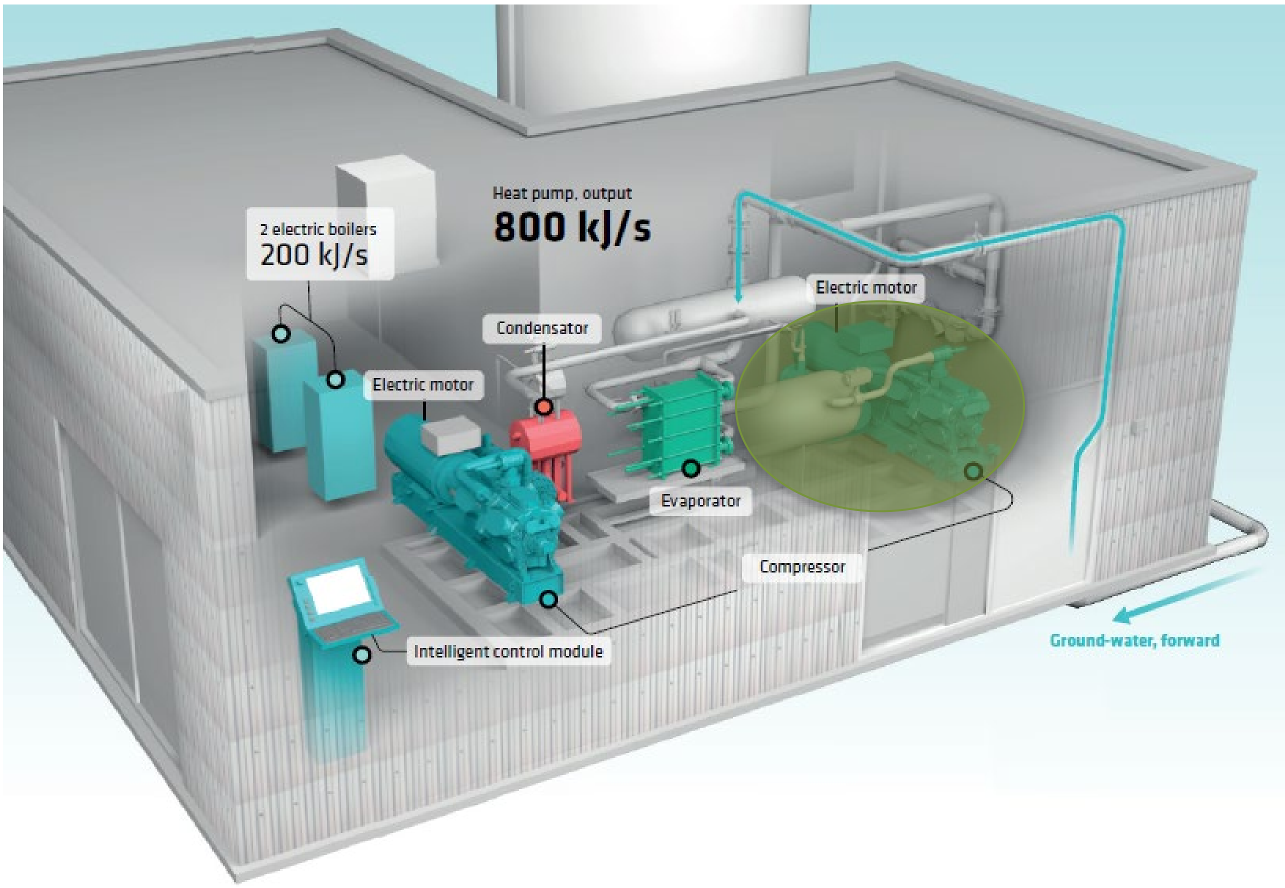

Figure 9: 3D drawing of the facility with the most important components.

Figure 9 shows the most important components of the flexible heat system in the building – i.e. the heat pump components (evaporator, condensator, compressors and their electric motor) and the electric boilers. The storage tank can be seen as the cylinder in the background, which is outside of the building, but attached by the tubes going in- and out of the storage tank. The green marked area is the part of the heat pump, which is shown in Figure 10, an example of how the system is seen from the installed facility at the Nordhavn site.

4.4 Picture from the Nordhavn site

Figure 10: Picture from the Nordhavn site - this is a picture of the high-pressure piston compressor.

Figure 10 shows a picture from the facility with one of the most important components – the high-pressure piston-compressor.

5. Perspective for the facility

The facility has been installed with a high degree of flexibility in order to fully test the system, as it is a demonstration project. Here, the heat pump technology can be tested fully whilst also testing the capability of a thermal storage tank and electric boilers. Most importantly, the interconnection of the entire system can be tested in which district heating can supply its flexibility towards the electricity sector. Figure 11 shows the flexibility pushed towards the electricity sector.

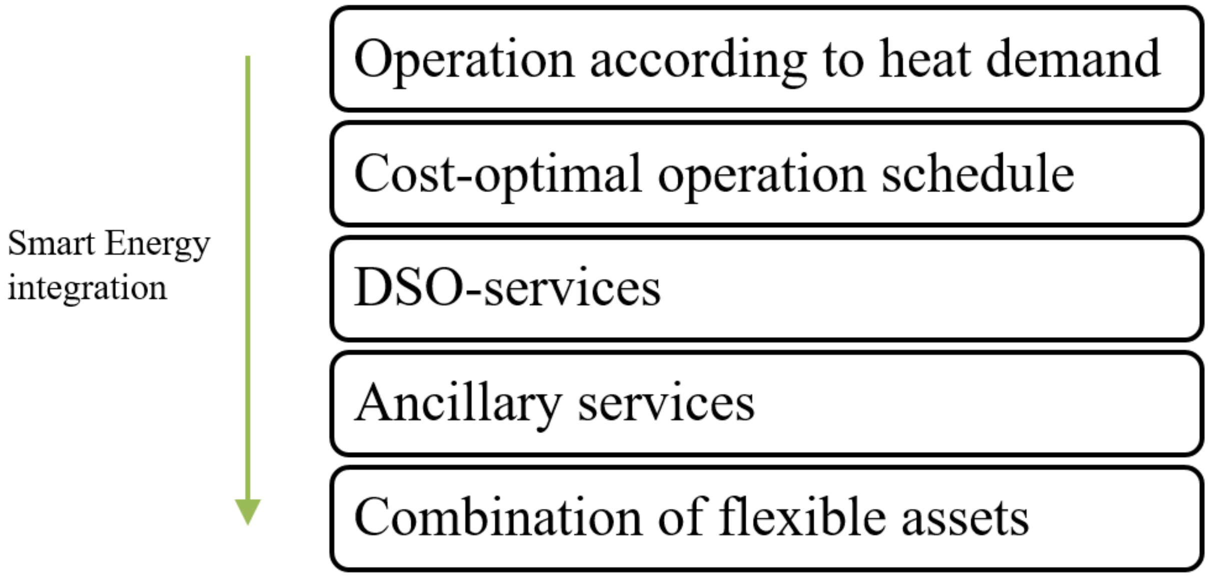

Figure 11: Integration towards the electricity sector by supplying the flexibility from the district heating sector. [Source: Wiebke Meesenburg, DTU Mechanical Engineering – Presentation at DTU Køle- og Varmepumpeforum 2019 with the headline "Feasibility and limitations of flexible operation of large-scale ammonia heat pumps."]

Here, it is tested to see how the system can operate in different steps in which it becomes more intelligently as we move further into Smart Energy integration.

Level 1 is to supply the heat needed for the costumers without using the flexibility of the tank.

Level 2 is to utilize the flexibility of the tank by running the heat pump and electric boiler primarily when the electricity prices are the lowest, and utilizing the stored heat in the tank when the prices are higher.

Level 3 is to help the local distribution grid by ramping the heat pump up or down depending on the conditions. If the distribution grid experiences a surplus of electricity production – which could be due to solar- or wind power – then FlexHeat can consume extra electricity for a period. On the other hand, if there is shortage of electricity in the grid, FlexHeat can shut down for a period.

Level 4 is to help the overall grid, the transmission grid. This is done by frequency-related services, which can help on a higher level of the grid.

Level 5 is combination of other assets, for example large-scale battery systems used for grid control or electric vehicles. Here, the heat pump can utilize their electric storage capabilities to achieve lower electricity procurement costs.

All of these initiatives together with a series of mechanical and thermodynamic tests of the system are used to illustrate the potential of the heat pump system and to lower the heat production cost as much as possible. Additional flexibility in the island district heating grid and the costumers are also tested and will be reported in T5.5b.

6. Conclusion

HOFOR has successfully built and commissioned a heat facility, which fulfils the criterions for customers, remote location, economy and sustainability. This was done by commissioning a 1.000 kJ/s flexible heat system consisting of a two-stage groundwater heat pump with ammonia as the refrigerant, two electric boilers and a large hot water tank. The facility was commissioned in May, 2018.

Intelligent control of the facility and the network will be thoroughly investigated in D5.5.b.