Techno-Economic optimization of cooling centrals on Odense city New University Hospital and University of Southern Denmark

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Master Thesis in Energy Technology

10. Semester

Institute of Chemistry-, Bio- and Environmental technology.

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University of Southern Denmark

Period: 1st September 2016 to 22th May 2017

Deadline: 22/05/2017

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1 Preface

This is a project by 10. Semesters students, and is done in context of a master study in Energy Technology on University of Southern Denmark. The scale of the project is 40 ECTS and with attention to district cooling in various scenarios along with investments into heat recovery on a modern Danish hospital and university. The project is carried out by Nicolaj Tidemand Haagensen and Anders Bloch.

We would like to thank Jonas Rosenlund Jensen from Technical Service on SDU for providing hourly demand profiles and system diagrams of cooling installations on SDU. We would also like to thanks Abid Rabbani and Lars Yde from SDU for providing feedback to presentation and answering questions during cluster meetings.

We would also like to thank Hans Peter Hansen from Medic OUH for providing contacts and data related to the coming New OUH.

We would also like to thank Peer Andersen from Fjernvarme Fyn for the initial meeting that led to the basis for this project.

We would also like to thank Henrik Wenzel from SDU for assisting at meeting and feedback on which direction the project should take.

We would also like to thank Kim Larsen from Caverion, who assist in maintaining cooling centrals on SDU.

2 Summary

All the way from regional municipality to national and European commission level, there's a political will for transitioning our society towards being fossil neutral. There is not only a will, but clear goals for renewable energy production and a Danish policy to be free of goal, gas and oil by year 2050. These policies could prove to be a challenge to our energy system, because there's a concern that the policies will introduce large quantities of fluctuating electricity producing technologies like windmills and solar panels. A way to counter such concerns is by having flexible demand, to that end heat pumps may be a suitable technology.

This thesis examines the potential for making investments into heat recovery solutions for existing and new cooling centrals on University of Southern Denmark and a new university hospital in Odense city. The purpose is to reveal the economic potential and the optimal utilization of heat recovery. The technology in examined in both cooling centrals are electric chillers and dry coolers along with heat pumps.

In total, 3 scenarios have been developed to facilitate this examination and each will shed light on different aspects of the same goal, to determine the potential for heat recovery in the two selected buildings. The first scenario is a business case into applying heat recovery to the existing cooling central on University of Southern Denmark. Second is also a business case into the coming New University Hospital in Odense city. Third scenario seek to discovery, if any, benefits to connecting the two buildings in a district cooling and – heating grid.

Hourly demand profiles are the basis for most of the calculations done throughout the report. Coolpack was applied to determining COPs for electric chillers on cooling centrals

The first scenario attempt to showcase two ways of utilizing cooling heat from electric chillers, one to substitute district heating from local supplier and the other by delivering it to hot water storage tanks and avoid electric heater electricity consumption on the university. The results for this scenario, showed NPV of a 20-year period to be -254,672 DKK for substituting district heat and -517,00 DKK for avoiding electric heater consumption. Also in relation to scenario 1, the business economic heat cost is 280 DKK/MWh for district heat and 358 DKK/MWh electric heater.

In regards to the second scenario, the total cost amounted to 88.9 million DKK. The **investment** cost is 40 million DKK, **O&M** 10.83 million DKK, **purchased electricity** 15.82 million DKK**, grid tariff** 1.94 million DKK, **EL-tariff** 5.59 million DKK, **VAT** 3.79 million DKK and **system tariff** 0.66 million DKK.

Thirds scenario was modelled in EnergyPro, and results showed a positive 17,784DKK when connecting the two to the contrary of leaving them separated. This is mostly due to efficient dry coolers being able to utilize its capacity to produce cooling for the other site and not just its own.

All results where subject to sensitivity analyses, and results showed the most significant barrier were the initial investment cost and the low number of operation hours on electric chillers.

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5.1 Introduction

The Danish energy policy aims to transition Denmark to be independent of coal, oil and gas in 2050. The results of such policy is, that the total Danish energy consumption needs to be supplied by renewable energy sources in 2050 [Danish Energy Agency, 2017]. This transition is also supported on a regional level on Funen, consisting of several stakeholders, Energiplan Fyn attempts to create a common ground and vision for the transition into fossil free society, as reported in (Energiplan Fyn, 2016). The transition is not restricted to national level, and the European commission is pushing for at least a 27% share of renewable energy consumption in 2030 (European commission 2017).

To make the transition and reach the set targets, many analyses points to an increase in electricity production, especially from solar and wind. This creates new opportunities on the supply side and heat pumps is often seen as a technology ready to supply heat to districts and individuals, as reported by (Energinet.dk 2016). The cooling production does like heat pumps have potential for synergy with fluctuating renewable energy sources. Furthermore, there is a potential for covering much of the existing cooling demand with technology such as electric chillers. Existing cooling plants are typically individual operated and about 0.5 MW, while at the same time exist benefits of scale to plants at 2 MW (Dansk Fjernvarme 2016) Besides, many new individual installations today have uncertainty attached to the needed maximum capacity which leads to overcapacity, an uncertain that can be avoided with district cooling. Today, cooling production is dominated by traditional cooling technologies with no heat recovery, but that is changing towards heat pumps and electric chillers with heat recovery of excess heat. Tightening regulations for comfort and insulation for buildings as well as increasing demands of process cooling to servers, means cooling demand will increase (Dansk Fjernvarme 2016).

To reach a cost-effective transition towards fossil free energy system, it's important to include all of the energy system, find synergies and optimize them, in that context district heat and –cooling can contribute to that endeavour.

5.2 Problem statement

Fjernvarme Fyn, a district heating supplier on Funen, developed a not entirely completed technical proposal to the execution of delivering cooling and heat for the new Odense university hospital, known as *New OUH,* on request of Medic OUH, consultant on the New OUH project. The proposal was not acted upon due legal reasons, and in order to determine the feasibility envisioned by Fjernvarme Fyn, this project attempts, among other things to, use that proposal as a starting point for one part of the project. The current project planning does not include heat recovery on cooling centrals for NEW OUH, but didn't rule out the possibility for a future investment into heat recovery is possible as indicated by Hansen, H (2016). This could mean NEW OUH is missing out on economic benefits by not utilizing excess heat. The cooling solution on NEW OUH includes district cooling, which opens opportunities for surrounding buildings like University of Southern Denmark, abbreviated SDU. Buildings on SDU generally only have process cooling and no heat recovery, and therefore case for a possible economic savings. Concerning data that originates from the New OUH project itself, it acts as a methodologically reasonable basis and is not necessarily factual.

Problem statement:

Assessment of how energy consumption for district heating and cooling on SDU and New OUH can be optimized individually by applying heat recovery on cooling centrals, and if there are any benefits to a connected solution district grid.

The assessment is done by examining three scenarios, which are as follows:

1) Applying heat recovery cooling production of electric chillers on SDU and utilize by raising the heat in a booster heat pump.

2) Raise the temperature and utilize for district heat in NEW OUH.

3) Examine the potential benefits of connecting NEW OUH and SDU by district cooling and district heating.

First scenario is based upon applying heat recovery to existing cooling production on SDU ending with a business case.

Second scenario examines the proposal by Fjernvarme Fyn, henceforth abbreviated FVF, will conclude in a business case to determine the feasibility.

Third scenario is an investigation into examining the benefits, if any, of connecting district cooling and district heating between the two sites SDU and New OUH.

5.3 Purpose

The report hope to provide valuable insight into heat recovery for cooling centrals on SDU campus by presenting the economical perspective in installing heat recovery on those centrals and the same goes for New OUH. Furthermore, what is the economic value of that excess heat to New OUH.

An important technical solution proposed by FVF is the synergy between heating- and cooling production and how are such solutions affected by changing framework conditions.

Gather data to establish demand profiles for SDU and New OUH, to be able to find solutions that fits SDU and New OUH in relation to their energy consumption and existing or planned technology solution.

It’s the hope of this project to provide insight into heat recovery for the cooling centrals on SDU campus by presenting a business case in installing heat recovery and utilizing excess heat on their existing cooling production. The same is relevant for New OUH, and takes it basis in the proposal by FVF. Lastly, an important goal is to provide results that could clarify the benefits of connecting SDU and New OUH by district heating and –cooling.

In terms of scope of the project, the focus will be on demand profiles which is hourly data for cooling or heating demand. Another relevant aspect of the project is to what purpose, and what quantities of excess heat from cooling production is available.

The scope includes the buildings and locations of SDU and New OUH. The report will largely revolve around data related to demand profiles for heating and cooling as well as examining the technical workings of cooling centrals.

Concerning the project’s look at cooling centrals on SDU, it will be dealt with as a business case. Whereas, the aspect of New OUH, will involve a feasibility analysis of utilizing excess heat from the cooling process and that of a thermal storage.

This concludes the purpose section and will move on to the methodology part.

5.4 Methods

This section describes by which means data was collected, managed and applied later in the result section. It also includes description of how the report I structure.

5.4.1 Project flow diagram

This section describes the project flow diagram which outlines the overall structure of the report and can be seen in Figure 1.

The first step is the problem identification, which consists of introduction and purpose for the report. The second step is the methodology, which consist of the report structure and review of the data and tools used for the project.

The third step will introduce cooling centrals and district heating at SDU and New OUH, a description of these topics and how the heating and cooling system is currently operated. The forth step introduces the three scenarios. The fifth step is comparative analysis, of the cooling centrals, and what and how framework conditions affect them.

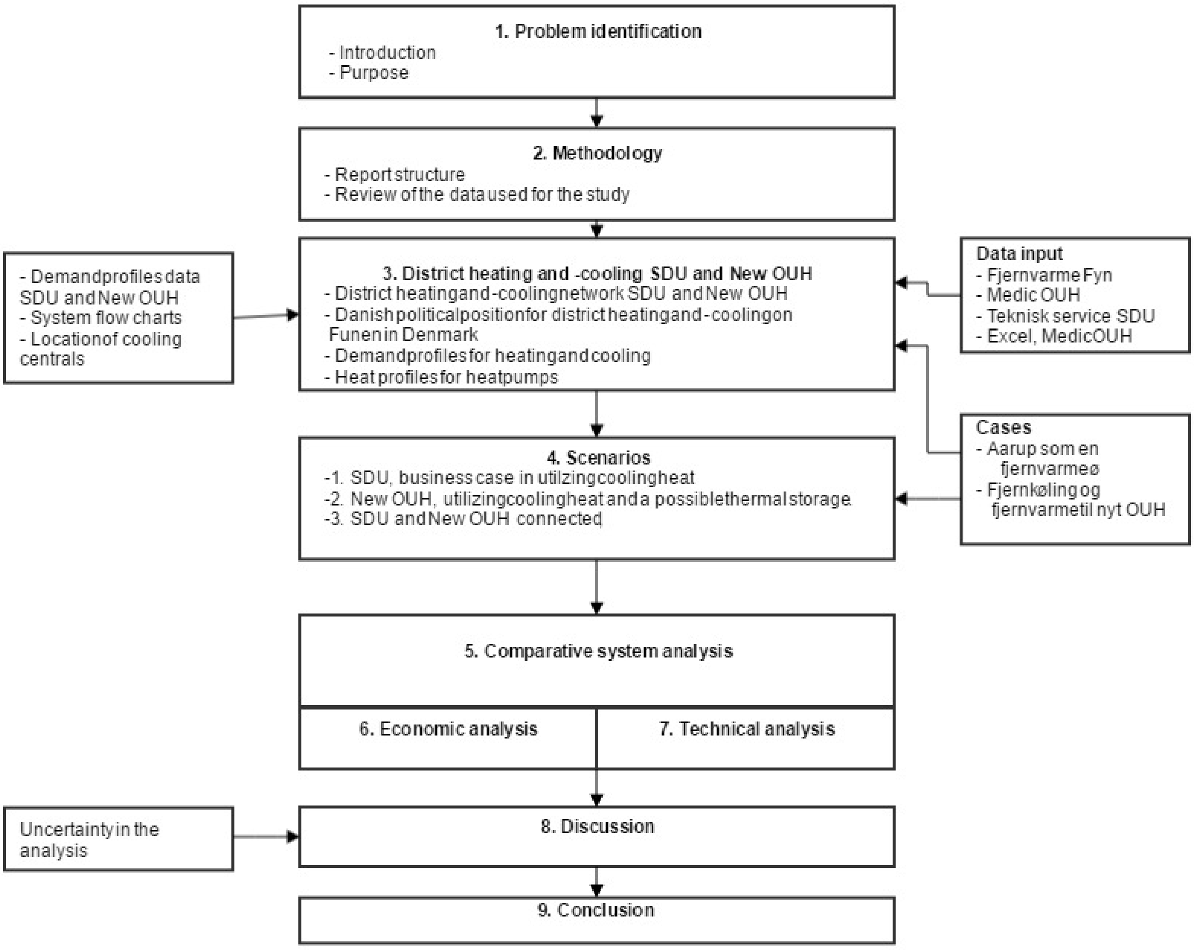

Figure 1: Flow diagram showing structure of report and various data input on left and right

The sixth step is an economic analysis, which consist of economic calculations done in excel and EnergyPro models. The economic analysis evaluates NPV, production cost and heat cost. The seventh step is technology analysis, which consists of analysis of the different technology there are planned and currently used on SDU and New OUH. The eighth step is discussion, which consist of discussions of the results and sensitivity analyses. The ninth step is conclusion, which consist of the collection of all the main part conclusion to answer the problem statement.

5.4.2 System Energy Analysis

To determine benefits and economic outcome of new investment and technical installations, the program EnergyPro, developed by EMD international A/S, is used.

EnergyPro is a program which can make energy models with multiple systems, transmission lines, storage storages and production units etc. With those systems made in EnergyPro, there can be used the reports integrated in EnergyPro to get graphical results of heat and cooling consumption, electric usage and a lot more details. It is also possible to extract economic results from EnergyPRO to excel, just need to have investment cost, energy taxes etc. In the project, EnergyPRO will be used to create the system design for scenarios 2 and 3. Regarding scenario 3, EnergyPRO is the economical tool used to examine the benefit of connecting systems and optimize production cost.

Crucial data for this report is the demand profiles, that is, hourly data of cooling- and heat demand for both SDU and New OUH and were provided by Technical Service on SDU and Medic OUH respectively. The demand profiles govern much of the important aspect about optimizing an energy system as important information can be deducted off them.

Illustrating the systems of examination helps in understanding the purpose and goal of this report, to that end, draw.io diagrams. They are helpful in constructing diagrams and flowcharts in simple and easy ways.

5.4.3 Business economics

To establish the optimal solution for private stakeholders, a business economic analysis is included. This analysis includes tax, fees and subsidies, and therefore indicates how such factors affect investments for businesses.

5.4.4 Socioeconomic

To assess the consequence of an investment in relation to the society, it must be done by a socioeconomic analysis. To that end, exist a guidance (Danish energy agency, 2007) that shows if an investment is a benefit or not to the society, and is therefore suitable for comparing different solutions. The socioeconomic analysis is devoid of tariffs, avoidable tax and subsidies, meaning prices are measured as factor prices factor prices. These prices however, are subjected to tariffs and therefore need to be multiplied by a factor of 1.17, called net tariff factor. Leading to calculations prices (In Danish: beregningspriser) which is reflective of the socioeconomic prices.

5.4.5 Heat pumps and electric chillers

Coolpack is a free program that DTU have provided and is used to make diagram cycles for cooling and heating system. Coolpack functions is to construct the diagram cycles by using the temperatures from evaporation and condensing as data for log(p)-h diagram to calculate the pressure, enthalpy and COPs.

5.5 Technology and theory

This section serves to describe the theory of technologies to understand further reading of the report.

5.5.1 Heat pumps

Heat pumps draws heat from a heat source and convert the heat to higher temperature through a closed process. The process either consists of a compression heat pump or absorption heat pumps, (e.g. steam and hot water).

The important aspect of heat pumps, is the ability to produce both heat and cooling, and at the same time. Compression pumps usually come with a practical heat output that is 3 to 5 times coefficient of performance, henceforth abbreviated COP, the drive energy. The COP factor depends on the efficiency of the heat pump and the temperature of heat source and heat sink and the temperature difference between them. In Figure 2, the energy flow is illustrated.

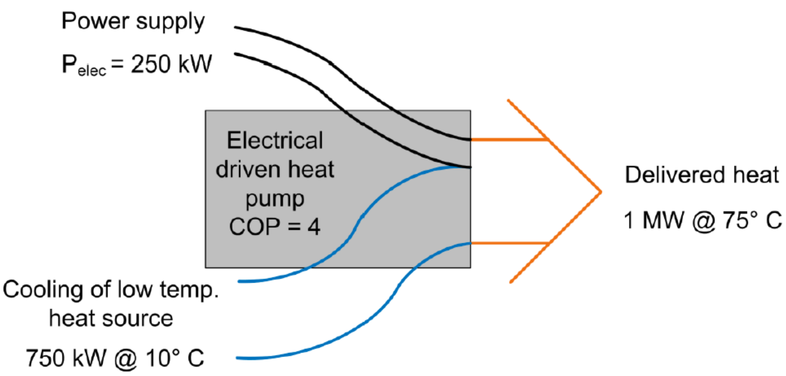

Figure 2: Traditional heat pump energy conversion.

The main components in a compression heat pump is the compressor itself, expansion valve and the two heat exchangers named condenser and evaporator. Within the closed system, is a working fluid circulated, heated by the heat source and can thereby evaporate. The vapor is compressed to raise temperature and pressure, and then enters the compressor delivering heat and condenses. The fluid reaches the expansion valve, returns to evaporator.

5.5.2 Electric chillers

The technical name for the type of chillers worked with throughout this report is vapor compression chillers, but will merely be written as electric chillers for simplicity. An electric chiller practically the same as a heat pump, just turned around to make use of the cooling side instead a system diagram of the electric chiller is illustrated in Figure 3.

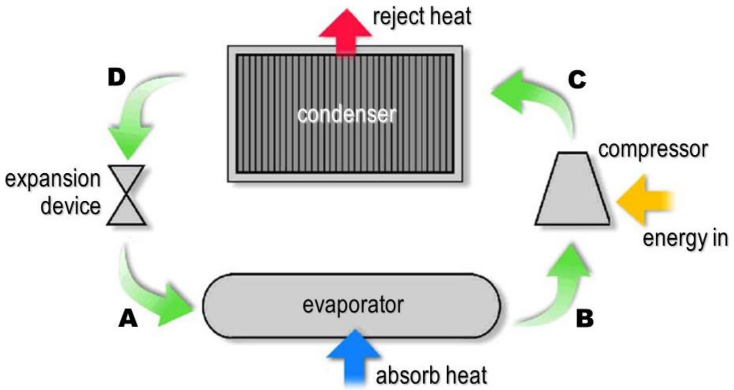

Figure 3 shows a vapor compressed cycle for at chiller system.

The electric chiller uses a circulating liquid refrigerant as the medium. The function of the liquid refrigerant is to absorb and remove heat from the space to be cooled and reject the heat to another medium. The electric chillers consist of 4 components which a compressor, a condenser, a thermal expansion valve and an evaporator. Circulating refrigerant going through the compressor in the thermodynamic state known as a saturated vapor. The refrigerant gets compressed to a higher pressure, that's leading to a higher temperature. The hot, compressed vapor, which is in a state called superheated vapor is at a temperature and pressure at which it can be condensed with either cooling water or cooling air flowing across the coil or tubes. At this point is where the circulating refrigerant rejects heat from the electric chiller and the rejected heat is carried away by either the water or the air.

The condensed liquid refrigerant, known as saturated liquid, is next leaded through an expansion valve where it undergoes an abrupt reduction in pressure. That pressure reduction leads in the adiabatic flask evaporation of a part of the liquid refrigerant. The auto-refrigeration effect of the adiabatic flask evaporation lowers the temperature of the liquid and the vapor refrigerant mixture to where it is colder than the temperature of the enclosed space to be refrigerated.

The cold mixture is then leaded through the coil or tubes in the evaporator. There is a fan to circulate the warm air in the enclosed space across the coil and tubes transport the cold refrigerant liquid and vapor mixture. That warm air evaporates the liquid part of the cold refrigerant mixture. At the same time, the circulating air is cooled and thus lowers the temperature of the enclosed space to the wanted temperature. The evaporator is where the circulating refrigerant absorbs and removes heat which is rejected in the condenser and getting transferred some other place by the water or air used in the condenser.

5.5.3 Dry coolers

A dry cooler is an air-cooled device that is used in connection with removal of excess heat. The cold media, normally water is circulated through the dry cooler, where heat exchange with the surrounding air heats up the media.

5.6 Coolpack electric chiller and heat pumps

In this section, the program Coolpack is used to construct diagram cycles that calculate the pressure, enthalpy and COP for the electric chiller and heat pumps for SDU and new OUH. The cooling COP is calculated by using the temperature for evaporating and condensing of electric chiller or heat pump. The electric chiller on SDU using the refrigerant R410A and the heat pumps on SDU and New OUH are estimated to use the refrigerant R290.

5.6.1 Four diagram cycles in Coolpack

There are set up 4 different log (p)-h diagram cycles in Coolpack to define 4 different "scenarios" for SDU and OUH. The first diagram cycle is for SDU electric chiller, the second diagram cycle is for booster heat pump on SDU, the third diagram cycle is for OUH heat pump and the forth diagram cycle is for OUH with heat pump and electric chiller. For all the diagrams cycles in Coolpack, is the superheat and sub cooling is set to 2 (273+2) Kelvin and an isentropic efficiency on 0.70.

5.6.2 SDU electric chiller diagram cycle

The first diagram cycle is for SDU electric chiller, that using an evaporating temperature on 8 °C and condensing temperature on 40 °C (Larsen, K 2016). This diagram cycle is illustrated in Figure 4.

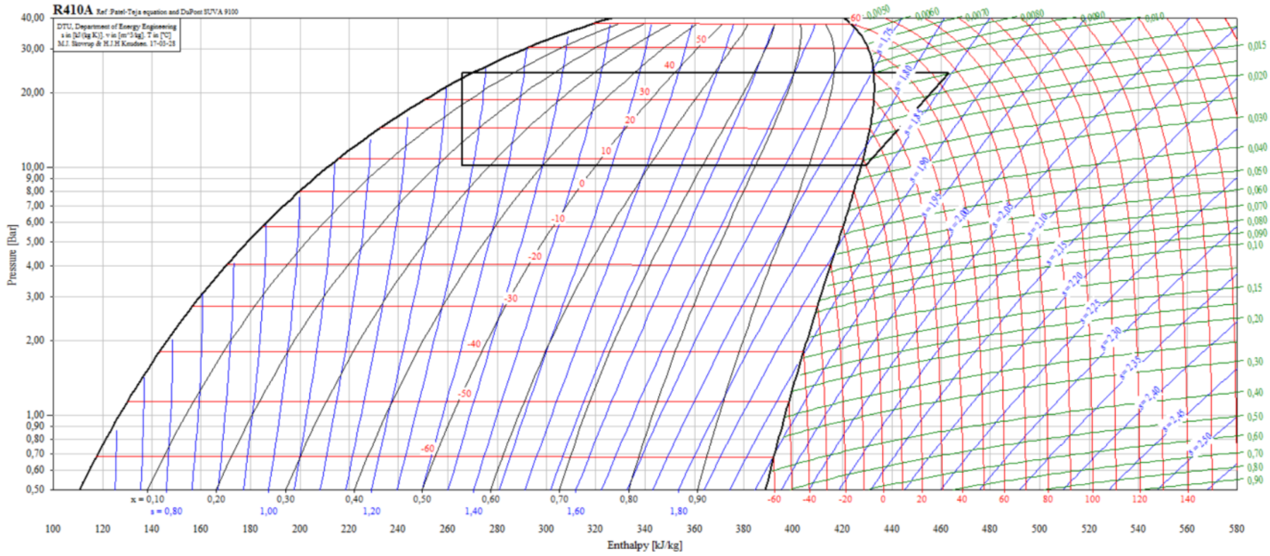

Figure 4: shows the diagram cycle for SDU electric chillers were the calculated cooling COP is on 4.85.

The SDU electric chiller diagram cycle shows that the minimum pressure is on 10.2 bar and the maximum pressure on 24 bar. That's gives a pressure difference on 13.8 bar from the min. pressure to the max. pressure. The calculated cooling COP is of 4.85 for the electric chiller on SDU. This cooling COP from Coolpack will be used as the cooling COP for the calculation in the data section Cooling heat from electric chillers, but also used as the cooling COP in the results section.

5.6.3 SDU booster heat pump diagram cycle

The second diagram cycle is shown and described for a booster heat pump on SDU, were the booster heat pump using an evaporating temperature on 40°C and condensing temperature on 70°C. The diagram cycle is illustrated in Appendix 9.

The cooling COP is calculated in Coolpack, but heat COP is calculated by using enthalpy values for the 2 points on the hot side (which is the 2 corner points on the line with the high pressure on 26 bar) from the diagram cycle and divide it with the enthalpy difference from the cool side (2 low pressure corner with 13.7 bar) to the hot side (high pressure corner point) in kJ/kg. These enthalpy values can be found on the diagram cycle corner points in Coolpack.

The SDU booster heat pump diagram cycle shows that the minimum pressure is on 13.7 bar and the maximum pressure on 26 bar. That's gives a pressure difference on 12.3 bar from the min. pressure to the max. pressure. The cooling COP is 5.49 and to calculate the heat COP this equation is used:

$$Heat\ COP = \frac{Hotsite\ point\ 2 - hotsite\ point\ 1}{enthalpy\ difference\ from\ cold\ to\ hot}$$

$$Heat\ COP = \frac{658\frac{kJ}{kg} - 391\frac{kJ}{kg}}{41\frac{kJ}{kg}} \approx 6.49\ COP$$

The results show that the heat COP for the booster heat pump is approximately 6.49, which is one COP higher than the cooling COP on 5.49. Since the heat COP is one value higher than the cooling COP make the calculation realistic.

5.6.4 New OUH Heat pump diagram cycle

The third diagram cycle is for OUH with heat pump and has the inputs for evaporating temperature on 12 °C and condensing temperature on 70 °C. This diagram cycle is illustrated in Appendix 10.

$$Heat\ COP = \frac{679\frac{kJ}{kg} - 391\frac{kJ}{kg}}{90\frac{kJ}{kg}} \approx 3{,}21\ COP$$

The results give that the heat COP is approx. 3.21 for the heat pump, which is one COP higher than the cooling COP on 2,21. The calculations seem to be correct because heat COP is just over one higher than the cooling COP. The diagram cycle for OUH with heat pump have min. pressure on 6.7 bar, max pressure on 26 bar. That's gives a pressure difference on approx. 19.2 bar from the min pressure to the max pressure.

5.6.5 New OUH electric chiller and heat pump diagram cycle

The forth diagram cycle is for OUH with an electric chiller and a heat pump and have an evaporating temperature on 12 °C and condensing temperature on 40 °C on the electric chiller. The heat pump has the evaporating temperature on 40 °C and condensing temperature on 70 °C. This diagram cycle is illustrated in Appendix 11.

The calculation of heat COP for OUH with electric chiller and heat pump is made in the same way as OUH with heat pump is made in section New OUH Heat pump diagram cycle. The only difference is just with the enthalpy values for the heat pump on OUH with electric chiller and heat pump.

$$Heat\ COP = \frac{658\frac{kJ}{kg} - 391\frac{kJ}{kg}}{41\frac{kJ}{kg}} \approx 6{,}49\ COP$$

The results give that the heat COP is approx. 6.49, which is one COP higher than the cooling COP on 5.49 for the heat pump on OUH with electric chiller and heat pump diagram cycle.

The OUH with electric chiller and heat pump diagram cycle in Coolpack have a min. pressure on 6.7 bar and max pressure on 13.6 bar for the electric chiller. The heat pump has a min. pressure 13.6 and max. pressure on 26 bar. That gives a pressure difference on approx. 7 bar for the electric and pressure difference is on approx. 12.2 bar on the heat pump.

5.6.6 Reason for an electric chiller and a heat pump for OUH

The reason to use an electric chiller and heat pump on New OUH scenario instead of just using heat pump, using the cool side and hot side. It is because the cooling COP is only on 2.21 then just one electric chiller is used, but if an electric chiller and a heat pump get used instead of one electric chiller, then the COP will be higher for both electric chiller and the heat pump. The electric chiller has a cooling COP on 5.49 and the heat pump has a heat COP on 6.49. Another reason to the COP is low with one heat pump is because the temperature on the water will need to be heated up from 12 °C to 70 °C for a heat pump and that gives a temperature difference on 58 °C. Compared to having an electric chiller and a heat pump where the temperature on the electric chiller need to increase the temperature from 12 °C to 40 °C, that gives a temperature difference on 28 °C and the heat pump need to increase the temperature from 40 °C to 70 °C, that result in a temperature difference on 30 °C.

The temperature difference from evaporating temperature to condensing temperature matching the calculated pressure difference required to increase the temperature from min. temperature to max. temperature. The calculated pressure difference for the heat pump is 19.2 bar and for electric chiller and the heat pump the pressure difference is 7 bar for the electric chiller and 12.2 bar for the heat pump. The results show that the pressure difference for electric chiller and the heat pump is lower then there are used an electric chiller and a heat pump instead of a heat pump and since the electric chiller and heat pump working optimal in the condition with a pressure difference on 6-8 bar. That leads to the results that an electric chiller and heat pump system gives results in relation to COP, pressure difference and the closest match for the working conditions. That describes the projects own method of calculating COP, and those COP's are almost identical to common traditional chillers according to Rambøll (Rambøll, 2016).

5.6.7 Part conclusion

Comparing the two New OUH Coolpack scenarios, it can be seen that the temperature difference on 58 °C for a heat pump with a COP on 2.21. Compared to looking at an electric chiller and a heat pump scenario for OUH, the temperature difference was on 28 °C and 30 °C with 5.49 cooling COP on electric chiller and 6.49 heat COP on the heat pump.

There can be concluded that Coolpack is used in the project to calculate cooling and heat COP, were the cooling COP for SDU is used in the results section later in this project. It can also be concluded that it gives higher COP results by using an electric chiller and heat pump instead of only one heat pump, as well as a good working pressure difference between 6-8 bar.

6 Demand profiles and physical frames of SDU and New OUH

This section of the report will give an understanding of the physical frames, location and technical installation of cooling centrals worked with throughout the report. In extension of that, this section describes aspects of the buildings on New OUH and SDU and their district heating and –cooling is also included.

Before proceeding, a clarification on the distinction between process cooling and comfort cooling is made to ease further reading. The distinction is necessary for both legislative and technical reasons and is part of the examined data.

Comfort cooling: When cooling is produced with purpose to keep a comfortable indoor temperature to the convenience of employees or customers.

Process cooling: Energy applied in a production and undergoes a conversion and then utilized to a specific purpose. Some examples include cooling of server rooms or other facilities with no permanent employees.

6.1.1 SDU Cooling centrals

Two cooling centrals reside on SDU campus seen in Figure 5, one for the Teknikum building, from now on called TEK, is seen in right-bottom corner and another for cooling server and supercomputer from now on called S&SC seen on the left side. Neither of the two has applied heat recovery. This means excess heat is as of now venting to the outside environment.

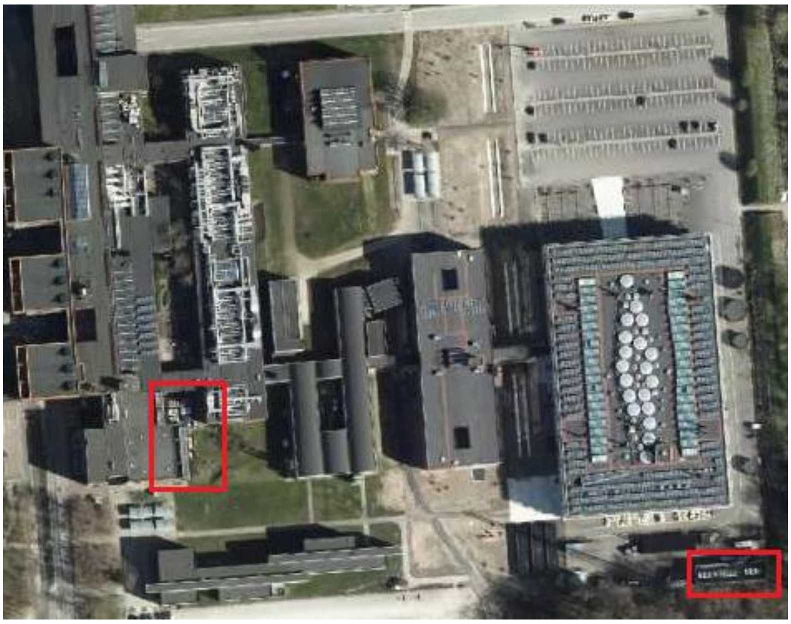

Figure 5: Aerial view of University of Southern Denmark, Odense. Red rectangles highlight cooling centrals present on SDU, [Geofyn.dk]

These two cooling centrals on SDU, total two dry coolers and five electric chillers. They are distributed as seen in Table 1.

Cooling Centrals SDU			
Description/Location	**Unit**	**SDU S&SC**	**SDU TEK**
Amount of electric chillers	**#**	3	2
Capacity of electric chillers	**kW**	250	300
Amount of Dry Coolers	**#**	1	1
Capacity Dry Cooler	**kW**	250	300
Total Capacity	**kW**	1000	900

Table 1: Number of units and capacity on SDU cooling centrals

The SDU S&SC is water cooled while that of SDU Tek is cooling glycol which then proceeds into the building and delivers cooling to water by a heat exchanger.

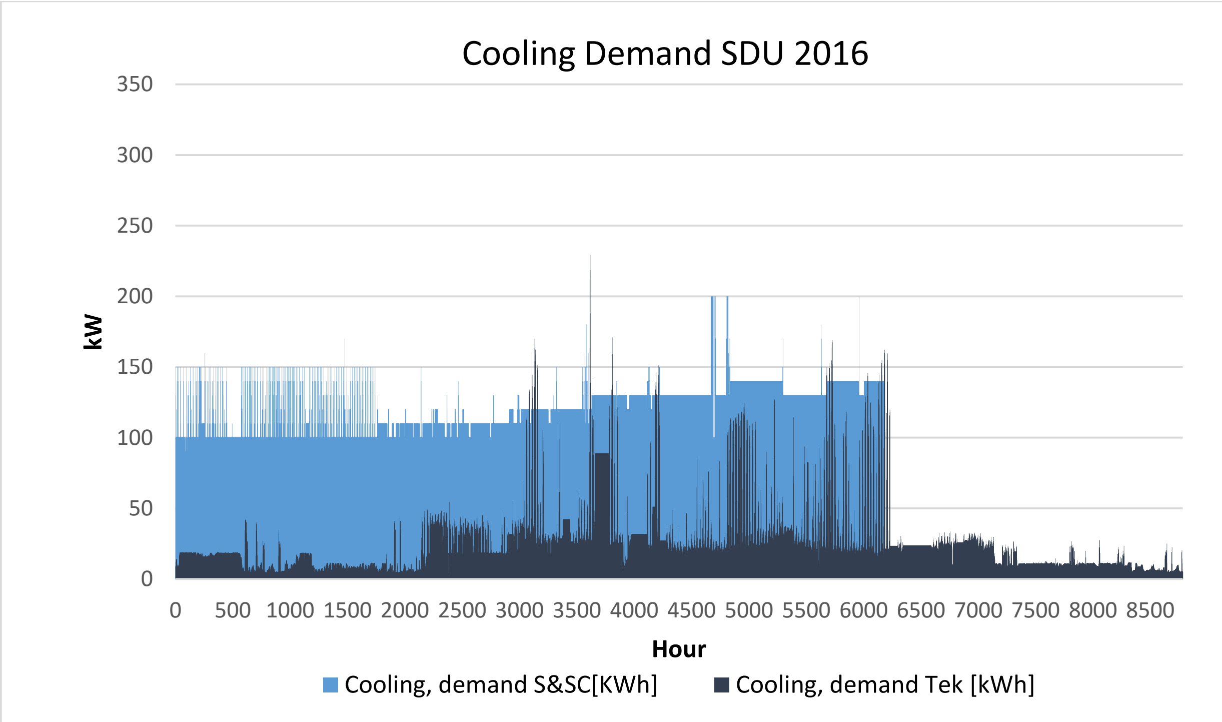

Figure 6: Cooling Demand for SDU cooling centrals; S&SC and Tek for year 2016 in kWh.

In Figure 6 the cooling demand for both SDU centrals is shown. The origin of the data set is obtained through on SDU who extract the data from their database. The data base sometime ceases to function, resulting in loss of data points. To compensate for that, it assigns the value of the earliest known hourly data, leading up to a series of lost data points, to any subsequent missed data. This results in some *flat* areas on the demand profiles. In regard to demand of S&SC, which appears very constant, it's partially due to it being a server and super computer which tends to have quite stable loads leading to equally constant cooling demands. The data arrives from a measuring device placed at the water pipes leading into server and super computer.

Now, looking at Table 1 and Figure 6, the combined capacity of the electric chillers is roughly three to four times greater than the demand at any one time. Reason being as informed by (Larsen, K 2016), is that only have one of the three electric chillers units is active at a time on the server and supercomputer cooling. This creates some safety in the production because each electric chiller unit is tested regularly and two units serve as backup. The large capacity could also be a consequence of counselling companies has a responsibility to recommend cooling capacities sufficiently large to cope with the expected maximum peak demand, which is in fact the case of New OUH (Hansen, H 2016). This also relates to the operation strategy between dry coolers and electric chillers, because in general it's either only dry cooling or only electric chiller units that produced cooling, there is no in between. The word general is used because, on inspection of the SDU S&SC on two occasions, it's was clear by audio, touch and visual that the electric chiller unit was providing some cooling because it was noisy, fans was active and emitted warm air. These visits happened on mornings during the winter months.The overall structure of the SDU cooling centrals can be seen in Figure 7 for SDU S&SC and Figure 8 for the Tek central. An important aspect of these centrals is the set point, that is, the forward temperature the cooling units are set to deliver. For central S&SC, the temperature set point is 14 °C and return temperature is about 18°C (Appendix 5)

While the same temperature data is lacking for SDU Tek, it's known the two cooling centrals share the same set points (Larsen, k 2016). These set points are noted on the bottom-right side of the figures along with the return temperature.

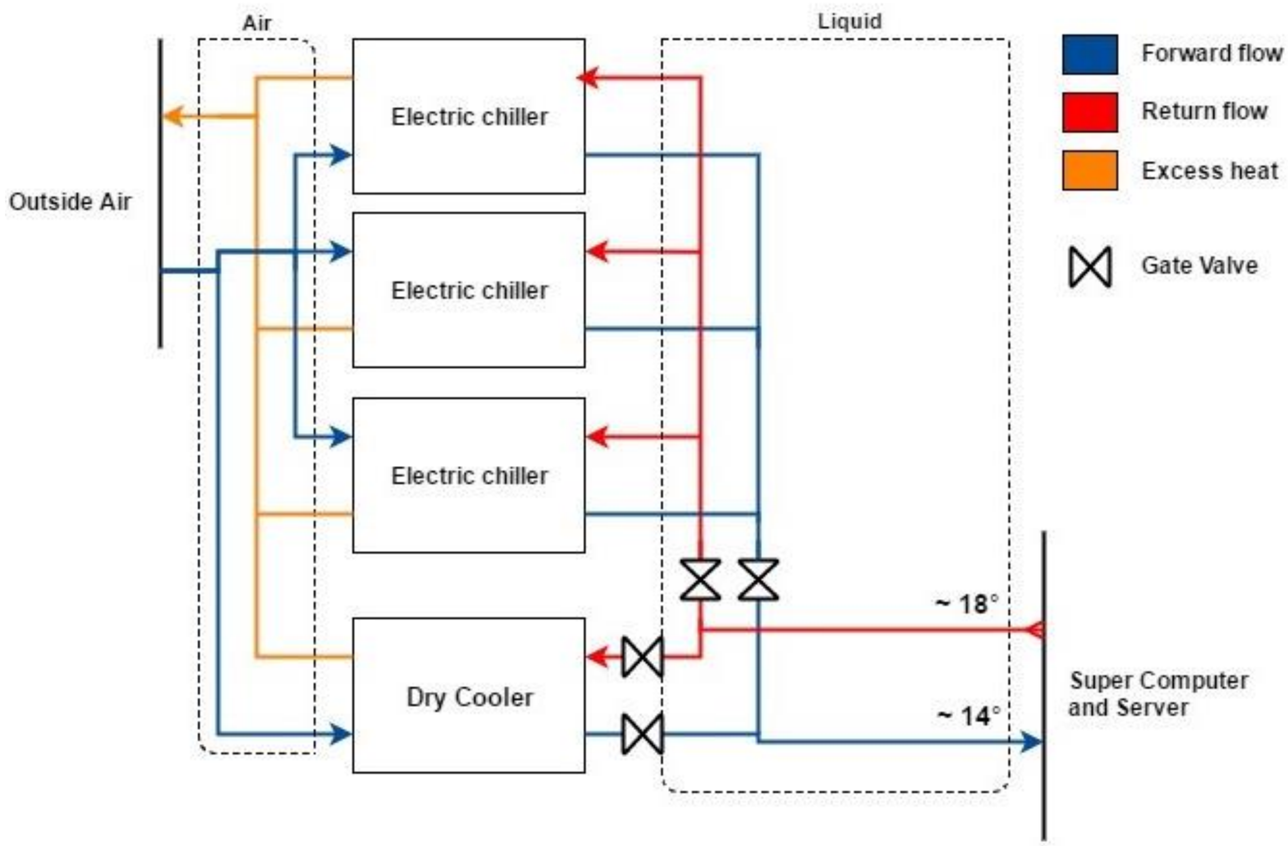

Figure 7: Simplistic overview of the cooling central for Server and Super computer. Showing how the units interact with the outside air on the left hand side, and how they interact with the Server and Super computer with liquid and its corresponding temperatures for forward and return flow, respectively 14 °C and 18 °C.

Both figures are constructed with cooling units in centre, electric chiller units on top and dry cooler at the bottom. Left side depicts the excess heat, the heat removed from the condenser side of the electric chiller and for dry coolers it's the "removal" of the 18 °C return temperature. Right side illustrate forward and return flows, 14 °C and 18°C, with several gate valves, these functions to uphold the operation strategy between dry cooler and electric chiller, that only one type can operate at a time. Something to note regarding the dry cooler when outdoor temperature reach -5°C, that simply leading the return flow through the tubes of the dry cooler without any ventilation is sufficient to reach the set point (Larsen, K 2016). The consequence being that the dry coolers have almost no electricity consumption, except for the pumps, when the outdoor temperatures reach -5 °C or below which happens about 304 hours a year in the test reference year, a set of temperature observations used throughout the report. Electric chillers are active at temperatures two degree Celsius above the temperature set point of 14 °C (Larsen, K 2016), an important note in relation coming calculations.

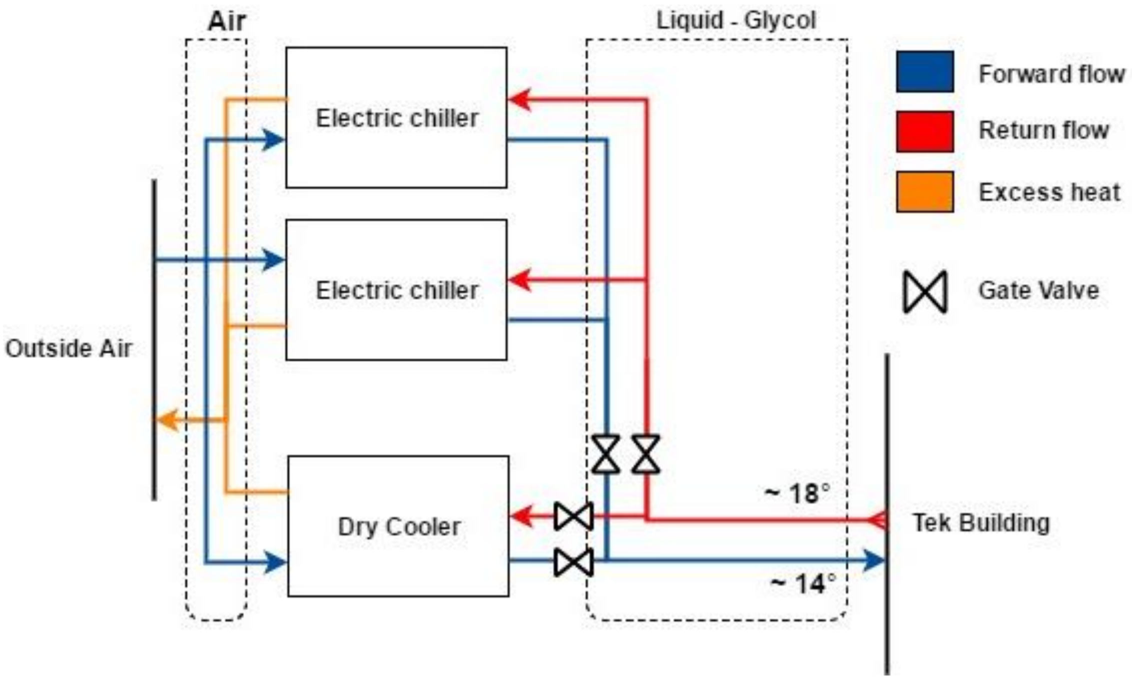

Figure 8: Simplistic overview of the cooling central for Tek. Showing how the units interact with the outside air on the left hand side, and how they interact with the Server and Super computer with liquid and its corresponding temperatures for forward and return flow, respectively 14 °C and 18 °C.

The primary focus in this report remain on the two major centrals S&SC and Tek, these holds the greatest concentrated production of cooling and therefore excess heat. Furthermore, they are monitored closely and have accessible data. This contributes to holding these as primary candidates for heat recovery and further examination.

On both figures, any pumps, responsible for creating the flow, are left out for the sake of simplicity.

Both cooling centrals is supplied by the same company, and therefore operate in similar ways. This means that in excel calculations and EnergyPro, some parameters like temperature set points for cooling units, are the same for both centrals.

6.1.1.1 Heat demand SDU

Heat demand is like the data for cooling demand, also acquired through *Technical Service SDU* and is seen in Figure 9. The heat is provided by Fjernvarme Fyn through district heating.

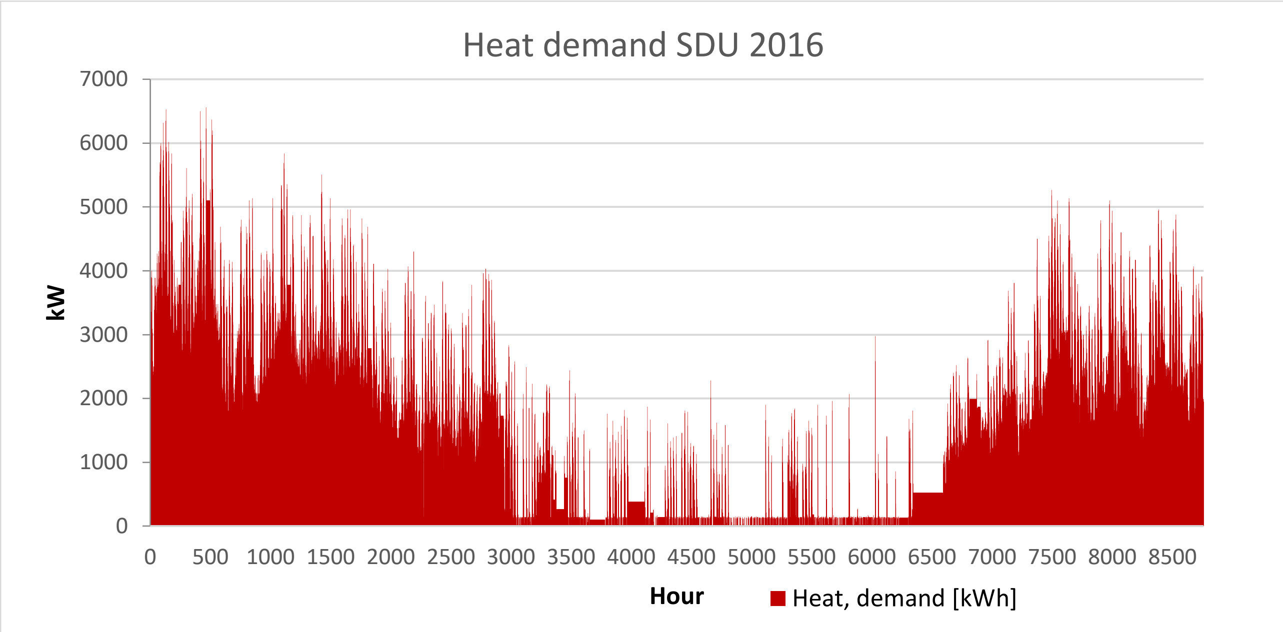

Figure 9: Heat demand of entire SDU Campus in 2016.

A thing to note in relation to the heat demand is, that during the summer month's there is no district heating, it's completely disabled. Instead, any heat demands during those months, mostly hot water, are provided by electric heaters, which correlate with the occasional spikes in heat demand. The data arrives from one measuring device and accounts for all district heat entering SDU Campus.

6.2 Description of New OUH

The following section describes NEW OUH in terms of the physical properties of the district cooling to the technicality of the cooling central. Also, the expected demands are introduced.

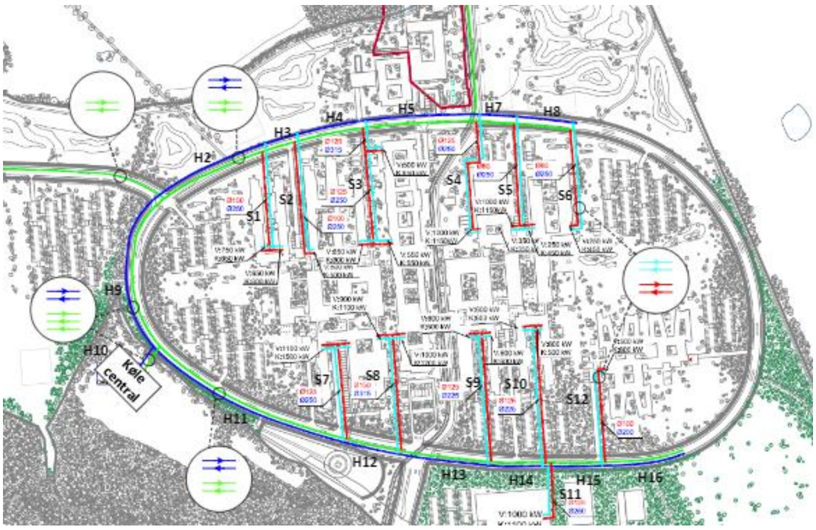

Figure 10: Drawing of the expected pipe installation of the New OUH as proposed by Fjernvarme Fyn.

The district heating, illustrated by green lines, are connected up top with SDU and to the west. The cooling central is located in bottom-left corner. The capacity of that central, is 7.1 MW of electric chillers and 7.1 MW of Dry cooler. From the cooling central the larger district cooling pipes runs alongside the district heating in a half elliptic shape. The heat and cooling is carried into the building by many smaller pipes illustrated by red and light blue lines. Both cooling and heating will consist of a return and forward going flow.

Now that the physical frame is described, the following will go into demands on New OUH.

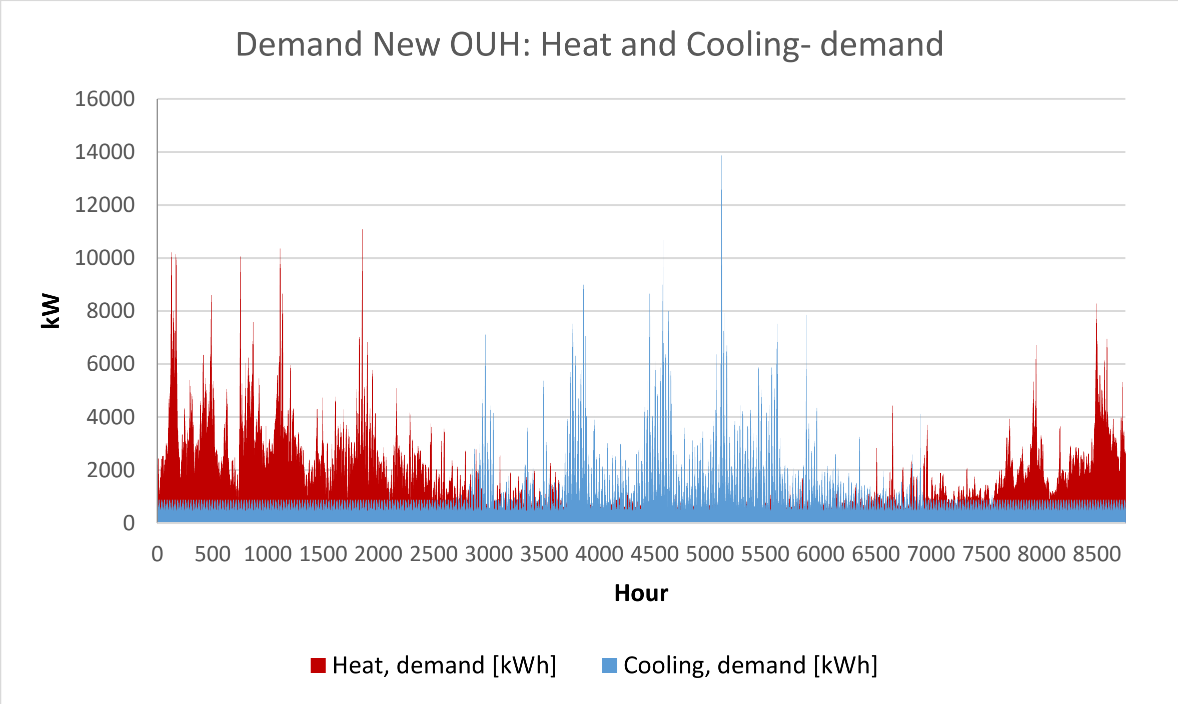

Figure 11: Estimated heat and cool demand for New OUH by Medic OUH.

The energy signature is calculations done by Medic OUH, and was done to have qualified estimations for the heat and cooling demand. The used data are based on the Danish reference year TRY[1], consisting of average outdoor temperatures over a period of 15 years. The demands are calculated from functions of time during the day and outdoor temperatures from experience with similar hospitals. It's important to note that document from which they origin is incomplete (Lading, J. 2017), which could explain the inconsistency in regard to some other data from New OUH (Appendix 8). That data shows estimated max cooling peak of 9.2 MW. In most cases, the hourly demands are used in calculations.

6.3 Energy system descriptions

In this section, all the data used for the calculations in the result section and is described and shown with tables for both socioeconomic and business economics analyses.

6.3.1 Electricity prices

In EnergyPro, the electricity data used in the model is spot prices of 2016 from Nord Pool Spot.

1

Appendix 6

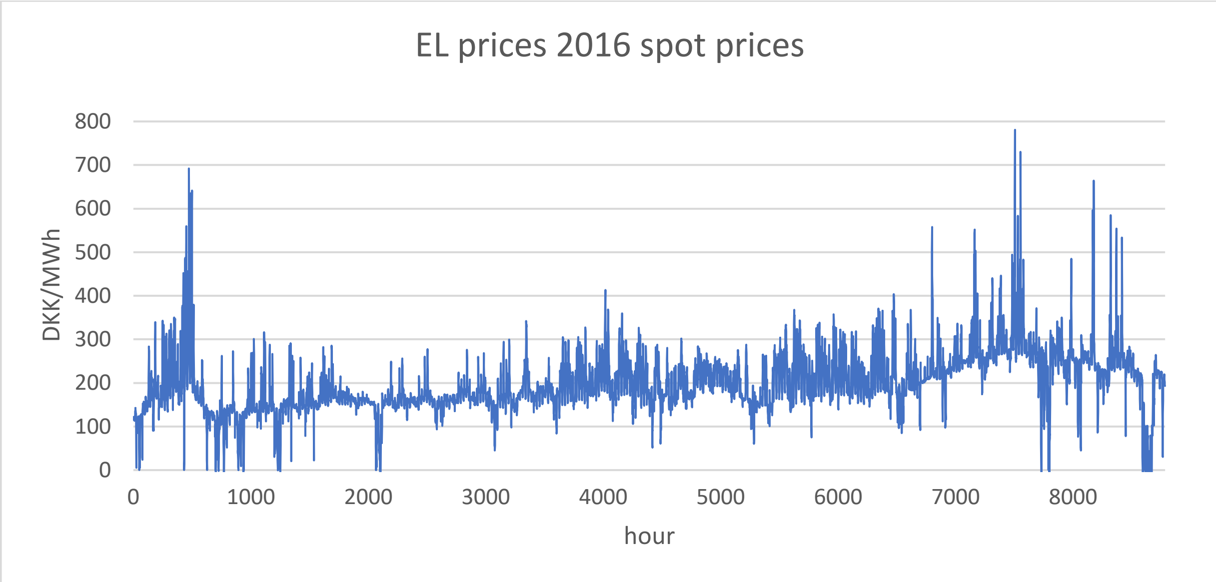

Figure 12: Hourly spot prices for 2016 (Nordpoolspot)

6.3.2 Fluctuating prices 2036

The prices will be used in the sensitivity analysis and its purpose made clear in that section. These prices are obtained through factor prices made by Energinet.dk. The factor prices are an expression of how much the spot prices deviate from the average price. And in the analysis by Energinet.dk, that deviation is smaller in 2035 than it is today and therefore has a steadier or less fluctuating EL price. This also means, that a spot price of desire can be multiplied the factor prices. A spot price of 589[2] DKK/MWh is applied to showcase year 2036. This described process leads to Figure 13.

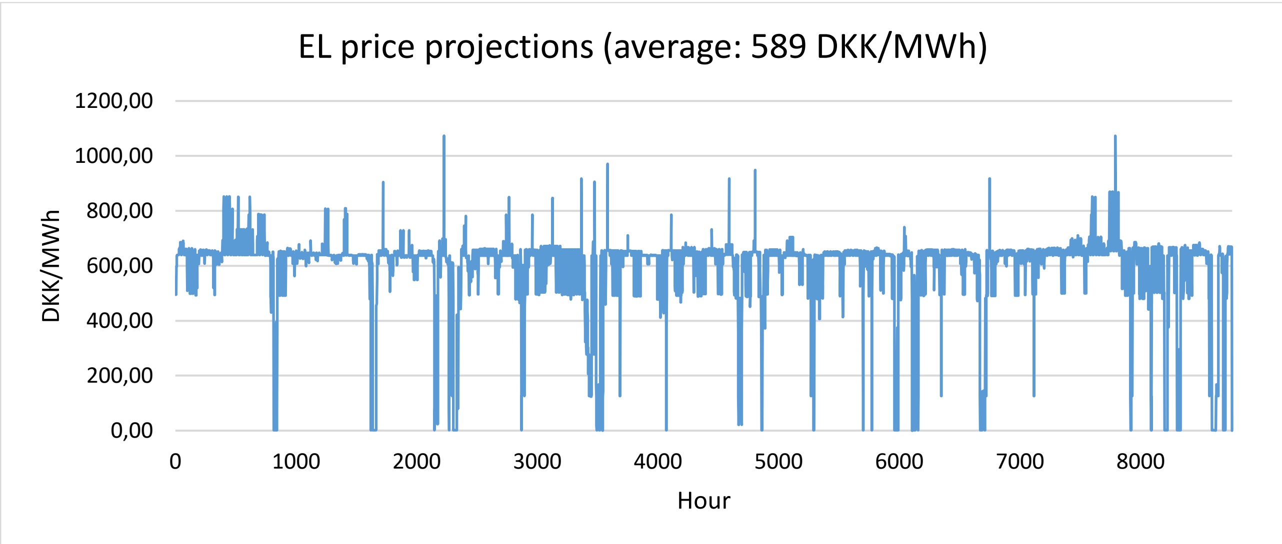

Figure 13: Projected electricity prices in year 2036 with low fluctuation as estimated by Energinet.dk

Now that spot prices have been described, the section moves onto the gathered technical and economic data.

[2] Appendix 1, with linear projection to year 2036.

6.3.3 Data booster heat pump

This section is description of the data used for booster heat pump. The data is shown in Table 2.

Booster heat pump	Price/value	Unit	Source
Lifetime	20	Years	(Danish Energy Agency, 2016) and (Energinet.dk, 2016)
Investment cost	3492	DKK/kW	(Danish Energy Agency, 2016) and (Energinet.dk, 2016)
Variable O&M	3.5	DKK/MWh	(Danish Energy Agency, 2016) and (Energinet.dk, 2016)
Fixed O&M	76.4	DKK/kW	(Danish Energy Agency, 2016) and (Energinet.dk, 2016)
Heat pump size: SDU New OUH	 60 2000	kW	Based on max peak cooling heat

Table 2: Data for booster heat pump on SDU

Lifetime is the expected life time of the booster heat pump. A heat pump typical have a lifetime between 10-20 years in the calculations, the lifetime is set to 20 years for the booster heat pump.

Investment cost is the initial cost of an investment. The investment cost includes installation cost and cost to pipelines etc. In calculations, the two cooling centrals is variable O&M can be divided into operation cost, which include cost by running the heat pump, and maintenance keeping the unit functional.
The variable O&M cost is dependent on the production. Fixed O&M cost is costs that not changing with increased or decreased production. It is expenses that needs to be paid and are independent of any business activity (Investopedia, 2017). That means it is not varies with the heat production.
Size of heat pump is based upon the day of max cooling demand and therefore also the day with the largest cooling heat which is the 25th August.

6.3.4 District heat saving

Description of the data used for district heat saving and production data. The data is shown in Table 3.

District heat savings	Price/value	Unit	Source
Full operation hours	1,227	Hours/year	(Technical Service,2017)
Business economics District heat price	0.374	DKK/kWh	(Fjernvarme Fyn, 2016)
Cooling heat SDU	55,064	kWh	(Technical Service,2017)
Socioeconomics district heat price	0.26	DKK/kWh	(Fjernvarme Fyn, 2017)

Table 3 shows data used for calculating the district heat savings, and production data.

The price on district heating is kept constant in calculations because during the period from 2007 to 2016, the district heat prices seem very steady (Energitilsynet 2017), and therefore see no reason to make any price projections on that part.

The district heat savings is based on the amount of the district heat you can save by utilizing the cooling heat from electric chillers on the SDU cooling central, instead of letting the cooling heat going out in the air. The district heat savings is equal to the amount of district heating no longer needed to purchase because of the heat recovery of cooling heat. The district heat saving is assumed that it can utilize all the cooling heat from electric chiller the whole year. To calculate the district heat saving the district heat price from FVF is used and it is multiplied with the cooling heat production from electric chillers. The data used for district heat savings is shown in Table 3.

Operations hours define the hours where the electric chiller is producing cooling to SDU S&SC. The operations hours are calculated in excel from the hour per hour data in the hours where the electric chillers are producing. The district heating price is based on FVF price setting, while the business economics price is excluding tariffs.

6.3.5 Electric heater saving

This section is about the data for electric heater and description of them. The data is shown in Table 4.

Electric heater savings	Price/value	Unit	Source
EL-price projections[3]	2016-2035	year	Danish Energy Agency. (2016)
O&M	2,4	DKK/GJ heat	(Ea Energianalyse, 2009)
Thermal efficiency	100	%	(Ea Energianalyse, 2009)
Electric consumption	55084	kWh	Technical Service SDU, 2017)

Table 4 shows the data needed to calculate the electric heat savings.

Spot prices are the raw electricity price for the socioeconomic analyses, and is projected to 2036, based on that the heat pump has a lifetime on 20 years. The spot price is used in calculation of the variable O&M and production etc.

Electric heater savings is based on replacement of the electric heaters with a booster heat pump which are utilizing the cooling heat from the electric chillers. To calculate the electric heater savings, the electricity consumption of electric heaters is multiplied spot price, and O&M is also included in the savings. Data for calculating electric heater savings is shown in Table 4. In Results and analysis of scenarios, both the district heat and electric heater savings, are called heat savings.

The efficiency for the electric heater is 100%, which means then the electric heater produces 1 kWh heat, it consumes the same amount of electricity, 1kWh.

The electricity savings of the electric heater, is equal to the cooling heat from electric chillers. This is due to the assumptions that the thermal efficiency is 100%.

[3] Appendix 1

6.3.6 Taxes, tariff and factors

This section is about the data of taxes, tariffs and factors and they are also described. The data is shown in Table 5.

Taxes, tariff and factors	Price/value	Unit	Source
Tax distortion factor	1.20	-	(Energistyrelsen, 2007)
Net tariff factor	1.17	-	(Energistyrelsen, 2007)
Grid tariff	5.9	Øre/kWh	(Energinet.dk, 2016 december)
PSO tariff	16.1	Øre/kWh	(Energinet.dk, 2016 december)
System tariff	0.02	DKK/kWh	(Energinet.dk, 2016 december)
Electric tax	0.91	DKK/kWh	(pwc, 2016 december)
Value added tax	25	%	(Energistyrelsen, 2016 april)

Table 5 shows the data for taxes, tariff and factors both used for private economic and socioeconomic results.

Tax distortion factor is a factor there is added to cost. The reason for having tax distortion in the socioeconomic results is because SDU are government funded. Tax distortion can be calculated together with net tariff factor that gives: $1.20 * 1.17 = 1.404$.

Net tariff factor is always calculated with the results on socioeconomic analyses. The net tariff factor for the socioeconomic results cover the taxes and tariffs. In the calculation is used a net tariff factor on 1.17.

Grid tariff is a cost for being connected to the electric grid, but also to be allowed to utilize the grid. In the calculation is a grid tariff 5.9 øre/kWh used.

Electric tax is the cost there is added to electricity price. In the calculation is used an electric tax on 0.405 DKK/kWh.

System tariff is a cost that energinet.dk requires maintain the system, and to make sure the electricity getting delivered. There is used a system tariff on 0.02 DKK/kWh in the calculation.

PSO tariff is a price added to the total cost by using the system. In the calculation, a PSO tariff on 16.1 øre/kWh is used. There also need to be mentioned that's the PSO is getting phased out at year 2022.

Value added tax is a cost added to the electric price and investment and it is on 25% of the price added to the cost.

The taxes, tariff and factors are used for socioeconomic and private economic analyses. Were the in socioeconomic analyses is used: Distortion tax factor, net tariff factor, grid tariff and system tariff. For private economic analyses is used: Grid tariff, electric tax, system tariff, PSO tariff, excess heat fee and value added tax.

6.3.7 Pipeline network

This section describes the data used for the pipeline network required for making the electric heater solution possible. The pipeline network is illustrated on Figure 14 and the data is shown in Table 6.

Figure 14 shows an air photo of whole SDU and used to illustrate the pipeline network on SDU (Geofyn, 2016).

Figure 14 shows an overview over the SDU buildings and the green lines shows where the planned pipeline network is going. The amount of the meter's pipeline needed is 400 meters and that is rough estimate. The pipeline used for transportation of the excess heat is a district heat pipe with dimension on 25 mm in diameter and they have a cost around 250 DKK/meter. The pipeline networks also have a cost to digging the pipes down in the ground between the buildings. The cost for digging for the calculation is set to 1000 DKK/meter (Ingeniøren, 2014). It is not all the pipes there is need to be dig down in the ground, only around 20 % of the pipeline network should be underground district heat pipes. The rest (80%) of the pipeline network is placed over ground inside the buildings on SDU, and are connected with nearby placed electric heater. The electric heater is spread out over whole SDU and there are 20 electric heaters, but not all the electric heater is getting connected since there isn't enough cooling heat to supply all the electric heaters. The location of the electric heaters is unknown, that's the reasoning for the placement of the pipeline network is just based on connection between some of the buildings. The cost of the pipeline network is added to the investment cost the booster heat pump since the pipeline network is needed to be utilize the cooling heat as heat source instead of the electric heater. This information leads to the data shown in Table 6.

Pipeline network	Price/value	Unit	Source
Electric heaters	20	Numbers	(Teknisk service,2017)
Distance for pipelines	400	Meter	(Geofyn, 2016)
District heat pipe price	250	DKK/meter	(BilligVVS, 2017)
Digging price for pipes	1000	DKK/meter	(Ingeniøren, 2014)

Table 6 shows the data for the pipeline network to utilize the cooling heat on SDU.

There is some extra cost to installation of pipelines to connecting the electric heaters. To calculate the cost, it's needed an estimation of how many meter pipelines there is needed to be used to connect them. To find out the estimation of meters of pipeline the website "Geo Fyn" is used.

6.3.8 Economic data

This section introduces economic terms used. The data is shown in Table 7.

Economic data	value	Unit	Source
Discount rate	4	%	(DLBR, 2014)
Required rate of return	4	%	(PWC, 2017)
Inflation	2	%	(Energistyrelsen,2016 april)

Table 7 shows other relevant data, such as discount rare, required rate of return and inflation.

The discount rate is used to decide if there is sensible relationship between the investment and the positive effecter, that the investment has in the future. The discount rate is typical set to 4-5%, but in the calculated is used a discount rate on 4%.

Required rate of return is based on the value the investor's sets compared to the how the market is. The required rate of the return in the calculation is set to 4%.

Inflation is added to the cost, since the value of money either decrease or increase. In the calculation, inflation on 2% is used.

6.3.9 Cash flow, payback time and NPV

The socioeconomic and business economic analyses are based on results from the calculations methods cash flow, payback time and NPV is used. They will be described in this section.

Cash flow is the calculated results of the cost like O&M, taxes, etc. and revenue like district heat savings and electric heater savings.

Net cash flow is the amount of money there is either earned or lost during a year. Net cash flow is calculated by subtracting the revenue with the expenses.

Payback time is calculated by using the investment cost and subtract it from the net cash flow to get the number of years it takes before the technology have paid itself back.

Net present value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$$

C_t is the net cash inflow during the period t, C_0 is the total initial investment costs, r is the discount rate and T is the number of time periods. The NPV is used to calculate the value of booster heat pump.

6.4 Cooling heat from electric chillers

A precondition to further calculations and as a basis for assessing the viability of the purpose is that of excess heat from cooling production, specifically electric chillers. The excess heat is directly related to feasibility of heat recovery solutions as it determines how much heat they can recovery and utilize elsewhere. This part of the report will undergo how that excess heat from cooling production is calculated and quantified.

The presented hourly data of cooling demand and electricity consumption in kWh's on SDU cooling centrals provide the basis for the calculation.

With knowledge regarding the type of coolant liquid and temperatures of the electric chillers on SDU, condenser- and evaporator side, it was possible to establish the amount of excess heat produced on the condenser side when producing cooling. This process is described in Coolpack electric chiller and heat pumps section, and shows a cooling COP of 4.85 and heating COP of 6 come close to what was assessed in Coolpack.

Now, not all the excess heat from the condenser can be utilized, between 10-20% can be utilized (Forening for Energi & Miljø, 2002). Through the report, 20% is used in calculations.

This method of approach leads to Figure 15, it's important to note the graph shows under the circumstances of electric chillers only operating above 16 °C.

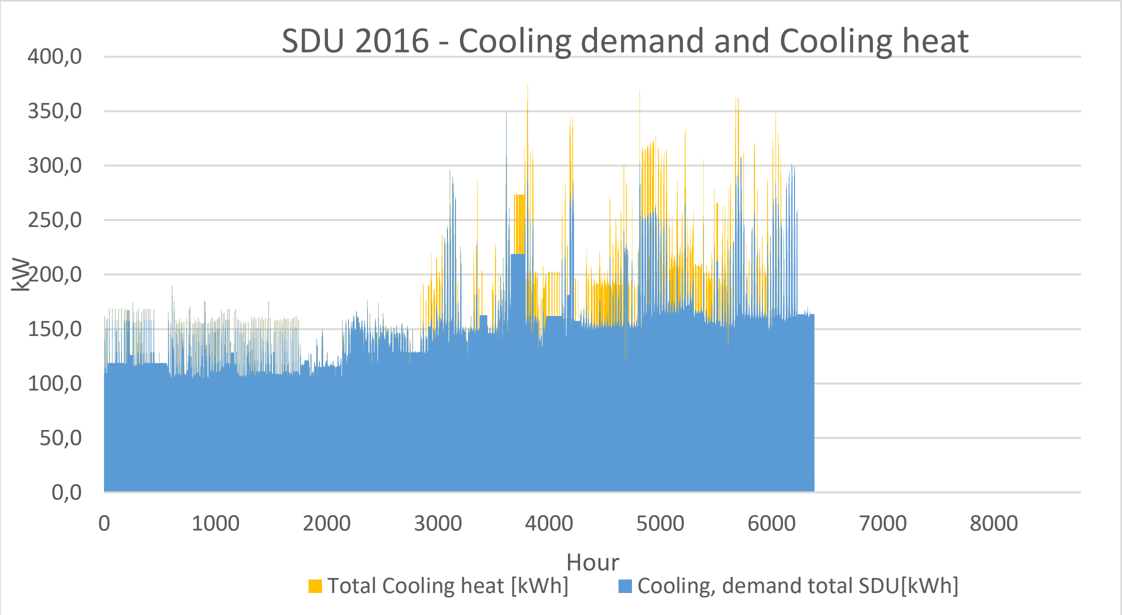

Figure 15: Cooling demand and excess heat on SDU 2016 with electric chillers active at outdoor temperatures above 16 °C.

At set point 16°C, the cooling heat off electric chillers amount to 55064 kWh.

6.4.1 Determining EL-tariff for New OUH

The main tariff on electricity is called EL-tariff and has been applicable since 1st of January 2017. However, depending on how the electricity was used, for either process- or comfort cooling, the consumer can receive compensation for the tariff. The consumption of electricity is regarded as process energy unless the electricity is used for heating water or comfort cooling. In general, companies can be compensated for the majority of the EL-tariff if the electricity was used for process energy. However, if the electricity is applied to comfort cooling the compensation is lower.

6.4.2 Modelling New OUH and SDU in EnergyPro

Modelling the site of NEW OUH and SDU is done to for the purpose of scenario 3.

Figure 16 is a picture of the modelled SDU site in EnergyPro, and accounts for both S&SC and Tek cooling central. The general structure of the EnergyPro is divided into three categories, the site are as follows from left to right: Fuel, production units and demand. The categories are connected by transmission lines, and those lines are coloured black, red and blue for electricity, heating and cooling respectively. Fuel in this case, is spot prices. Production units are the electric chillers and dry cooler. Though there are multiple units of electric chillers, they are combined to a single unit for simplicity and in term of modelling, there is no real difference. The reason for two electric chillers originates in the taxation on EL-tariff when producing cooling for comfort or process. In the case of separated locations, SDU exclusively produces process cooling. Therefore, two units taxed differently depended on the purpose of the produced cooling are necessary. The demand is hourly data as presented in Figure 6 and Figure 11.

In regards to the connection between the sites, is based upon the dimensions of the district cooling grid proposed by FVF (Appendix 3) and the capacity of SDU. This leads to a dimension of a cooling capacity of 0.75 MW between SDU and New OUH. In regards to dimensions on electric chillers and dry cooler, which is 0.75MW and 0.3MW respectively.

The production units are modelled by an IF function:

$$If(ODT(\_) > 16; 0.75; 0)$$

The function is determined by the out door temperature, meaning if the temperature is above 16°C the output of the unit, in this case electric chiller, is 0.75 MW otherwise 0 MW. The electriccal input is then the 0.75 MW devided by a COP.

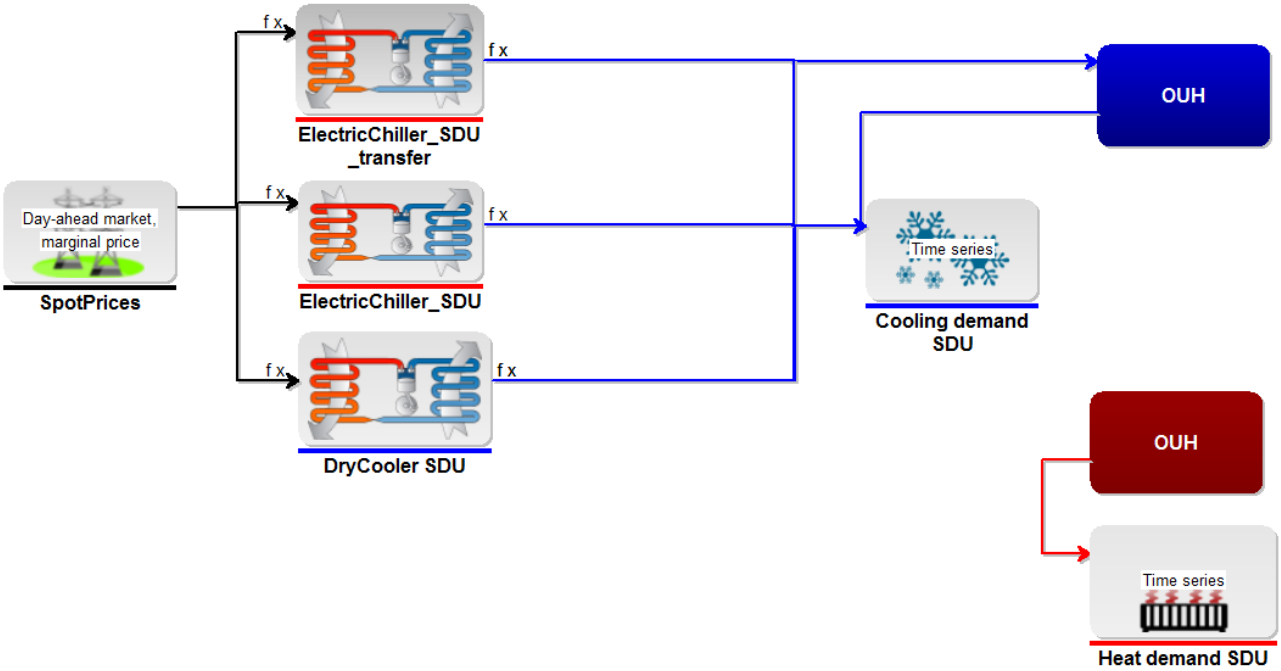

Figure 16: EnergyPro model of SDU

Figure 17 is a picture of a simplified New OUH cooling central, and the EnergyPro structure follows that of SDU with the addition of a cooling storage and a heat production. Concerning dimensions of storage, which is based upon (Technical description, 2015), is a 1300m^3 tank with 18°C at the top and 12°C at the bottom. The cooling production is 7.1MW, meaning the dry cooler and electric chillers both have capacities of 7.1.

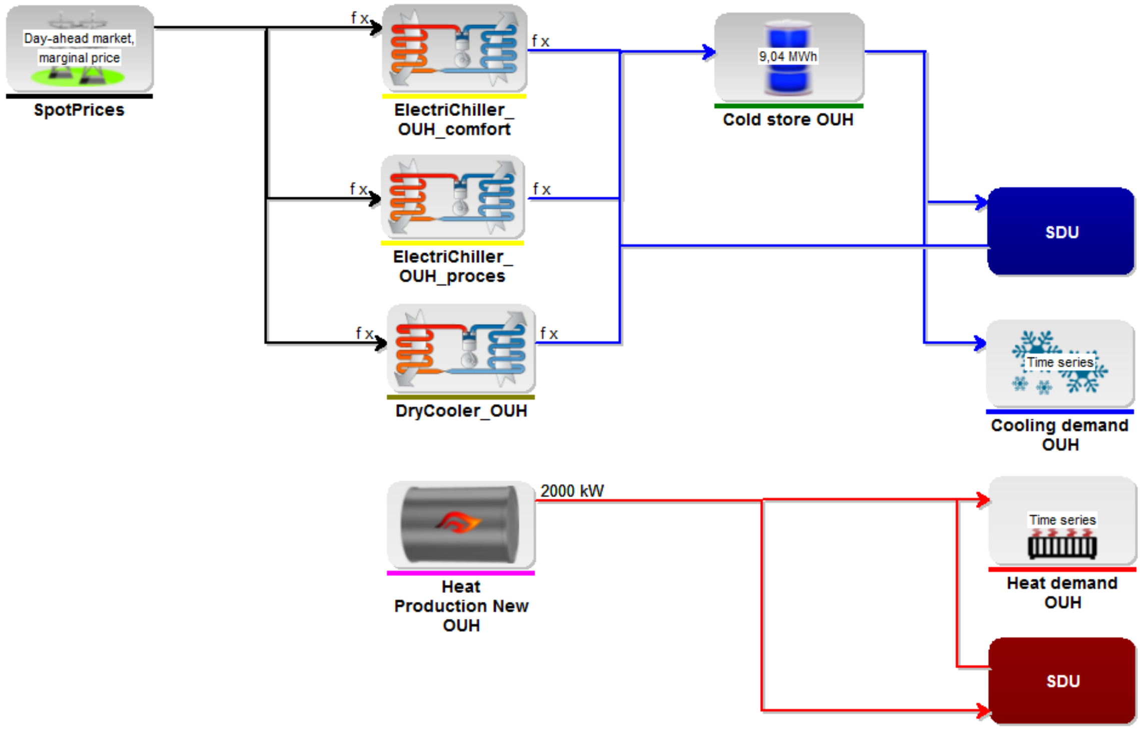

Figure 17: EnergyPro Model of New OUH.

Two other EnergyPro models with fewer units, and less focus on determining EL tariff was used in calculations of scenario 3.

6.4.3 Two solutions for scenario 1

Now that the data and energy system descriptions has been introduced, there seem only two ways for SDU to utilized its cooling heat:

Electric heater: It's known the district heating is closed during summer months, and there are 20 hot water storage tanks throughout SDU (Jensen J, 2017). So in that aspect, one way to utilize the cooling heat is by feeding it into hot water storage tanks. This solution however, have the obstacle of making it technical possible, to counter that it's necessary to connect a series of nearby tanks in proximity to the cooling centrals. This solution is one way to utilize the cooling heat, by substituting the electric heater during summer with cooling heat.

District heat: Instead of buying district heat from the grid to cover demand, cooling heat from electric chillers could replace some of that demand. The obstacle being that SDU have little use, as the majority of the cooling heat is available when SDU have closed its district heat. However, for the sake of comparison the second solution will be to use cooling heat to substitute district heat. How in practice that would happen, is a black box in this report.

This concludes the prerequisites for next section of result.

7 Results and analysis of scenarios

The following section includes business economics and socioeconomics followed by a comparison for all three scenarios.

7.1 Scenario 1 – Heat recovery on SDU analysis

In this section, the business economic results are shown and illustrated for the cash flow and payback time, NPV and heat price for booster heat pump. This section also includes the taxes, tariffs and added value tax since it is a business economic analyses. Description of the data used for business economic results can be found in the section Energy system descriptions

7.1.1 Business economic results

The initial results will begin with Business economics.

7.1.1.1 District heat solution

This section shows the results for the cash flow and payback time for installation of a booster heat pump on SDU cooling central.

The cash flow results for installation of a booster heat pump. The results consist of district heating saving as the revenue and O&M, electric purchase, grid tariff, PSO, electric tax, added value tax and system tariff as the expenses. The results are illustrated in Figure 18.

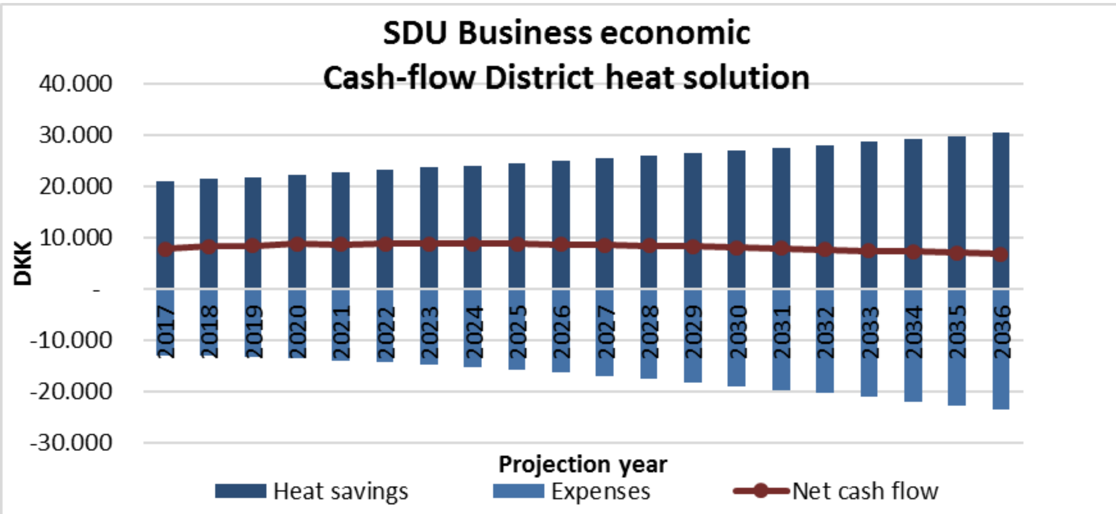

Figure 18: Business economic cash flow – SDU district heat solution

On Figure 18 is the district heat savings increasing in value every projection year. At year 2017, the revenue from district heat savings on 20,875 DKK, while at year 2036 the district heat savings is on 30,367 DKK. That's gives a difference on 9,492 DKK. The reason for high difference on the heat savings is that the spot price does increase to 589 DKK/MWh in 2036 and the inflation also increases over the years. The results for the expenses in 2017 are 13,057 DKK and in 2036 it is on 23,588 DKK. That's gives a difference on 10,531 DKK. All the other expenses do not increase as much as the revenue every year, since it isn't effected by changing spots price except O&M, El purchase, PSO (phases out in 2022) and added value tax. Also, the net cash flow is increasing over the 20 years, because of the revenue from heat savings is higher than the expanses for the booster heat pump.

This part show results for payback time and uses the investment cost of the heat pump and the net cash flow. The results are illustrated in Figure 19.

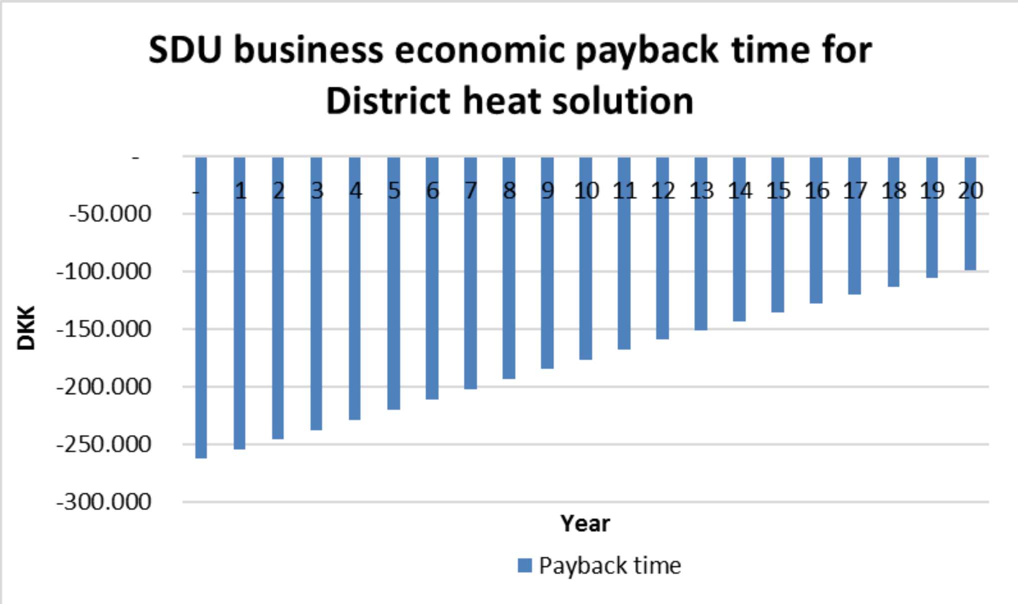

Figure 19: shows the payback time for booster heat pump with the district heat savings over 20 years.

On Figure 19 year 0 is the investment cost of the booster heat pump for replacement of the electric heater. What is also shown is how the net cash flow is reducing the investment cost over the 20 year of the heat pump life time. It can be seen, that the booster heat pump does not pay itself back before after 20 years. After the 20 years, there isn't revenue for using the booster heat pump to utilize the cooling heat.

7.1.1.2 Electric heater solution

In this section, the results for cash flow and payback time for booster heat pump with electric heater savings will be described and illustrated.

In the section the cash flow results will be described and illustrated for a booster heat pump with electric heater savings. All data are the same as used for the booster heat pump with district heat savings in section District heat solution except it is now electric heat savings instead district heat savings. The results are illustrated in Figure 20.

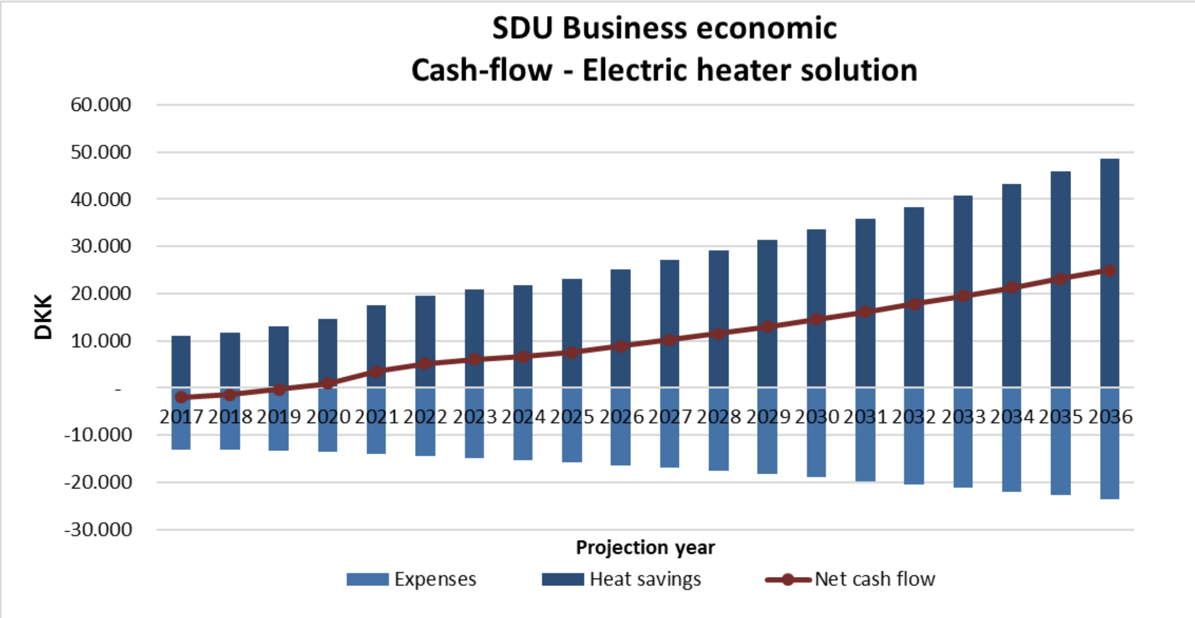

Figure 20: Business economic cash flow – SDU Electric heater solution

What is seen on Figure 20 is that the electric heater savings does increase in value every projection year. At year 2017, the revenue from electric heater saving on 11,046 DKK, while at year 2036 the electric heater savings is on 48,605 DKK. That gives a difference on 37,559 DKK. The reason for high difference on the savings is that the spot price does increase to 589 DKK/MWh in 2036 and the inflation also increases over the years. The results for the expenses in 2017 are 13,057 DKK and in 2036 it is on 23,595 DKK. That's gives a difference on 10,538 DKK. All the other expenses do not increase as much as the revenue every year, since it isn't effected by changing spots price except O&M, El purchase, PSO (phases out in 2022) and added value tax. The figure also shows the net cash flow and it does increase a lot over the 20 years, because of the revenue from heat savings is much higher than the expanses for the booster heat pump.

In the section the payback time results are shown and described for a booster heat pump. The payback time result uses the investment cost of the heat pump and the net cash flow. The results are illustrated in Figure 21.

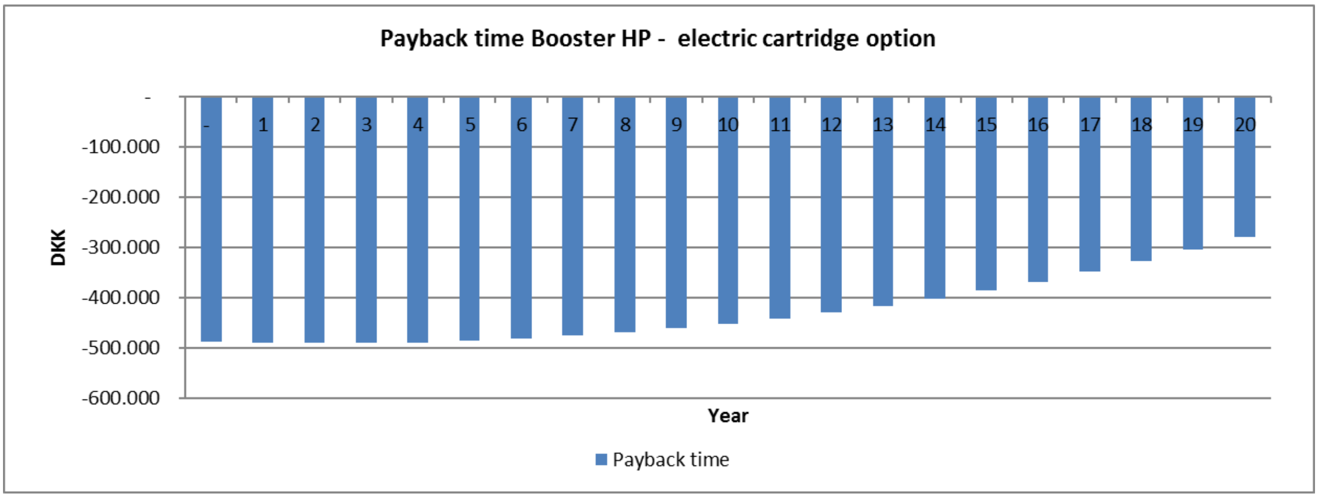

Figure 21: shows the payback time for the booster heat pump over 20 years' lifetime.

On Figure 21 year 0 is the investment cost of the booster heat pump with replacement of the electric heater. In regard to the net cash flow, it reduces the amount of the investment cost over the 20 years of the heat pump life time. After the 20 years, there is still 279,336 DKK left to pay of the investment cost for the booster heat pump that means in electric heater solution the booster heat pump do not pay itself back.

7.1.1.3 Comparison of Electric heater and district heating solution

In this section, the results from total cost of the booster heat pump both with district heat savings and electric heater savings will be compared and described. The NPV will also be compared for the 2 solutions.

In this section, the total cost results is all the expenses that the booster heat pump needs to be paid over the heat pump lifetime, that also include the investment cost. The results are made for both solutions of booster heat pump with district heat savings and with electric heater savings. The results also are compared with the 2 difference solutions of what the booster heat pump replaces. The results are illustrated in Figure 22.

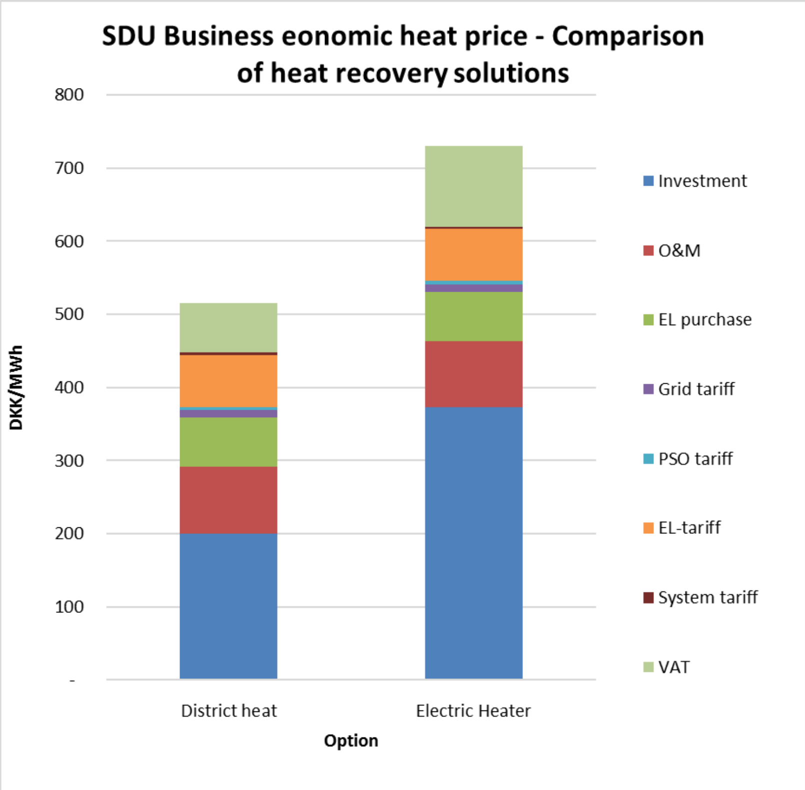

Figure 22: Business economic heat prices – SDU heat recovery solutions.

On Figure 22 can be seen the total cost results for booster heat pump for the 2 solutions. The results show that the highest cost is the investment, but the investment cost is higher on electric heater solution than the district heat solution. The investment cost for the solution with district heat is 200.26 DKK/MWh compared to electric heater solutions with an investment cost on 372.31 DKK/MWh. That's gives at difference on 172 DKK/MWh. The other expenses are the same for the 2 solutions, which is O&M on 91.31 DKK/MWh, El purchase on 67.36 DKK/MWh, grid tariff on 10.35 DKK/MWh, PSO tariff on 4.26 DKK/MWh, el-tariff on 71.05 DKK/MWh, system tariff on 3.51 DKK/MWh and VAT for district heat solution on 66.91 DKK/MWh and for electric heater solution it is on 109.92 DKK/MWh. The main reason for the high difference in investment is because of the investment cost to the pipeline network for electric heater solution.

In this section, the NPV results is described and compared for the booster heat pump with the 2 solutions. The results are illustrated in Figure 23.

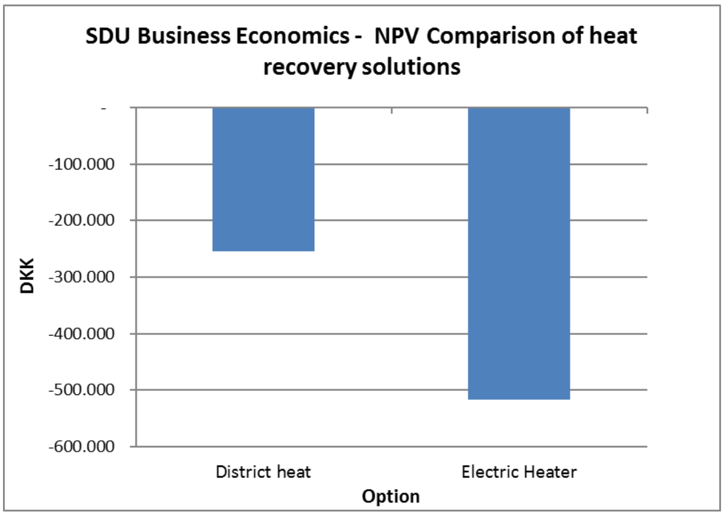

Figure 23: Business economic NPV – SDU heat recovery solutions

Figure 23 shows the NPV for booster heat pump with the two solutions. The results show that the district heat solution having the best NPV results since it closer to be positive results compared to the electric heater solution. The result on district heat solution is on -254,672 DKK and the electric heater solution is on -517,005 DKK.

7.1.1.4 Part conclusion

Looking at the cash flow for booster heat pump with district heat saving and electric heater savings can be seen that electric heater solution is, because the revenue is higher that the costs, which give a higher, net cash flow.

The payback time on the booster heat pump with district heat solution is after 20 years, while with the electric heater solution is paid back is also sometime after its lifetime. However, the NPV shows both investments in total will end in a loss because the investment cost is so high.

Looking at the heat price for booster heat pump for the two solutions the picture is a bit difference, since the investment cost is a lot higher for the booster heat pump with the electric heat saving than the solution with district heat saving, because there is needed a pipeline network cost to connect the booster heat pump to the electric heaters.

7.1.2 Socioeconomic results

In this section, the socioeconomic results are shown and illustrated. The results are based on cash flow and NPV methods and also show the heat price of the booster heat pump. The data used for results can be found in the data description section Energy system descriptions .

7.1.3 Comparison of electric heater and district heat solutions

In this section, the results from the socioeconomic analyses are illustrated and compared with the heat price for booster heat pump over a 20-year period for the district heat solution and electric heat savings. The NPV results also getting compared for the two solutions and getting rounded with a part conclusion.

In this section, the heat price for the two solutions for booster heat pump is set up and will get compared together. The results for heat price for the two solutions are illustrated in Figure 24.

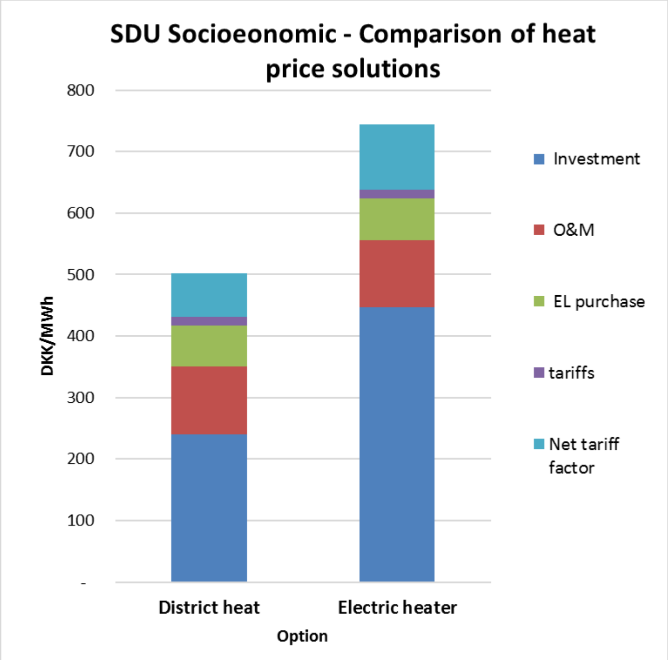

Figure 24: Business economic heat prices – SDU heat recovery solutions.

Figure 24 shows heat price of the two solutions for the booster heat pump. The results indicate that the investment cost is lot higher for electric heater solution than the district heat solution. The investment cost is on 240.32 DKK/MWh for district heat solution and 446.77 DKK/MWh on the electric heater solution. The net tariff factor on 70.93 DKK/MWh for electric heater solution compared to 106.03 DKK/MWh on the district heat solution. The results are the same for both solutions on 109.58 DKK/MWh for O&M, 67.36 DKK/MWh for el purchase and 13.86 DKK/MWh for tariffs. The reason for the high investment on the electric heater solutions is there is included the pipeline network cost to connect the booster heat pump with the electric heaters.

In this section, the results for NPV for the booster heat pump with district heat savings and electric heater savings. The results are illustrated in Figure 25.

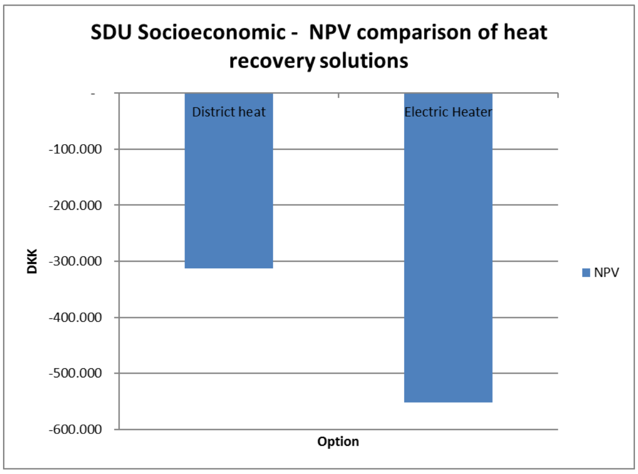

Figure 25: SDU Socio economic NPV – Heat recovery solutions.

On Figure 25 shows the Socioeconomic NPV results for the booster heat pump the two solutions. The district heat solution ends in -312,000 DKK while the electric heater solution is -552,150 DKK. The largest contributors to these numbers are the large investment on the electric heater solution and the difference between savings.

7.2 Scenario 2 – Cooling central New OUH

This scenario section, will make a business analyses of the total production cost of installing and running the cooling central proposed by FVF. The calculation is done for a 30-year period, as that is the lifetime of the electric chiller. Further applied data in this section is found in Energy system descriptions. Same electricity prices from scenario 1 is applied in this scenario, but now that the life time is 30, a linear increase is made to have electricity prices for a 30-year period.

Seen in Figure 26 is seen the total production cost of running the cooling central on New OUH. Furthermore, this figure introduces the term reference, as it is the price that have the data that closest reflect what the actual price of New OUH cooling central might cost in scenario 2 sections.

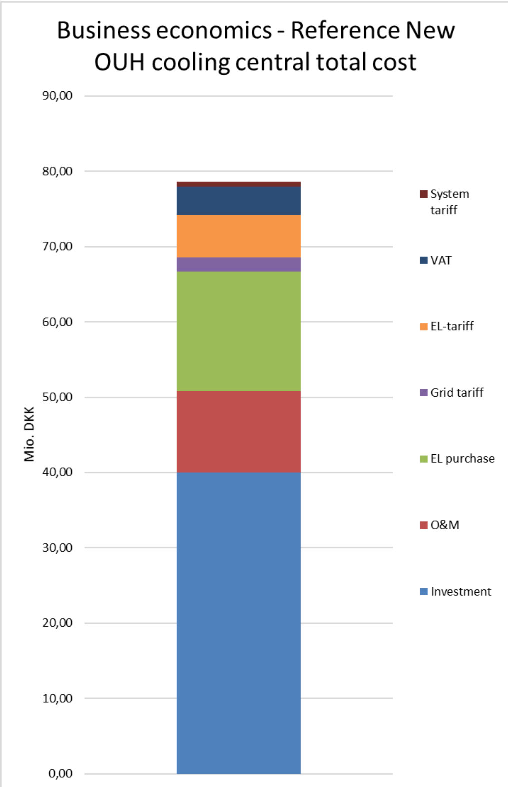

Figure 26: Business economic constituents for total production cost on cooling central New OUH

The total production cost amounts to 88.9 million DKK. The **investment** cost is 40 million DKK, **O&M** 10.83 million DKK, **purchased electricity** 15.82 million DKK**, grid tariff** 1.94 million DKK, **EL-tariff** 5.59 million DKK, **VAT** 3.79 million DKK and **system tariff** 0.66 million DKK.

Electricity consumptions accounts for dry coolers and electric chillers and the EL tariff is calculated in the EnergyPro models. The purchased electricity cost constitutes of electricity for running dry coolers and electric chillers to meet the demand of New OUH.

Since, the actual proposed New OUH cooling central is not build yet, the known temperature set point from SDU is carried over to this, which is on 16°C.

7.3 Scenario 3 - Connected New OUH and SDU

This scenario will look into the benefits of connecting the future New OUH and SDU. To that end, the chosen parameter of comparison will be production cost. The exported data from EnergyPro which constitutes the results are from energy conversion and cash flows. This gives the first result of production cost. Figure 27 shows production cost and its constituents in a one year period modelled in EnergyPro. The model is based on the producing units covering the demand profiles of both SDU and New OUH. The following term, reference, describes the case of SDU and New OUH in models with capacities and demands as mentioned in Demand profiles and physical frames of SDU and New OUH. The terms are also used in the following sensitivity section.

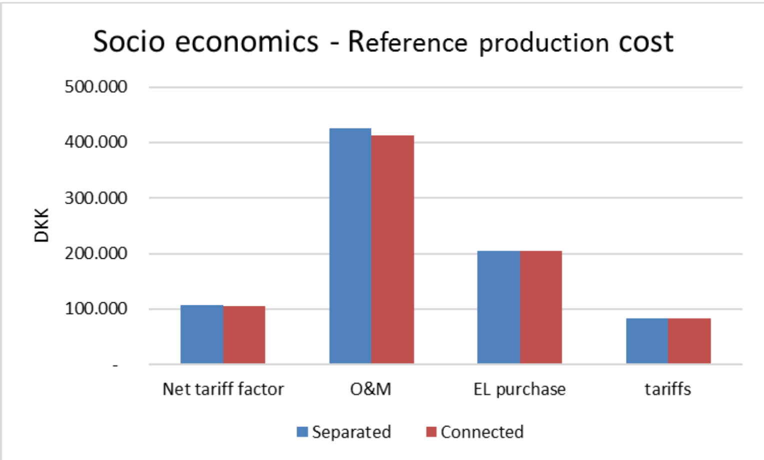

Figure 27: Production cost of scenario with separated and connected New OUH and SDU for year 2016.

These values represent the production cost of one-year period and are found by running the model two times, one where transferring cooling and heat between the SDU and New OUH is enabled and one with no transferring. This approach shows how expensive the running cost is, and the two numbers can be compared. In Figure 28 is shows the difference between production cost from previous figure.

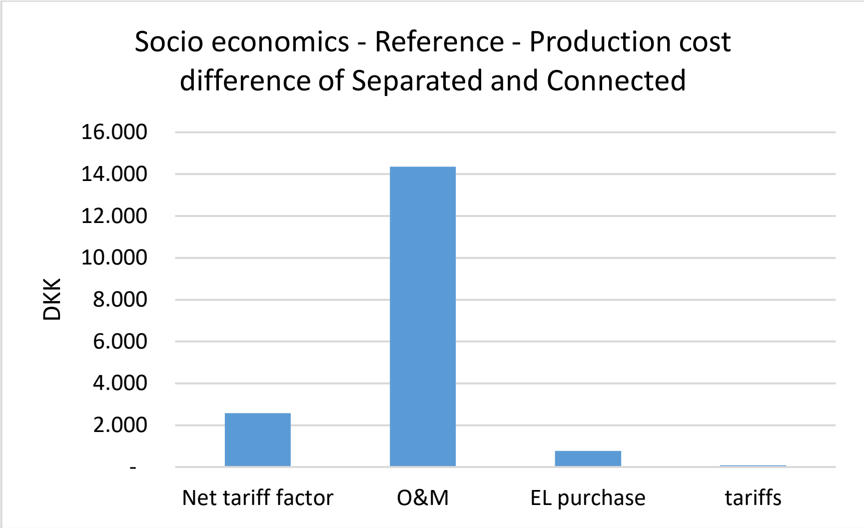

Figure 28: Reference socio economics of production cost difference between separated and connected

Meaning, when connecting the two sites in EnergyPro, there is a saving of 2,572 DKK in Net tariff factor, 14,362 DKK in O&M, 770 DKK in electric purchase and 80 in tariffs, system tariff and grid tariff. Meaning, that by connecting New OUH and SDU the socio economic benefit is 17,784 DKK in production costs over a period of one year and 2016 spot prices.

8 Sensitivity analysis

Now, many of the parameters used throughout the report have some or large uncertainties attached to them and could have skewered the results. Therefore, in that context some parameters need to be reconsidered, and examined to see how it influences the results.

8.1 Scenario 1 – SDU heat recovery analysis

This section cover the sensitivity analyse on for scenario 1, the two heat recovery solutions on SDU. The reference results are based on spot prices for 2016. The analyses are focuses on three different sensitivities. The first one is reduction of the spot price with 20% for the electricity and using the projected electricity prices of 5th of May 2017 (Appendix 2). The second is reducing investment cost with 30%. The third sensitivity is increasing the numbers of operations hours by changing the temperature set point for the electric chiller from 16 °C to 13 °C, this changes the numbers of operation hours from 1227 hours to 2392 hours, which is a difference of hours.

8.1.1 Business economic sensitivity NPV with district heat solution

In this section, the sensitivity analyse results is for a business economic model. The NPV results is for a booster heat pump with district heat savings solution and will be described and illustrated. The results are illustrated on Figure 29.

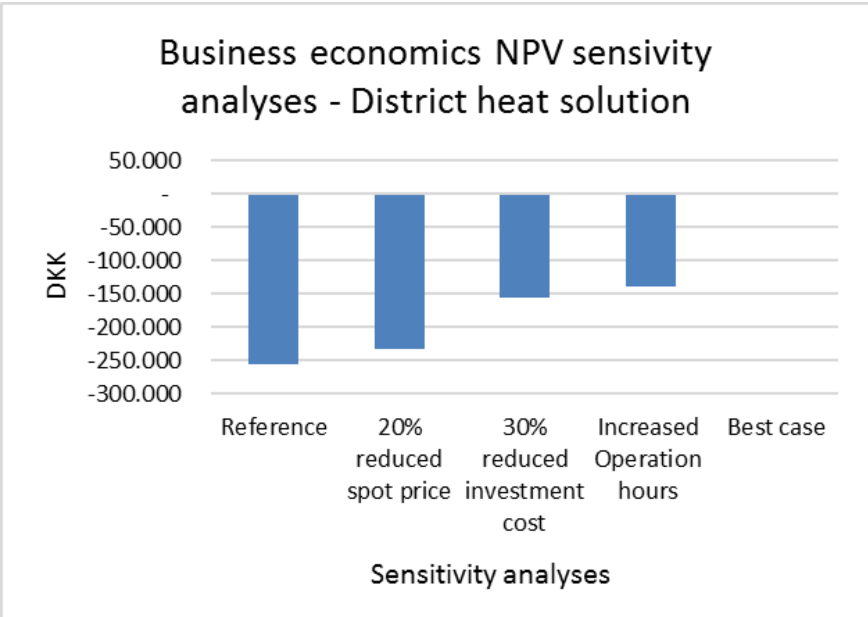

Figure 29 shows the NPV sensitivity analyses for business economic results with district heat solution.

On Figure 29 can be seen the results from the sensitivity analyses on business economic NPV for district heat solution. The reference scenario does have a NPV on -254,672 DKK, compared to the sensitivity analyses NPV results on -233,398 DKK with a 20% reduced spot price, -155,957 DKK with a 30% reduced investment cost and -138,761 DKK with an increased number of operations hours from 1227 hours to 2392 hours, because of changed set point temperature from 16 °C to 13 °C. There is also made a best case, which including all the sensitivities and have NPV results on 788 DKK. With a reduced spot price, the results for the NPV getting 21,274 DKK higher than reference scenario, because the cost for buying electricity is reduced with 20 %. The NPV increases with 98,714 DKK then the investment cost is reduced med 30% on the booster heat pump compared to the reference scenario. The investment cost is a big part of the expanses for the booster heat pump, but still not high enough to give profit for investing in the booster heat pump if the investment cost reduction is added. In the case with increased number of operations hours for the booster heat pump, because the temperature set point changing from 16°C to 13°C on the chiller. That's leads to a NPV on 115,910 DKK higher than the reference scenario. The reason for the high NPV is that the operation hours increases on the electric chiller on SDU cooling central, that also lead to increased amount of cooling heat that can be utilized from the electric chiller to the booster heat pump. Lastly there is the best case NPV on 255,460 DKK higher than the reference scenario. which gives a little profit of 788 DKK after the 20 years of lifetime on the booster heat pump.

8.1.2 Sensitivities on business economic NPV with electric heater solution

In this section, the sensitivity analyses result for business economic NPV for a booster heat pump with electric heater savings solution, will be described and illustrated. The results are illustrated on Figure 30.

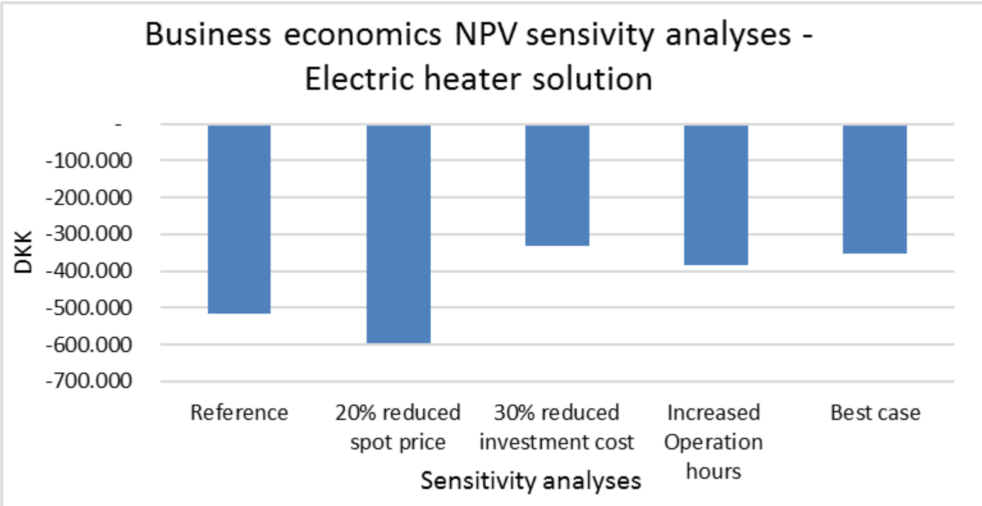

Figure 30: Shows the sensitivity analyses business economic NPV results for booster heat pump with electric heater savings solution.

On Figure 30 can be see the results from the sensitivity analyses on business economic NPV for electric heater solution. The reference scenario does have a NPV on -517,005 DKK, compared to the sensitivity analyses NPV results on -597,847 DKK with a 20% reduced spot price, -333,485 DKK with a 30% reduced investment cost and -138,761 DKK with an increased number of operations hours from 1,227 hours to 2,392 hours, because of changed set point temperature from 16 °C to 13 °C. With a reduced spot price, the results for the NPV getting -80,842 DKK lower than reference scenario, because the cost for buying electricity is reduced with 20 %. The reason for that NPV is decreasing is because in the electric heater solution the electric heater is replaced with the booster heat pump, so the expense on the electric heater is the revenue for this scenario. The NPV increases with 183,520 DKK then the investment cost is reduced with 30% on the booster heat pump compared to the reference scenario. The investment cost is a big part of the expenses for the booster heat pump, but it isn't enough to give profit on the NPV, since the investment cost is much higher on electric heater solution compared to the district heat solution. In the case with increased number of operations hours for the booster heat pump, is because the temperature set point changing from 16°C to 13°C on the electric chiller. That's leads to a NPV on 134,627 DKK higher than the reference scenario. The NPV is still only on -382,378 DKK that is not enough to give profit with the increased operation hours. The reason for the higher NPV is that then the operation hours increases on the electric chiller on SDU cooling central, that also leads to an increasing amount of cooling heat that can be utilized from the electric chiller over to the booster heat pump.

8.1.3 Sensitivities on socioeconomic NPV with district heat solution

In this section, the sensitivity analyse results for socioeconomic NPV for a booster heat pump with district heat savings solution, will be described and illustrated. The results are illustrated on Figure 31.

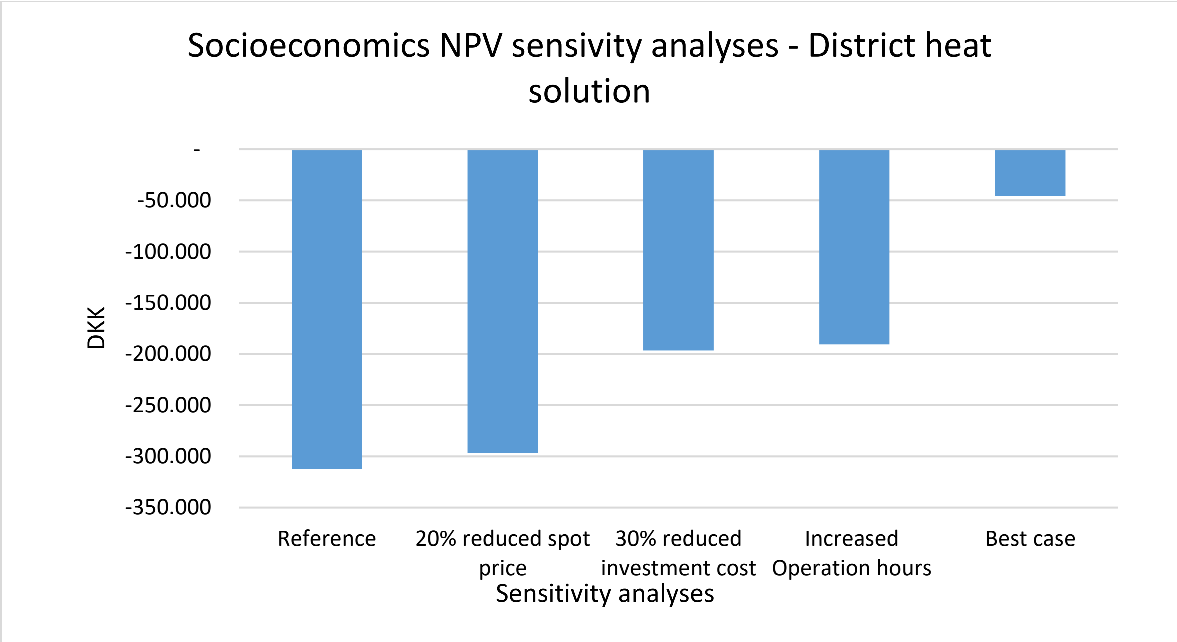

Figure 31: Shows the sensitivity analyses socioeconomic NPV results for booster heat pump with district heat savings solution.

On Figure 31 can be seen the results from the sensitivity analyses on socioeconomic NPV for district heat solution. The reference scenario does have a NPV on -312,265 DKK, compared to the sensitivity analyses NPV results on -296,933 DKK with a 20% reduced spot price, -196,562 DKK with a 30% reduced investment cost and -190,741 DKK with an increased number of operations hours from 1227 hours to 2392 hours, because of changed set point temperature from 16 °C to 13 °C. With a reduced spot price, the results for the NPV getting 15,332 DKK higher than reference scenario, because the cost for buying electric is reduced with 20 %. The NPV increases with 115,703 DKK then the investment cost is reduced med 30% on the booster heat pump compared to the reference scenario. The investment cost is a big part of the cost for the booster heat pump, but it is not enough to make the NPV positive, which mean there is not profit for investing in the booster heat pump if the investment cost reduction is added because of the higher investment cost in Socioeconomic results with district heat solution. In the case with increased number of operations hours for the booster heat pump, because the temperature set point changing from 16°C to 13°C on the chiller. That's leads to a NPV on 121,524 DKK higher than the reference scenario. The NPV does not give a profit with the increased operation hours since it is still on -190,741 DKK. The reason for the high NPV is that then the operation hours increases on the electric chiller on SDU cooling central, that also increasing the amount of cooling heat that can be utilized from the chiller over to the booster heat pump.

8.1.4 Sensitivities on socioeconomic NPV with electric heater solution

In this section, the sensitivity analyse results for socioeconomic NPV for a booster heat pump with electric heater savings solution, will be described and illustrated. The results are illustrated on Figure 32.

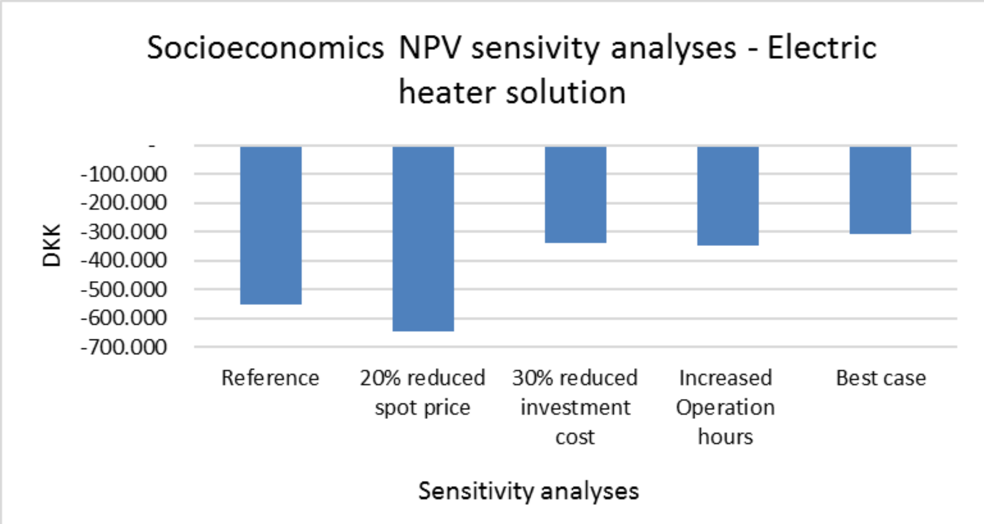

Figure 32: shows the sensitivity analyses business economic NPV results electric heater savings solution.

On Figure 32 can be seen the results from the sensitivity analyses on socioeconomic NPV for electric heater solution. The reference scenario does have a NPV on -552,150 DKK, compared to the sensitivity analyses NPV results on -644,533 DKK with a 20% reduced spot price, -337,045 DKK with a 30% reduced investment cost and -346,533 DKK with an increased number of operations hours from 1227 hours to 2392 hours, because of changed set point temperature from 16 °C to 13 °C. With a reduced spot price, the results for the NPV getting -92,383 DKK lower than reference scenario, because the cost for buying electric is reduced with 20 %. The reason for that NPV is decreasing is because in the electric heater solution the electric heater is replaced with the booster heat pump, so the expense on the electric heater is the revenue for this scenario. The NPV increases with 215,105 DKK then the investment cost is reduced with 30% on the booster heat pump compared to the reference scenario. The investment cost is a big part of the cost for the booster heat pump, but it isn't enough to give profit on the NPV, since the investment cost is much higher on electric heater solution compared to the district heat solution. In the case with increased number of operations hours for the booster heat pump, is because the temperature set point changing from 16°C to 13°C on the chiller. That's leads to a NPV on 243,390 DKK higher than the reference scenario. The NPV is still only on -346,533 DKK that is not enough to give profit with the increased operation hours. The reason for the higher NPV is that then the operation hours increases on the electric chiller on SDU cooling central, that also increasing the amount of cooling heat that can be utilized from the electric chiller over to the booster heat pump.

8.1.5 Sensitivities on business economic heat price with both solutions

In this section the sensitivity analyse results for business economic heat price for a booster heat pump with both district heat and electric heater solutions, will be described and illustrated. The results are illustrated on Figure 33.

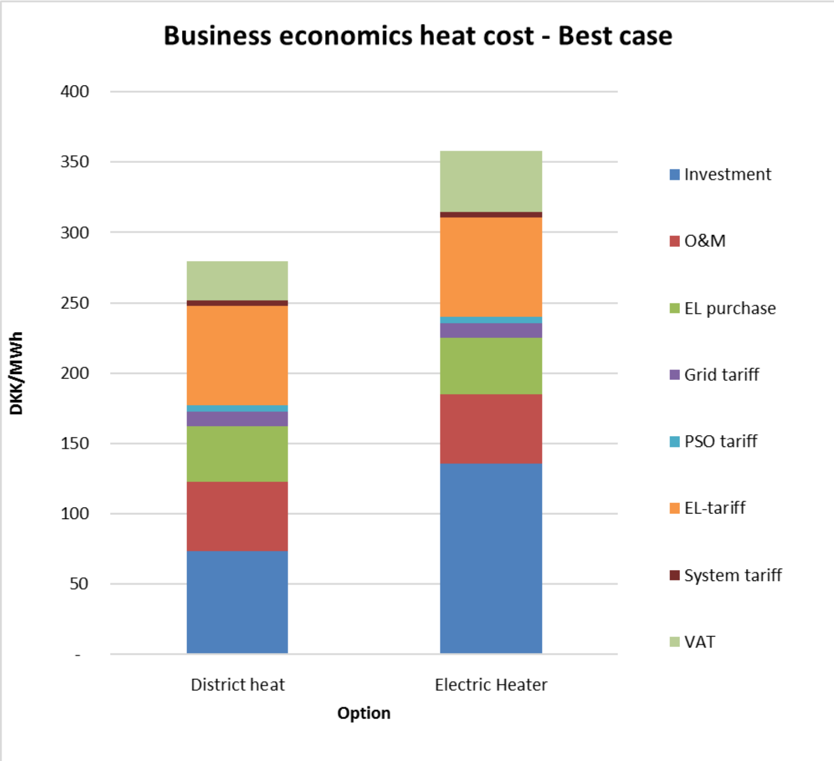

Figure 33 shows the business economic heat cost for best case with all sensitivities included.

The figure shows the business economic heat cost results for the best case scenario for a booster heat pump. The best case consist all the sensitivities results merged together, to give the best results. The best case has 20% reduced spot price, 30% reduced investment cost and increased operation hours. The investment cost is the biggest of the expenses, the results is an investment cost on 73.03 DKK/MWh for district heat solution and 135.77 DKK/MWh for electric heater solution. That is a difference on 127.23 for district heat solution and 236.54 for electric heater solution. The reason for the high change in investment cost is the operations hours, because of the increased cooling production from the electric chillers, which does lead to a higher production of cooling heat from the electric chiller. With the increased production, the cost is spread out over a bigger amount of cooling heat. Also, the reduced investment cost also has a part in the low investment cost. The increased operation hours also reducing the O&M cost since it is based amount of heat production the booster heat pump utilize. The spot price with 2017 projection and the 20% reduced spot price does reduction the cost for el purchase, since the 2017 project have lower prices on the electricity prices in the future years. The VAT does also getting reduced based on the reduction on the other expenses made in the sensitivity analyses. The tariffs expenses are unaffected by the sensitivities made in this project.

8.1.6 Sensitivities on Socioeconomic heat price with both solutions

In this section, the sensitivity analyse results for socioeconomic heat price for a booster heat pump with both district heat and electric heater solutions, will be described and illustrated. The results are illustrated on Figure 34.

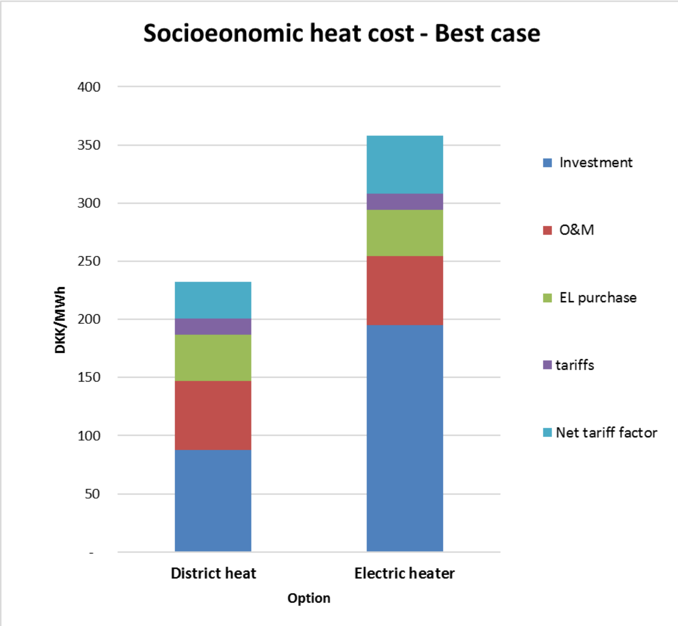

Figure 34: Shows the socioeconomic heat cost for best case with all sensitivities included.

Figure 34 shows the business economic heat cost in the best situation were all the sensitivities is added or removed to the heat cost. Also for the socioeconomic heat cost, the investment cost having the biggest change from 240.32 DKK/MWh to 87.64 DKK/MWh for district heat solution and from 446.77 DKK/MWh to 162.93 DKK/MWh for electric heater solution. That gives a difference on 152.68 DKK/MWh for district heat solution and on 283.84 DKK/MWh for electric heater solution. The reason for big difference is the same as for business economic heat cost. The spot price 20% reduction and projection to 2017 spot price, did reduced the cost to el purchase by 27.44 DKK/MWh down to 39,92 DKK/MWh. The net tariff factor is reduced based of the overall reduction of the cost from the other expenses reductions. The tariffs cost is unaffected by the sensitivities.

8.2 Scenario 2 – Cooling central New OUH

The production cost is subject to uncertainties in its data gathering and therefore a sensitivity analyses follows. The analyses will cover, investment cost, the set point for dry coolers and electricity prices. And relate it to the reference seen in Figure 26.

The investment cost of the cooling central on the New OUH. The investment cost is more than half of the total cost, and may have some uncertainty to it, despite the data coming from Johnson controls. Also, in a discussion with the cluster meeting, one participants addressed the high investment cost from Johnson controls. Therefore, a sensitivity into reducing investment cost is made as seen in Figure 35.

The total production cost amount to 66.63 million DKK, which is a 18% decrease in comparison to the reference.

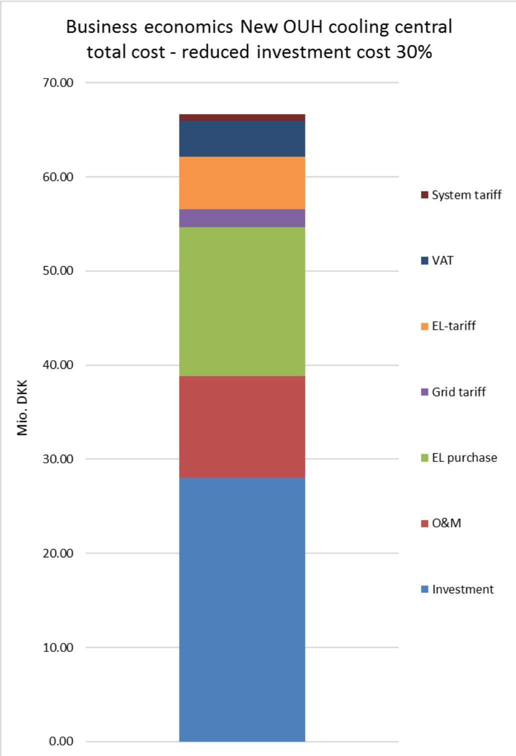

Figure 35: Business economic constituents for total production cost on cooling central New OUH and reduced investment cost of 30%.

Despite a 30% reduction, investment cost is still the largest factor in total cost, and addresses the importance of it.

The second biggest constituents of the total production cost Is the electricity purchase, which is directly related to the electricity consumption. The in the case of the reference, 2016 projections were used (Appendix 1). In the sensitivity analyses, electricity price projections from 2017 (Appendix 2) is used to see its impact. The result can be seen in Figure 36.

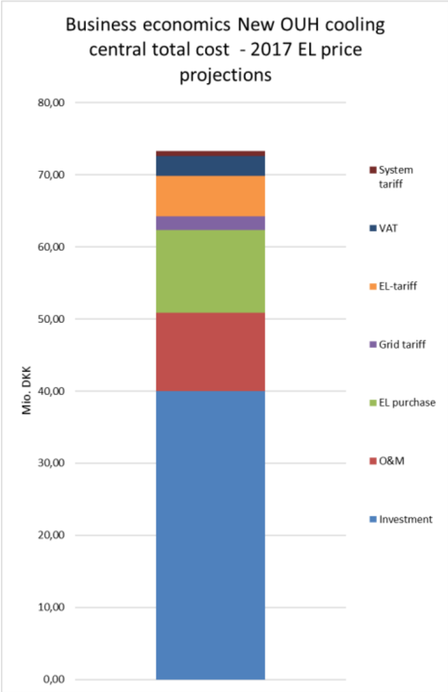

Figure 36:: Business economic constituents for total production cost on cooling central New OUH and e.

This changed electricity price lowers the total production cost to 73.28 million DKK. A 7.3 percent reduction in comparison to the reference.

Another important factor is the set point for which dry coolers and electric chillers are set to activate. It plays a significant role due to the difference in COP between the two cooling technologies. In the reference, the set point was 16°C, but a cluster meeting led to consider set points as low as 10°C. Figure 37 shows Productions cost with a dry cooler set point at 10°C. This also means the electric chillers increase in operation hours, and dry coolers decrease.

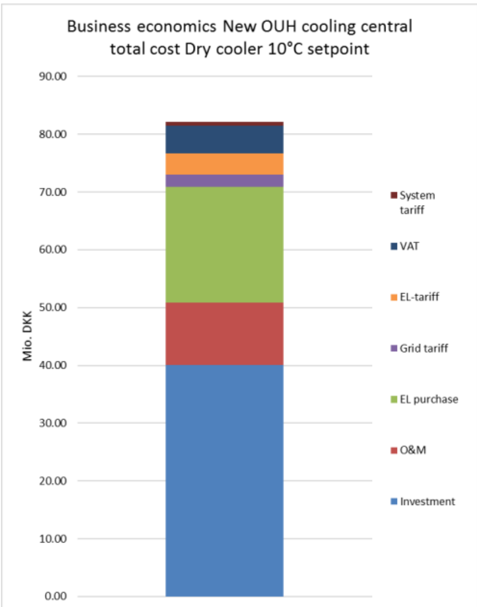

Figure 37: Business economic constituents for total production cost on cooling central New OUH with a dry cooler set point of 10°C.

This results in change of EL-tariff which is modelled in EnergyPro. The total production cost amount to 82.19 million DKK, a 4% increase of production cost.

8.2.1 Part conclusion

In short, the investment cost is the largest constituent of the production costs, and with the uncertainty regarding it, the investment cost should be carefully examined before deciding to move ahead. Concerning the set points for cooling units, it affects the operation hours of units and thereby O&M. Also, it affects many factor and requires attentiveness when changed. Lastly, the investment cost reduction led to the largest reduction of production cost at 18% reduction.

8.3 Scenario 3 – Connecting SDU and New OUH

The results of scenario 3 is done with one set of conditions, this section will examine how the results is affected by changing framework conditions. The sensitivity analysis is done by changing parameters, factors and the like in EnergyPro and extracting to excel for further process.

In the data gathering there is little difference in the variable running costs of the production units between the New OUH and SDU sites, which perhaps may not be the case in practice. Therefore, the following sensitivity analyses will shed light on the effects if there are different production costs for units between the SDU and New OUH. The sensitivity will in large, consist of diagrams showing the differences in production cost between the sites.

In Figure 38 the COP value on dry cooler and electric chiller on New OUH has been raised from 15 to 20 and 4.85 to 6 respectively. This is done to see what happens when one site, has more efficient production units than the other.

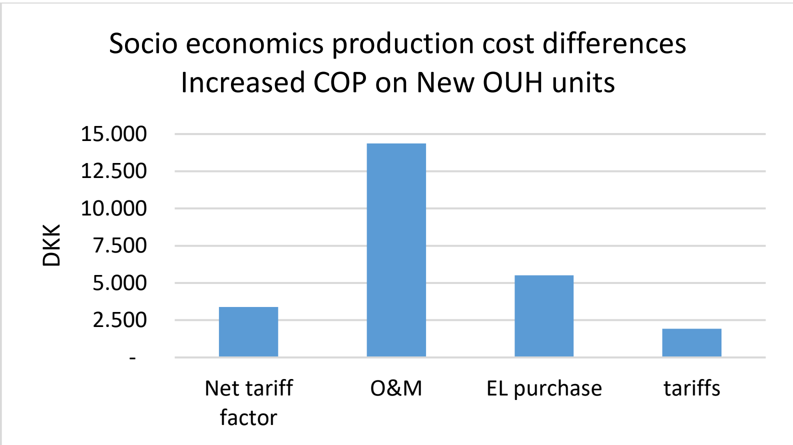

Figure 38: Reference socio economics of production cost difference between separated and connected SDU and New OUH, with raised COP on New OUH to make them more efficient.

The results show the differences are 3,381 DKK for Net tariff factor, 14,373 DKK for O&M, 5,518 DKK for electrical purchase and 1,920 DKK for tariffs in favour of connecting the two sites under these conditions. This result is as expected, it would be cheaper to produce the cooling on OUH than replace more expensive cooling on SDU because the units on OUH have high COP and therefore less electricity per kWh cooling produced. This is one benefit possible when connecting the two sites as new OUH could have new modern and more efficient units compared to SDU.

Energinet.dk has a projection for how future electricity price fluctuate on hourly basis. Since New OUH is set to be ready at year 2022, the situation may just be, that electricity prices will move to be steadier and less fluctuating compared with today's prices. Therefore, a model was run with Energinet.dk price fluctuation in Figure 13, along with a projects electricity price for year 2035. The Figure 39 shows the outcome.

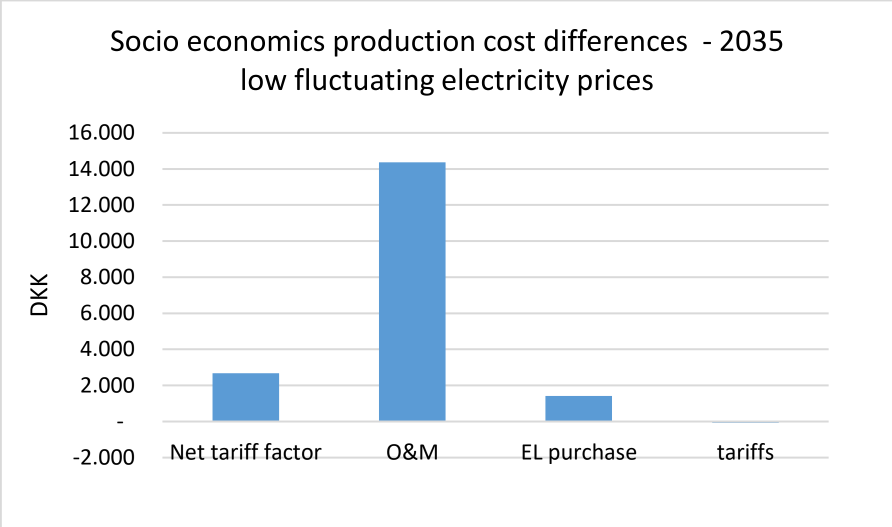

Figure 39: Reference socio economics of production cost difference between separated and connected sites and, with future electricity price and –fluctuation.

The results are identical to the reference scenario, despite the higher electricity prices the difference between the two remains the same. However, if it were the case of increased COP for New OUH, the production cost difference would increase.

In talks with (reference), he addressed the set point of 16 °C was too high for the dry cooler on New OUH to deliver the cooling demand, and instead thought 10 °C was more reasonable set point. That in conjunction with the fact it was observed on winter morning days that some electric chillers were active despite temperatures well below 16 °C on visits to SDU cooling centrals. For those reasons, modelling OUH with dry cooler set point at 10 °C is seen in Figure 40 to see the consequences.

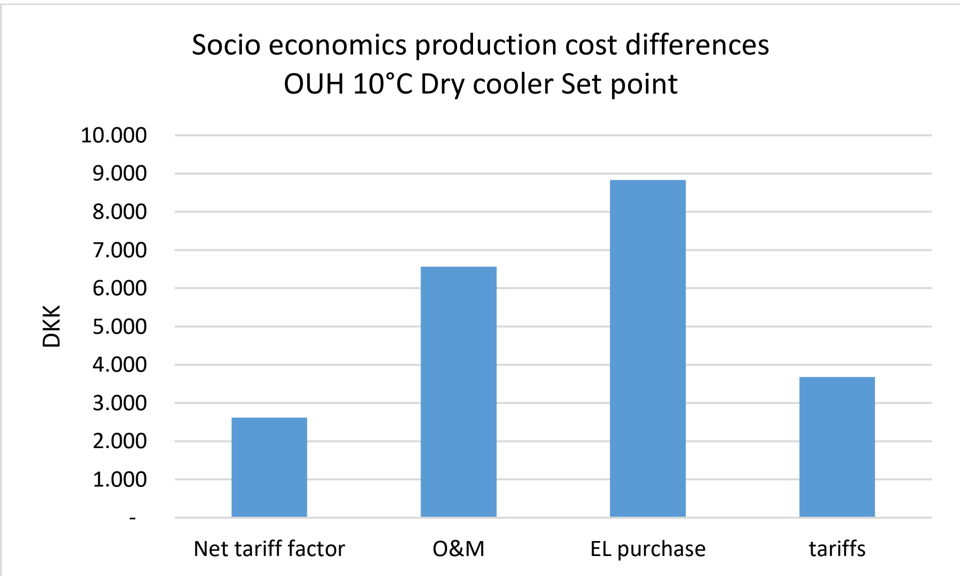

Figure 40: Reference socio economics of production cost difference between separated and connected sites and, with 10°C dry cooler set point.

The important part to note here is O&M is now reduced to 6,568 DKK and electrical purchase has gone up to 8,829 DKK. The electrical purchase benefit is now just under 9,000, this is due to there is now an increase in cooling production from electric chiller and less from dry coolers. Furthermore, because of increased electricity consumption from electric chillers, the benefit to a connected SDU and New OUH regarding tariffs is not 3,680 DKK.

To conclude, Figure 41 shows under which framework conditions the largest benefits to connecting SDU and New OUH is present.

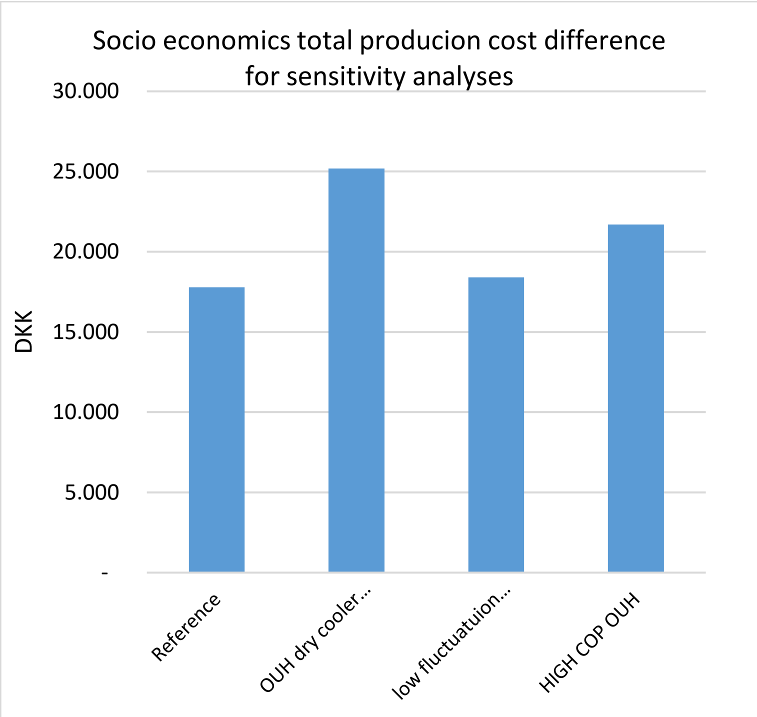

Figure 41: Socio economics total production cost difference for examined sensitivity analyses in scenario 3.

The important factor is what set point the dry cooler has. Also, any difference in the production units in terms of COP will also increase the benefit. In general, there is a benefit to connecting SDU and New OUH, because it's possible to take advantage of dry coolers, with much high COP than electric chillers. Meaning, while in the case of separate sites, the dry coolers can only produce cooling to the point of the demand to their respective sites, despite not producing at full capacity. However, when connected it's possible to use transfer cooling and thereby dry coolers replace some of the electric chiller production.

9 Discussion

In the investment cost for booster heat pump with electric heater solution on SDU is also included the pipeline network, but to define how many meters of district heat pipes there is needed. Is it required to know how much heat the electric heater produce, where it is located on SDU and how big area the electric heater produce heating to. All these factor is unknown in this project, but known factors is that there are 20 electric heaters and they are placed on SDU. Out from that it can be predicted that the electric heaters are spread out in the different buildings of SDU. The 2-text part below is about the pipeline network cost with more details about connections of electric heater and the digging price for district heat pipes.

The pipeline network expenses are based that SDU do need to have a network of district pipes to utilize the cooling heat from the chillers with a booster heat pump. The district heat pipes on 25 mm and have a cost on 250 DKK/meter, but that price can vary if the dimension of the pipes is too small or if their different size of pipes between of some of the buildings on SDU. Also, it's depending on how many of the electric heater that can be connected with the cooling heat from the chillers, the more meters of the district heat pipes is needed to utilize as much of the cooling heat as possible. But the pipeline network does have high expenses for each meter of district heat pipes there needed to get installed to connect them with more of the electric heater around on the SDU. That leads to there is needed more cooling heat to be able to utilize it before it worth to investing in more pipeline network for SDU.

The pipeline network also need to dig some of district heat pipe down in the ground between the buildings, and that cost for digging the district heat pipeline down in the ground is on 1000 DKK/meter. So that is a high added investment to have been installing more pipeline network for. That why the number of pipelines Are only set 20% of the whole the pipeline network to be dig down in the ground. Also, the digging price is also a bit high, since it based of the digging price for digging down the bigger district heat pipes, which need to transport the heat over a longer distance, compared to the SDU where it just around to the different buildings on SDU and the dimension of the pipes are also much smaller.

Electric chillers are operating at an outdoor temperature at over 16 °C, but sometimes it seems that the electric chillers still were running with an outdoor temperature lower that the 16 °C. Since the results in our project is based on that either the electric chiller is running then the outdoor temperature is above 16 °C or else the dry cooler is activated with an outdoor temperature lower than 16 °C. If the case was that the electric chiller still was running at an outdoor temperature lower than 16 °C, it would change the results in the project a lot. Since then the amount of the cooling production would be a lot higher and that could lead to a higher amount of the cooling heat from the chiller there could be utilized in a booster heat pump. Also, if the chiller was running at lower outdoor temperature than the set point the number of operations hours would also increase for the electric chiller and as well for the booster heat pump.

In the sensitivity analyses was one of the sensitivity to increasing the numbers operation hours, by changed the outdoor temperature set point 16 °C to 13 °C on the electric chiller. By setting the set point temperature to 13 °C the numbers of operation hours increased from 1227 to 2392. The increase has a big impact on the results if the electric chillers running at lower outdoor temperatures.

The COP for booster heat pump is a bit high, because the temperature the heat pump needs to increase it too isn't so high and that gives a high COP, but if the temperature difference getting higher the COP will get lower. But the heat pump still need aim toward having a working pressure on between 6-8 bar for being an ideal working heat pump.

The efficiency used in the project for the electric heater is on 100%. That's means the electricity amount is equal to the amount of heat that the electric heater produce. But if the efficiency isn't on 100% and just on 90% it would have a big impact on the results in the project, since the with a lower efficiency then the electricity consumption would increase for the electric heater. That's leads to higher expenses on the electric heater solution, because the expenses for using the electric heater is revenue because the electric heater getting replaced with heat production from booster heat pump.

In the calculation for the SDU cooling production isn't included all the electric chillers, since the electric chiller there produce the cooling needed for the supercomputer is quite new. That's means that there wasn't production data for a whole year of the electric chiller for supercomputer cooling. But in the futures year that electric chiller could be included in the total cooling production. That's lead to the amount of cooling heat would be higher and the gives better results for SDU scenario.

Also if the electric chiller for supercomputer the forward temperature set point on 15 °C, that mean it would be a possible increased numbers of operation hours, since that the other chillers operates at 16 °C outdoor temperature set point. where the dry cooler isn't active.

With fluctuating prices based on more flexible production in the grid, leading to smaller deviation in the spot prices, but also more stable spots prices. The fluctuating prices would conflict with the results in this project with new future projections prices.

So far, the report has only covered the two main cooling centrals of SDU, however, there are 179 small decentralized cooling units spread across SDU campus. Those units' accounts for a wide range of technologies such as compressors, heat pumps and free cooling and might not all be suitable for heat recovery. Also, that the pipeline network expenses would be really high to compared to the small value of cooling they does produce.

In reality an investment is required along with a technical solution to connect the SDU two centrals. However, that is kept as a black box and the required investment for that is assumed to be included in the investment cost of the booster pump.

it can be discussed that if the made sensitivities on the tariffs and taxes in the project the results for the NPV and the heat price could be a lot lower cost, compared to the results in the project

10 Conclusion

It can be concluded that Coolpack is used to calculate the used cooling COP for the electric chillers on 4,85 COP for this project. Coolpacks also have results for a heat pump where both the heat and cooling side is used, which gives a cooling COP only on 2.21 and heat COP on 3.21, but it is a quite low COP because of the temperature difference on 58 °C, compared to results from having an electric chiller and a heat pump, that gives a cooling COP on 5,49 for electric chiller and heat COP 6,49 for the heat pump. The COP is so high because the temperature difference is only 28 °C for electric chiller and 30 °C for heat pump with the correct working pressure difference conditions between 6-8 bar. The following section will conclude on scenario one results. The business economics heat cost of the reference calculations shows, district heat solution at 515 DKK/MWh and electric heater solution at 730 DKK/MWh. These prices are fairly high in comparison to what FVF can deliver at about 370 DKK/MWh.

In regards to conclusion of the heat cost sensitivity analyses, the business economics heat cost shows that the district heat solution will give the lowest heat prices. When changing investment cost, electricity prices and operation hours on electric chiller will yield a price as on heat cost of 280 DKK/MWh and electric heater 358 DKK/MWh. This is a price difference on 28% in favor of the district heat solution.

Socioeconomics, shows the same pattern concerning the best case sensitivity analysis, in this case, the prices are 232 DKK/MWh for district heat solution and 380 DKK/MWh for electric heater solution. This is a difference of 64%. These sensitivities show that the district heat solution seems robust to changing framework conditions, and certainly more resilient than the electric heater solution.

The NPV for scenario 1 give negative results in both heat recovery solutions, since the investment cost is too high. The NPV results business economics is on -254,672 DKK for district heat solution and -517,005 DKK. For socioeconomic NPV results is on -312,265 DKK for district heat solution and -552,150 DKK for electric heater solution. That's lead to the installation of booster heat pump on SDU would not benefit the society.

It can also be concluded out from the sensitivity analyses on the business economics NPV results that on the reference scenario is the NPV on -254,672 for district heat solution. The only situation where the NPV is positive, is with the best case where all the sensitivities reduction is added to the NPV result on 788 DKK in business economic for district heat solution. All the other NPV results from the sensitivity analyses have negative results for both business and socioeconomic perspective for both recovery solutions. Which mean the booster heat pump would not give any profit to the society on SDU.

Concerning the conclusion of scenario 2 and the investment of a cooling central on New OUH, the parameter of comparison was the total production cost and the constituents. The reference showed that the total cost of the cooling central over the life span of the central was 78.64 million DKK. In relation to sensitivity analyses, the factor with the most significant impact were the investment cost, and results showed a reduction of 30% to the investment cost translated 66.63 million DKK, an 18% reduction to the reference.

In conclusion, what results has shown, it that from what data was gathered, the investment cost were often the major part of the cost. Also, the investment into heat recovery on SDU, faces obstacle because of low operation hours on its electric chillers and high investment cost.

In this case of scenario 3, which investigate the possible benefits of connecting future New OUH and SDU in a locale district cooling. These results exported from EnergyPro models, and concluded that over one-year period modellings the socioeconomic benefits to connecting the two sites were 17,784 DKK.

In the sensitivity analysis the largest impact on the reference results were that of increased operation hours by lower the set point for the electric chillers. This meant, that if New OUH would have electric chillers with set points of 10°C the benefit increases to 25,000 DKK. Furthermore, it was concluded in an examination into the effect of future low fluctuate electricity prices, that it wouldn't have any significant impact, there is a slight increase, but that is due to higher electricity prices.

11 Perspective

With the future change in requirement for refrigerant for electric chillers and heat pumps, SDU might need to decide about either replacing the electric chiller with new electric chiller there is using the new refrigerant, also because the lifetime on the current electric chiller might not last the 20 years that is the projection of this project. The current refrigerant used on the electric chiller is R410A, which is an older refrigerant that does polluter a lot more than the newer refrigerant. A possible refrigerant for a new electric chiller could be R32 (Danfoss, 2017) which does polluter a lot less then R410A and can be used for the temperature which an electric chiller operating at.

Utilize the cooling from the ground water could be as an alternative for an electric chiller, which is not included in the project. But there might be issued utilizing the ground water as cooling for SDU, because of the safety and the environment from digging down to the ground water and using it.

It can be discussed that there is not considered the losses in the district heat grid on both SDU and OUH and as well in the district cooling grid on OUH. The losses in the grids is only a small part of the total cost of the of the whole pipeline grid system and is not included in the results of the project, because of how small value it is.

Then looking at OUH heat profiles it can be seen, that there is a lot of the high spikes of heat demand in short period of time during the year. A possible solution is to use a short time storage that could be store either heat or cooling to equalize the highest peak of the heat and cooling demand during the year.

An solution that the project hasn't been considering is to sell the excess heat to the Fjernvarme Fyn, instead of using the cooling heat from the electric chiller in a booster heat pump to have some district heat savings or to replace some of the electric heater production of heat.

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13 Appendix

13.1 Appendix 1

Danish energy agency 2016 electricity price projections.

Tabel 7: Samfundsøkonomiske priser på el. Bemærk at prisen efter 2025 ikke er et udtryk for spotpriserne og derfor ikke bør benyttes til selskabsøkonomiske analyser.

2016-priser kr./MWh	Spotpris/ El-produktionsomkostninger	An virksomhed* (> 15 MWh)	An husholdning* (< 15 MWh)
2016	190	477	487
2017	189	476	486
2018	196	483	493
2019	216	505	515
2020	235	525	536
2021	281	574	585
2022	306	601	611
2023	323	620	630
2024	331	628	638
2025	345	643	653
2026	367	667	677
2027	389	690	701
2028	411	714	725
2029	433	738	749
2030	456	762	773
2031	478	786	796
2032	500	810	820
2033	522	834	844
2034	545	858	868
2035	567	882	892

* Inkl. nettab. Om muligt bør der korrigeres i forhold til den specifikke tidsprofil ved konkrete tiltag eller anlæg, der forventes af afhænge af prisvariationen henover året.

Note 1: Kun nødvendig PSO relateret til net, forsyningssikkerhed og øvrige omkostninger (ingen direkte støtte til VE, forskning of udvikling eller andre tilskudsordninger) er regnet med i priserne i tabellen.

Note 2: Ved "virksomhed" forstås alle typer kunder med et årligt elforbrug på mere end 15 MWh.

Figure 42: Danish energy agency 2016 electricity price projections.

Appendix 2

Danish energy agency 2017 electricity price projections.

Tabel 7: Samfundsøkonomiske beregningspriser på el.

2017-priser kr./MWh	Rå samfundsøkonomisk beregningspris på el*	An virksomhed** (> 15 MWh)	An husholdning** (< 15 MWh)
2017	186	394	516
2018	184	391	513
2019	191	399	521
2020	217	426	548
2021	227	437	559
2022	238	449	571
2023	249	460	582
2024	259	471	593
2025	270	483	604
2026	280	494	616
2027	291	505	627
2028	302	516	638
2029	312	528	650
2030	323	539	661
2031	333	550	672
2032	344	562	684
2033	355	573	695
2034	365	584	706
2035	376	596	717
2036	386	607	729
2037	397	618	740
2038	408	629	751
2039	418	641	763
2040	429	652	774

* Den rå samfundsøkonomiske beregningspris på el består af en fremskrivning af spotprisen til og med 2020, derefter en lineær overgang til de beregnede, langsigtede elproduktionsomkostninger i 2040.
**Inkl. nettab på 6 pct. For fleksible enheder som varmepumper, elpatroner og kraftvarmeanlæg, der driftes efter elprisen, bør der korrigeres for årsvariationerne i elprisen, som beskrevet nedenfor.
Note 1: Kun nødvendig PSO relateret til net, forsyningssikkerhed og øvrige omkostninger (ingen direkte støtte til VE, forskning of udvikling eller andre tilskudsordninger) er regnet med i priserne i tabellen.
Note 2: Ved "virksomhed" forstås alle typer kunder med et årligt elforbrug på mere end 15 MWh.
Note 3: Bemærk, at prisen efter 2020 ikke er et udtryk for spotpriserne og derfor ikke bør benyttes til selskabsøkonomiske analyser

Figure 43: Danish energy agency 2017 electricity price projections.

13.2 Appendix 3

proposal by FVF of how Cooling central, district cooling and -heating could look like.

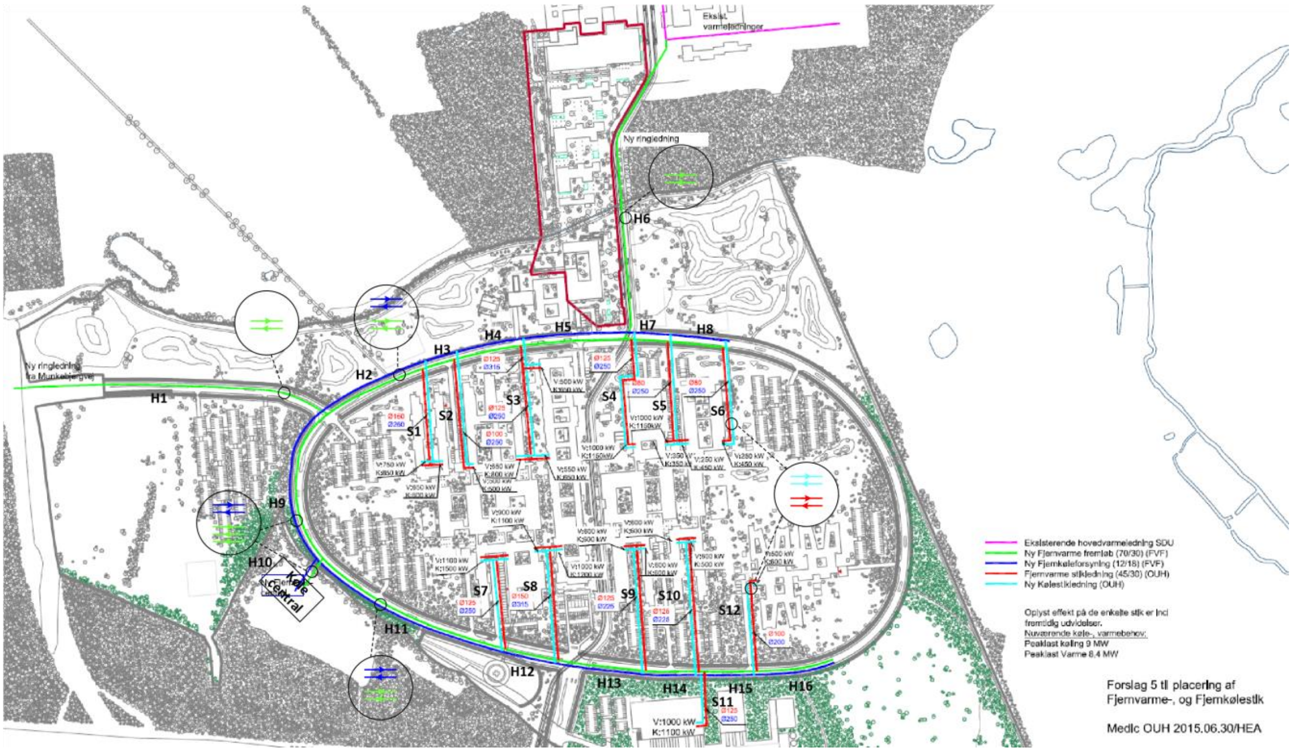


Figure 44: Grid for district cooling and district heating as proposed by Fjernvarme Fyn.

13.3 Appendix 4

Specifikation on district cooling pipes with delta temperature 8˚C.

Lednings be-tegnelse	Max køle effekt, kW	Max flow, m^3/h	Max hastighed, m/s	DN dimension	Indvendig rør dia, mm	Kanal længde, m
D1	1 350	145.3	0.743	250	263	170
D2	500	53.8	0.275	250	263	170
D3	2 100	226.1	0.818	300	312.7	220
D4	1 500	161.5	0.584	300	312.7	195
D5	1 600	172.2	0.881	250	263	170
D6	450	48.4	0.248	250	263	165
D7	1 500	161.5	0.584	300	312.7	175

D8	2 300	247.6	1.266	250	263	205
D9	1 200	129.2	0.661	250	263	195
D10	1100	118.4	0.949	200	210.1	200
D11	1 100	118.4	0.949	200	210.1	85
D12	600	64.6	0.518	200	210.1	140
R2	7 500	807.4	1.841	400	393.8	165
R3	6 150	662.1	1.974	350	344.4	40
R4	5 650	608.3	1.814	350	344.4	95
R5	3 550	382.2	1.382	300	312.7	165
R7	2 050	220.7	1.128	250	263	50
R8	450	48.4	0.248	250	263	80
R9	7 500	807.4	1.841	400	393.8	270
R10	15 300	1647.1	2.374	500	495.4	70
R11	7 800	839.7	1.915	400	393.8	295
R12	6 300	678.2	2.022	350	344.4	80
R13	4 000	430.6	1.558	300	312.7	135
R14	2 800	301.4	1.541	250	263	80
R15	600	64.6	0.330	250	263	85
R16	0	0.0	0.000	250	263	120

Table 8: District cooling specifikations.

13.4 Appendix 5

Screenshot from ENERGI.SDU of cooling central SC&S, with forward and return flow temperatures.

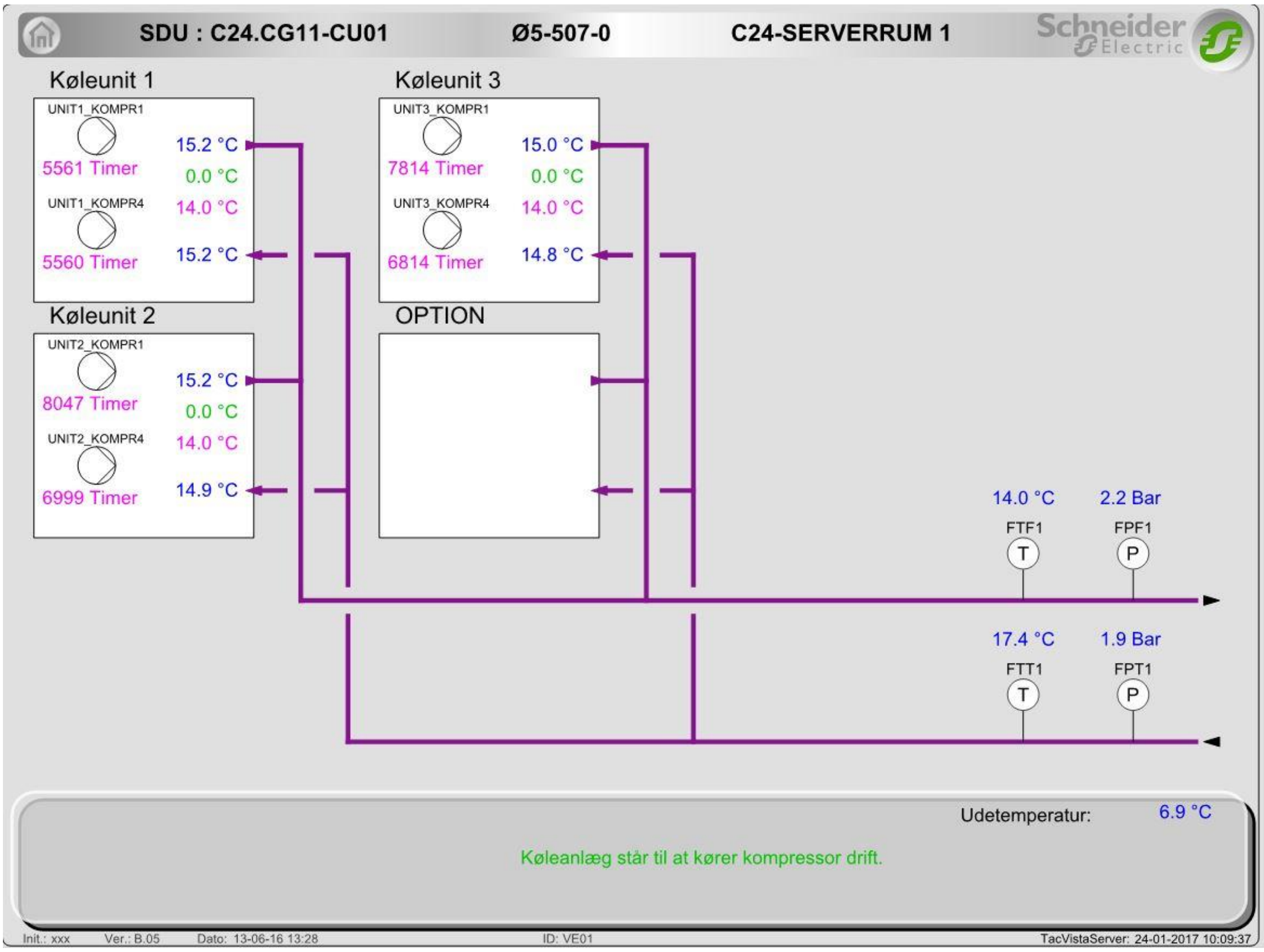


Figure 45: Screenshot from ENERGI.SDU of cooling central SC&S, with forward and return flow temperatures.

13.5 Appendix 6

Test reference year, temperatures readings from a 15 year period.

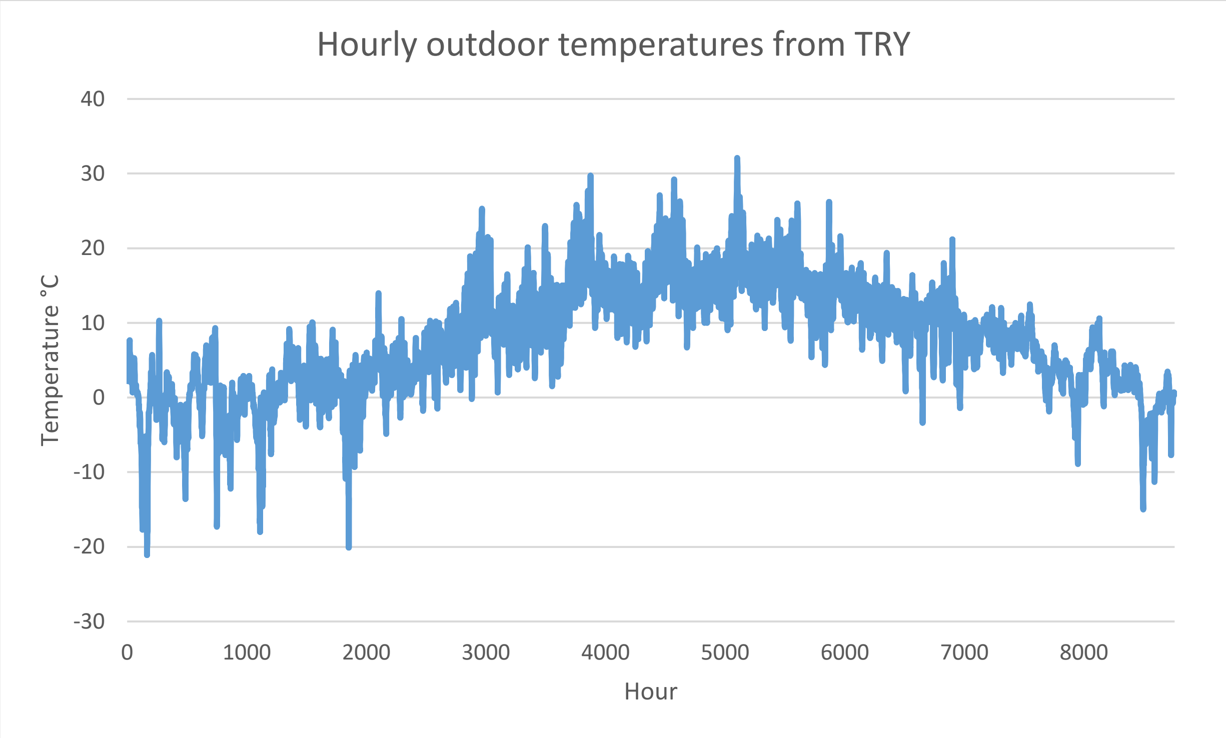


Figure 46: Test reference year, temperatures readings from a 15 year period.

13.6 Appendix 7

Cash flow

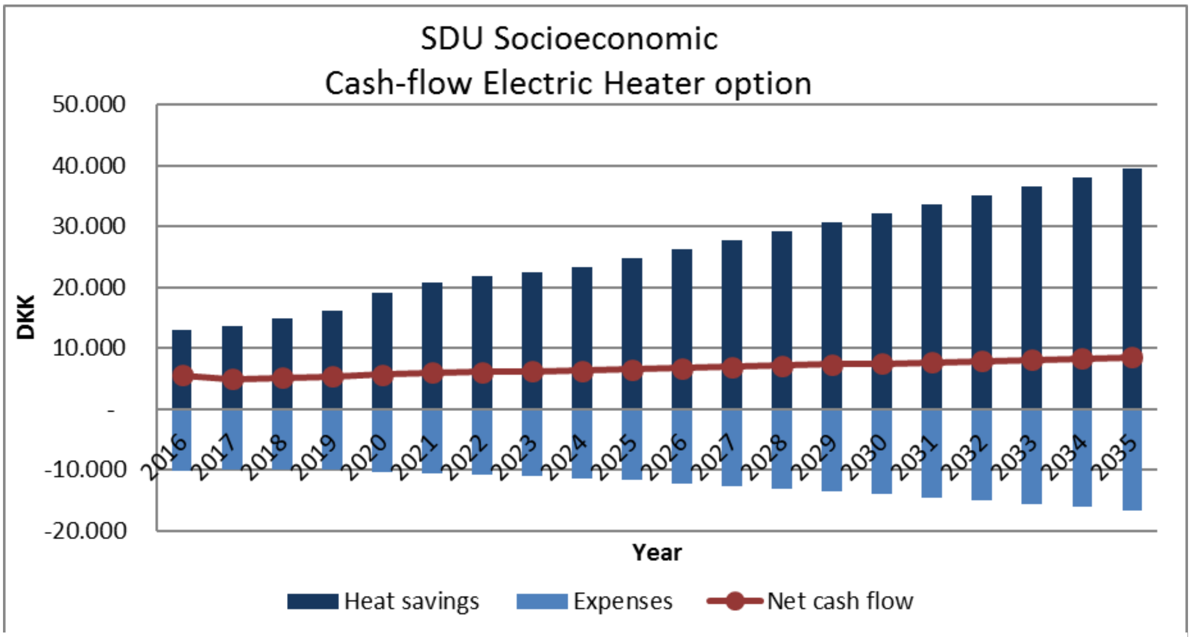
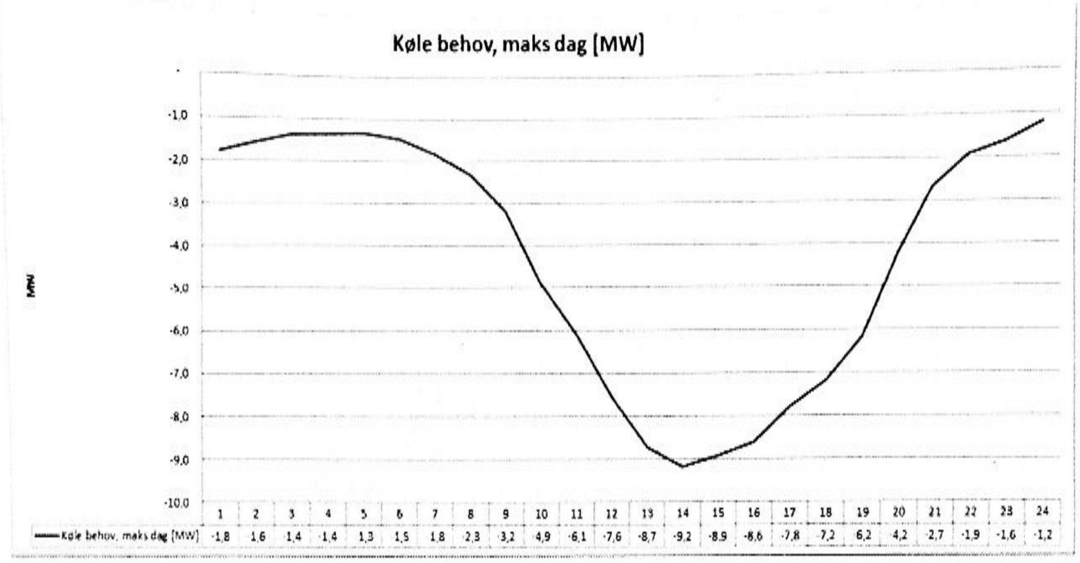


Figure 47: Socioeconomic cash-flow for electric heater solution.

13.7 Appendix 8

Document from Medic OUH showing max Peaks of heat- and cooling demand.

Kølebehov PEAK



Varmebehov PEAK

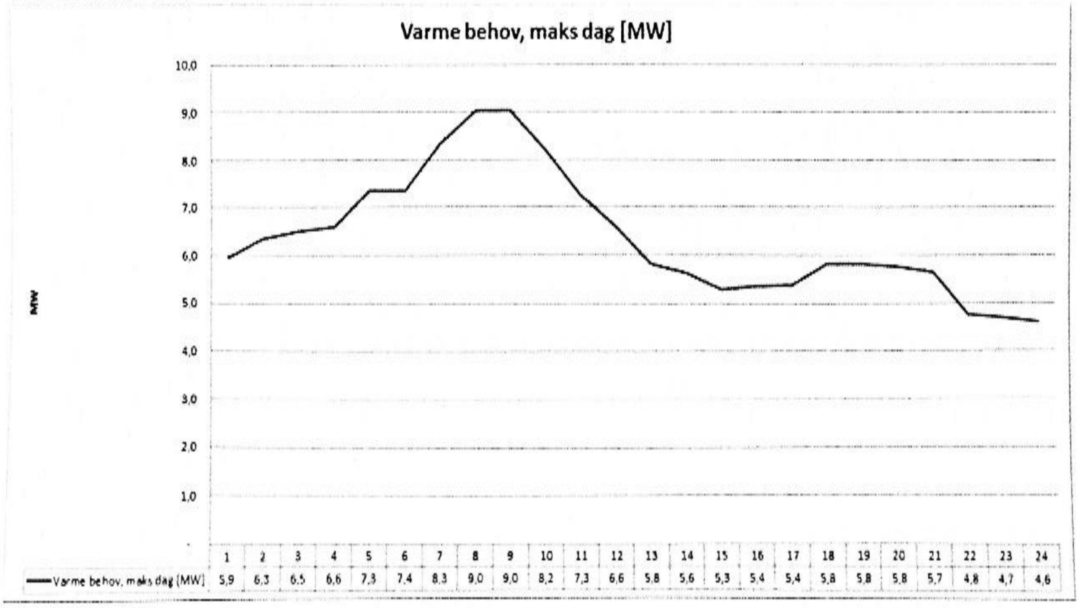


Figure 48: Document from Medic OUH show max peaks of heat- and cooling demand.

13.8 Appendix 9

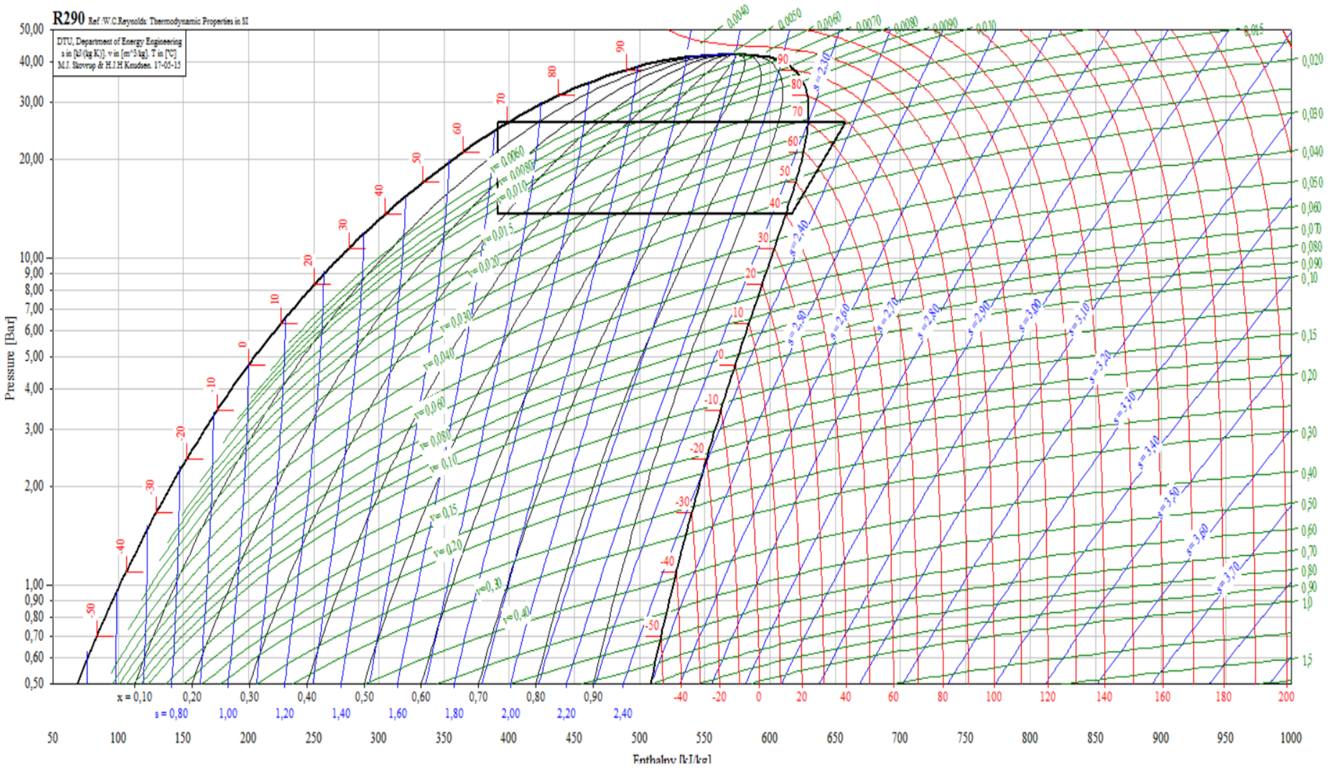


Figure 49 shows the diagram cycle for the booster heat pump on SDU.

13.9 Appendix 10

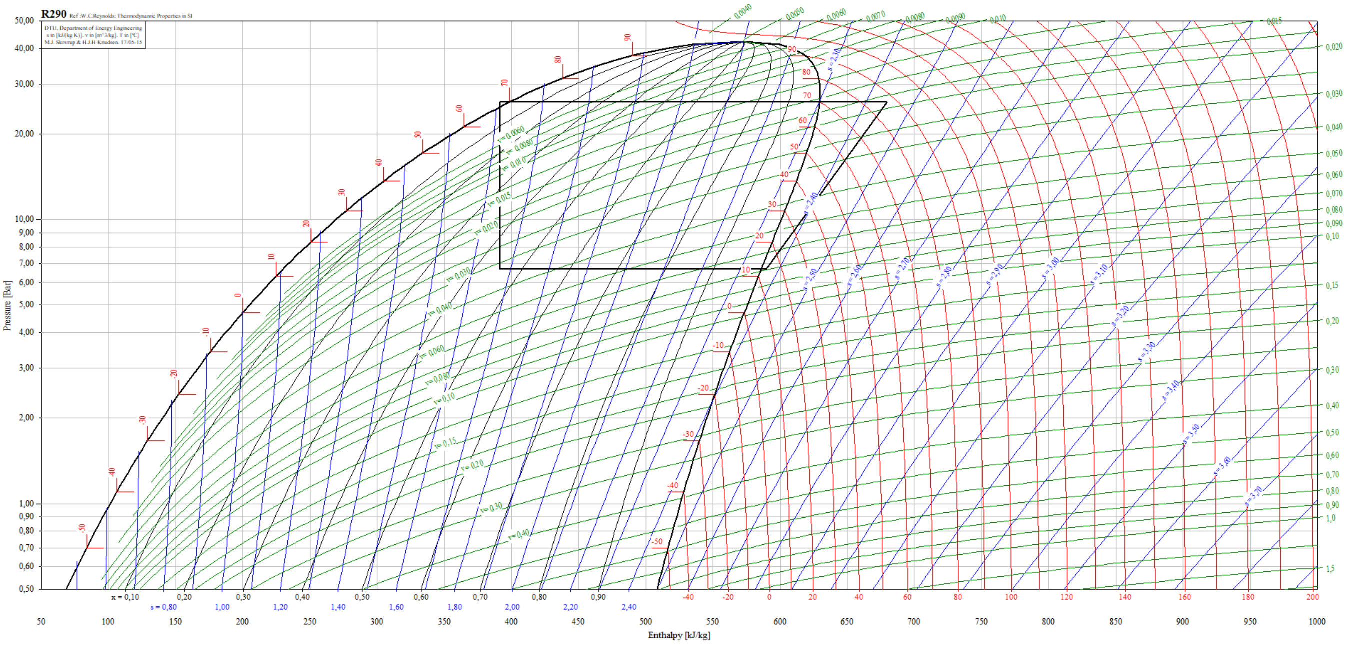


Figure 50: Diagram cycle for OUH with heat pump and the calculated cooling COP is on 2.21 and heat COP on approx. 3.21 COP

13.10 Appendix 11

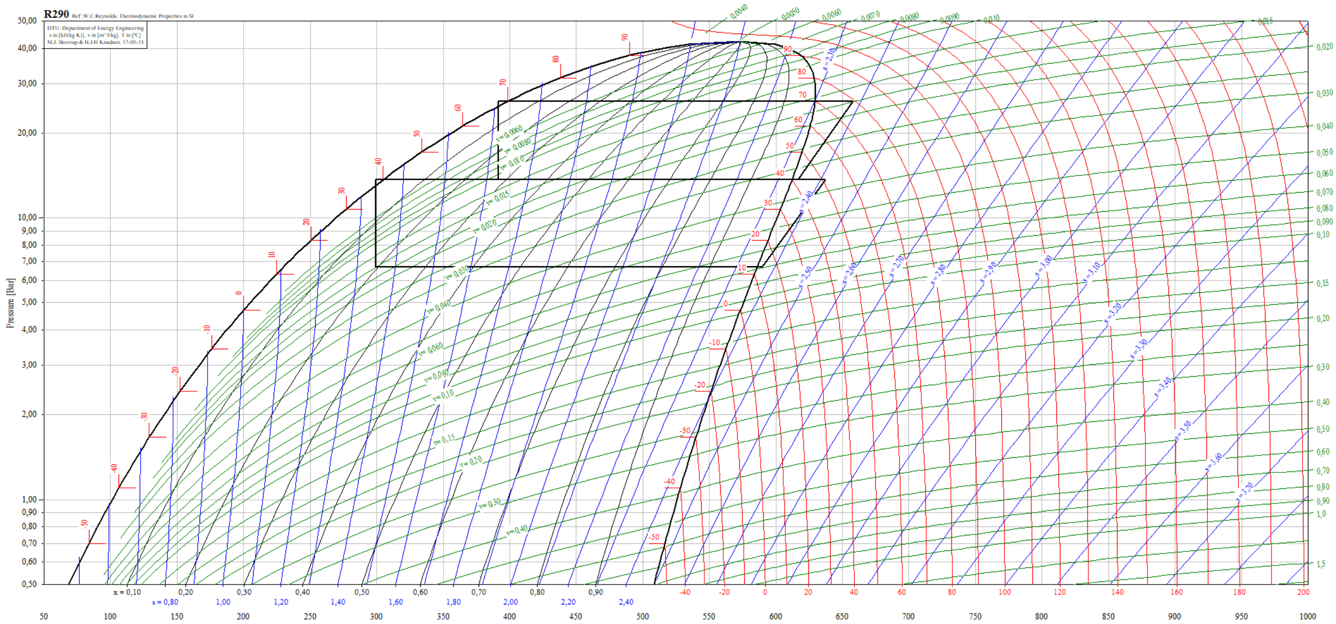


Figure 51: shows diagram cycles for OUH with electric chiller and heat pump and the calculated cooling COP is on 5,49 for the electric chiller and COP on 6,49 for the heat pump.

13.11 Appendix 12

One method of calculating process cooling and comfort cooling.

Assuming the month of January is representative for process cooling of all twelve months, because process cooling tends to be for purposes that have fairly constant and steady demand. Therefore, the following statement is applicable to determine comfort cooling:

$$Process\ cooling = Cooling_{jan} * 12$$
$$Comfort\ cooling = Cooling_{year} - Process\ cooling$$

$$CH_{year} = 496666MWh * 12 = 5959990MWh$$

$$Comfort\ cooling_{year} = 8992616MWh - 5959990MWh$$

$$Comfort\ cooling_{year=}3032626MWh$$

$Cooling_{jan}$ being cooling in month of January and $Cooling_{year}$ the total cooling for the year.

The result leads to **6000 MWh** process cooling and **3033 MWh** comfort cooling.

13.12 Appendix 13

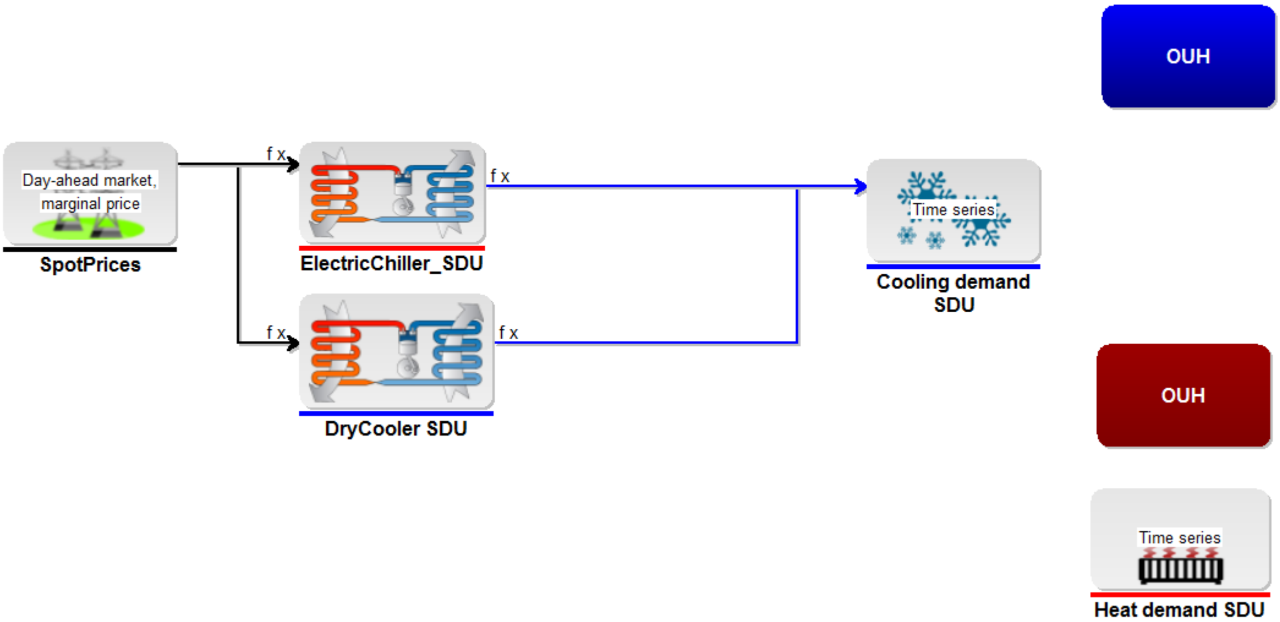


Figure 52: EnergyPro systemdesign model for SDU.

13.13 Appendix 14

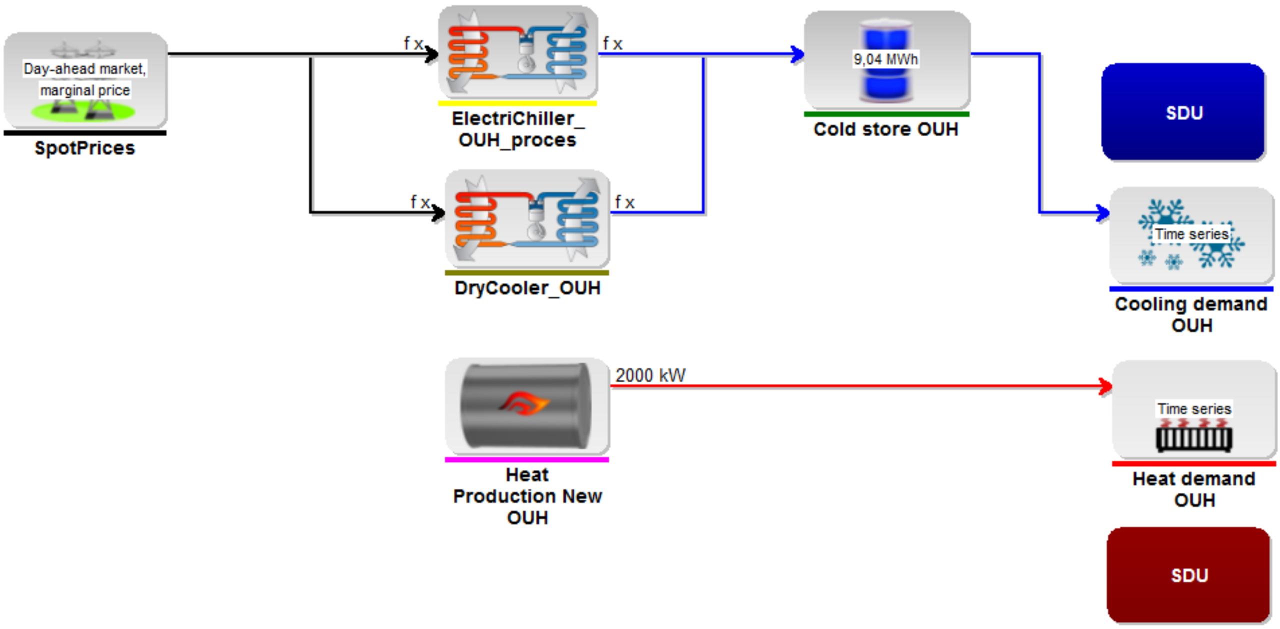


Figure 53: EnergyPro systemdesign model for SDU