Feasibility of production technologies in a DC network

– Case study of Odense City

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PREFACE

This bachelor project is conducted by Martin Grunnow Vinstrup and Klaus Christian Jespersen in relation to 6th semester on Energy Technology at University of Southern Denmark during spring in 2017.

The purpose for this project is to investigate the business case in establishing district cooling (DC) in Odense for IKEA, Bilka [supermarket], Rosengårdcentret [mall] and possibly Nyt OUH [hospital] and University of Southern Denmark (SDU). The target audience for this project is Fjernvarme Fyn, but also other utilities, who have an interest in the economy of DC.

The project is based on the iterative project model, where models used to calculate the economy of the DC solution is optimized as more and more knowledge of the reality is gathered.

This project has received a lot of input, which has been a huge help in making this project as realistic as possible. Thanks to:

- Anders Bloch and Nicolaj Tidemand Haagensen, two SDU students, for data about SDU and Nyt OUH cooling demand and data about the production units at SDU and at Nyt OUH (suggested production units)
- Bry-air, Johnson Control and Thermax for offer on adsorption chiller, electrical chiller and absorption chiller, respectively
- Gert Laursen from Odense municipality for input about ATES (Aquifer Thermal Energy Storage) legislation
- Jens Ole Pihl-Andersen from HOFOR DC for allowing us to see their absorption chiller and sea water cooling and thereby allow us to gain insight into DC
- Johan Linderberg from Vandcenter Syd for introduce us to GEUS database and provide general understanding of the geological behind ATES
- John Tang from Dansk Fjernvarme, Sebastian Houe from PwC and Niels Henning Nielsen from skat for help about taxes in relation to the DC technologies
- Lars Hjortshøj Jacobsen from Ingeniør Huse for help to estimate ATES potential, help estimating economically figures for ATES and general understanding of ATES
- Leif Holm Tambjerg and Christian Frandsen at EMD international for inputs in relation to energyPRO
- Lisa Christensen science assistant at Legal institute at SDU for help to interpretation of the law about district cooling
- Palle Mathiasen from Udvikling Fyn for help with various smaller questions
- Peer Andersen from Fjernvarme Fyn for data about the district heating network in Odense city, realistic sales and buy price for heat between Fjernvarme Fyn District Heating and a DC company, IKEA cooling demand and general inputs to the project
- Rosengårdcentret and John Christensen, Section manager at technical department in Bilka for delivering cooling demand data and data about their existing production units
- Stig Niemi Sørensen, director of ENOPSOL, for general inputs about ATES
- Lars Yde, Energiplan Fyn, Abid Rabbani, SDU and Henrik Wenzel, SDU, for supervising

Contact details is provided in Appendix 15.22.

Report template inspirited by Rambøll. Front page background image is an edited version from (Rambøll, 2017, p. 1). The map on the front page show the estimated technical potential of DC in Denmark, where blue indicate the highest potential (Petersen, 2014, p. 31).

ABSTRACT

District cooling (DC) covers currently only 4 % of the Danish cooling demand, even if studies show that several locations have a potential. This project will unveil the potential for a district cooling solution for 5 closely located customers in Odense.

The optimal solution is assessed through modelling of the cooling demand on a seasonal basis, considering the individual user profiles.

The potential of Aquifer Thermal Energy Storage (ATES), absorption chiller, adsorption chiller and electrical chiller is considered for the DC company and the selected customers.

When pursuing technologies with a high COP factor, Aquifer Thermal Energy Storage (ATES) have excellent properties, useable in a district cooling solution. Given the available heat price and conditions, absorption chiller and adsorption chiller is too expensive in comparison with the ATES solution and the electrical chiller.

It is possible to deliver a cheaper cooling price though district cooling than an individual solution without considering the remaining lifetime on the customers existing cooling facilities. The success of the business case requires for the customers to participate. The remaining lifespan of the current cooling facilities refrain key customers to migrate to DC.

The business case is unfeasible under the current circumstances. The district cooling company has to explore other organisational structure to reduce the excess heat tax. It is possible to make a feasible business case if the construction costs are shared with Odense Letbane as they operate on the same route.

SYMBOLS AND ABBREVIATIONS

Abbreviations

Abbreviation	Full word / Definition.
AHG	Act on heat recovery and ground water cooling
ATES	Aquifer Thermal Energy Storage
COP	Coefficient Of Performance – when used in general
COP-a	Coefficient Of Performance, cooling – a<u>b</u>sorption chiller or a<u>d</u>sorption chiller. Defined as: $\text{COP-a} = \frac{Q_{out,cooling}}{W_{in}+Q_{in,heat}}$, where $Q_{out,cooling}$ is the cooling output, W_{in} is the internal pump work and $Q_{in,heat}$ is the heat input.
COP-c	Coefficient Of Performance, cooling – used for electrical chiller. Definition as $\text{COP-c} = \frac{Q_{out,cooling}}{W_{in}}$, where $Q_{out,cooling}$ is the cooling output and W_{in} is the internal pump work
COP-h	Coefficient Of Performance – used for heat pump. Defined as: $\text{COP-h} = \frac{Q_{out,heat}}{W_{in}}$, where $Q_{out,heat}$ is the heat output and W_{in} is the internal pump work
COP-p	Coefficient Of Performance – used for the pump work in relation to ATES. Calculated as: $\text{COP-p} = \frac{\rho * c_p * \Delta T * \eta_{pump,total}}{\Delta p}$ Where c_p is the specific heat capacity, ΔT is the temperature different between the district cooling supply and return pipe, ρ is the density of the water and Δp is the pressure loss in the pump and heat exchanger used.
DC	District cooling
DH	District heating
EIA	Environmental impact assessment
IRR	Internal Rate of Return. Definition: The discount rate that makes the Net Present Value (NPV) equal to zero.
MARR	Minimum Attractive Rate of Return Definition: The investment is accepted if MARR is greater than the IRR. If MARR is equal to IRR, then the project is indifferent to the company.
NPV	Net present value. Definition: "The net present value (NPV) of an investment project is the difference between the project's present value (PV), the value of a portfolio of financial instruments that track the project's future cash flows and the cost of implementing the project. Projects that create value are those whose PVs exceed their costs and thus represent situations where a future cash flow pattern can be produced more cheaply, internally, within the firm, than externally, by investing in financial assets. These are called positive NPV investments." (Hillier, Grinblatt, & Sheridan Titman, 2012, p. 312) The NPV is calculated with the formula: (Investropedia, 2017) $$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$$

	t is the time period, T is the total number of time periods, C_t is the net cash inflow in period t, r is the discount rate and C_0 is the total initial investment costs (in year 0).
OD	Location with drinking water interests
OSD	Locations with special drinking water interests
ROI	Return on Investment
RT	Refrigeration ton. Same as Ton of Refrigeration (TR). Convert to kW by multiplying by 3.517 $\left[\frac{kW}{TR}\right]$
TR	Ton of refrigeration. Convert to kW by multiplying by 3.517 $\left[\frac{kW}{TR}\right]$

Symbols

Symbols	Definition
c_p	Specific heat capacity $\left[\frac{J}{kg*K}\right]$
q_m	Mass flow $\left[\frac{kg}{s}\right]$
q_v	Volume flow $\left[\frac{m^3}{s}\right]$
Φ	Cooling transfer capacity $[W]$
T_r	Temperature return pipe [℃]
T_s	Temperature supply pipe [℃]
ρ	Density $\left[\frac{kg}{m^3}\right]$
d_i	Diameter, inside pipe $[m]$
d_y	Diameter, outside pipe $[m]$
v	Velocity in pipe $\left[\frac{m}{s}\right]$
$v_{viscosity}$	Kinematic viscosity $\left[\frac{m^2}{s}\right]$
wt	Wall thickness of pipe $[m]$
Re	Reynolds number [-]
λ	Friction factor [-]
k	Roughness $[m]$
$\frac{pf}{L}$	Pressure gradient $\left[\frac{Pa}{m}\right]$
Q	Effect $[W]$
ΔT	Temperature difference [℃]
W_{out}	Work out $[W]$
$\eta_{pump,total}$	Overall pump efficiency [%]
η_{pump}	Pump efficiency [%]
W_{pump}	Work by pump $[W]$
COP_{pump}	Coefficient Of Performance [-]
$W_{pump,ATES}$	Work by pump in relation to ATES $[W]$

TABLE OF CONTENT

1. INTRODUCTION

Denmark is a pioneer country within district heating, but when it comes to district cooling (DC) we are behind despite the fact, that DC and district heating is very similar. In Sweden around 40% of the cooling demand is covered by DC, in Denmark it is only around 4%.[1] Ramboll have asked 394 utilities about the largest barrier they see in relation to DC. 254 utilities answered the questionnaire:[2]

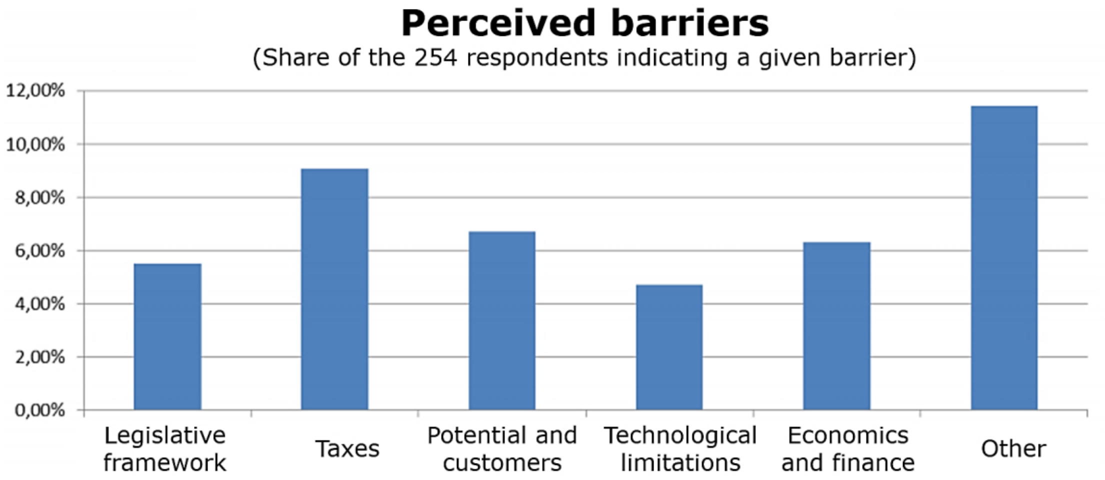

Figure 1.1 Questionnaire given to 394 utilities about perceived barriers in relation to DC, where 254 answered the questionnaire. They are only allowed to indicate the largest barrier (only one answer is allowed). Graph translated from Danish to English and is from (Petersen, 2014, p. 51)

Economy and taxes are the highest perceived barriers beside "other". In this project the economic potential of DC will be investigated by analysing the potential of DC in Odense for some selected companies. This study will help discover whether this barrier have the same effect on the DC business case.

1.1 Background for the project

Fjernvarme Fyn has in collaboration with Vattenfall made estimations on the DC potential in Odense. They have conducted a map which show the DC demand potentials, shown in Figure 1.2. It indicates that there is a DC potential in the downtown area ("Zon 1"), around the university area ("Zon 2") and in Tietgenbyen ("Zon 3").[3]

Ramboll has analysed the economic potential of DC for all of Denmark and their map (shown on the front page of this report, where blue is the highest potential) indicates that there is a technical potential in Odense City.[4] The next steps are to analyse the business case for some selected companies.

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[1] (Rambøll and Aalborg Univiersity, 2016, p. 4)
[2] (Petersen, 2014, p. 51)
[3] (Odense Municipality, 2017)
[4] (Petersen, 2014, p. 31)

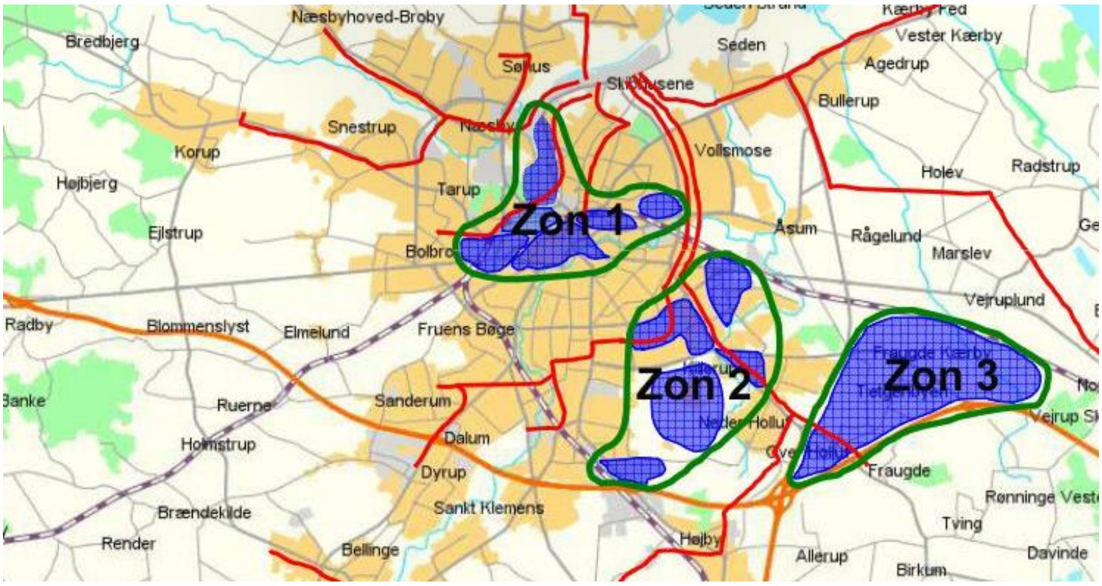


Figure 1.2 Area in Odense with DC potential (cluster with high cooling demand density). Map from (Fjernvarme Fyn, 2017)

IKEA is located in "Zon 2". Fjernvarme Fyn has installed two containers with external electrical chillers for IKEA, at an adjacent address. IKEA receives cooling from these containers. The plan from Fjernvarme Fyn, is to expand to more customers, but this has not happened so far. Fjernvarme Fyn is interested in doing a project to investigate the economy in expanding to Bilka (supermarket) and Rosengårdcentret (mall) as primary target group, secondary Nyt OUH (hospital) and University of Southern Denmark / SDU – all placed in "Zon 2".

One of the problems with DC is that no connection obligation exists and thereby have many potential DC customers already invested a lot of money in their own cooling production units. Consequently, they have no interest in DC.[5] Nyt OUH is estimated to have nearly twice the cooling demand as the other 4 customers in total.[6] It is critical to conduct this project before Nyt OUH decide on their cooling investment, in order to influence their decision on investing in a DC solution.

[5] (Petersen, 2014, p. 43)

[6] Table 6.1

1.2 Project objective and scope

This project will investigate the business case in delivering DC to Bilka, IKEA, Rosengårdcentret, Nyt OUH and SDU including:

- Estimate the cooling demand for the individual customers.
- Analyse the technological potential of electric chiller, absorption chiller, adsorption chiller and aquifer thermal energy storage (ATES) in a DC solution
- Calculate the economic potential, by modelling a district cooling solution for the selected customers.

The following delimitations have been selected for this project:

- Only the 4 mentioned cooling technologies will be investigated because these technologies are assessed as the most relevant technologies in collaboration with the Fjernvarme Fyn
- Possible income from heat sales at Nyt OUH and the DC company from an electrical chiller, is not considered in the business case.
- The heat sold to the district heating company from the aquifer thermal energy storage (ATES), is subject to the heat supply act and as such require a positive socioeconomic calculation to be built.[7] This is not considered in this report.
- Time could have been used to find more potential customers but this could be a project on its own and is therefore out of the scope for this report.
- Design of the district cooling network is not a part of this project. This project only focuses on the economy of a district cooling network. This is chosen because knowing the exact design of the network does not give more precise results because the given economic figures are too general.
- DC will only be supplied at above freezing point temperatures as explained for in more detail in section 5.
- The savings potential for the individual customers will be calculated based on their current installation and cooling demand profile.

[7] (PlanEnergi, 2012, p. 4)

1.3 Project structure

The project first describes the technologies, which will be considered in the DC solution. The difference between district heating and district cooling is introduced. The model to calculate the yearly operation costs are introduced followed by more details about the construction of the objects in the model. Lastly the model is verified to ensure reliable results. The business case for the chosen district cooling solution is presented and the potential of the technologies are analysed. Finally, a sensitivity analysis is conducted to establish the outcome of relevant parameters.

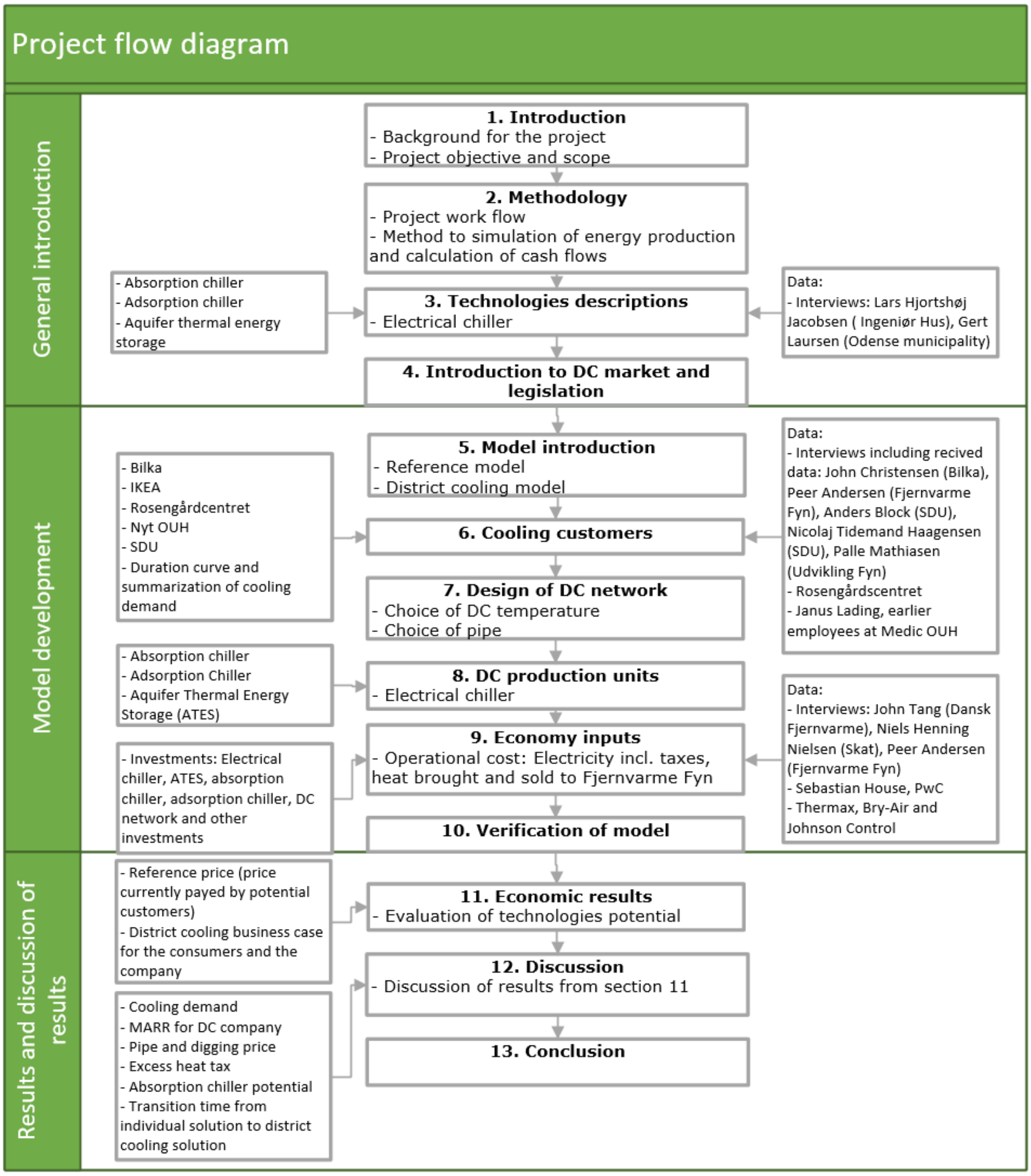


Figure 1.3 Project flow diagram. Show the structure of the project and how various data and cases is used.

2. METHODOLOGY

This project is based on an iterative process. The iterative process is for example seen in relation to the development of the two energyPRO model, which is used to analyse the economy of the DC solution. First, the overall structure of the model was made, but that model took 2.5 days to run and therefore the model was simplified. The cycles of improving the model (**development**, Figure 2.1), **test** of the new improved model and **evaluation** of the model was run through several times. The result was a model that only takes about 2 min. Through various meetings, the degree of detail and the exact conditions are implemented in the model. For example, the overall structure of the ATES (Aquifer Thermal Energy Storage) were first developed in energyPRO-model, then the model was updated with the correct cooling capacity and finally, the efficiency of the ATES was implemented.

Because of the highly iterative process milestones planning were used instead of a linear time schedule such as a Gantt Chart.

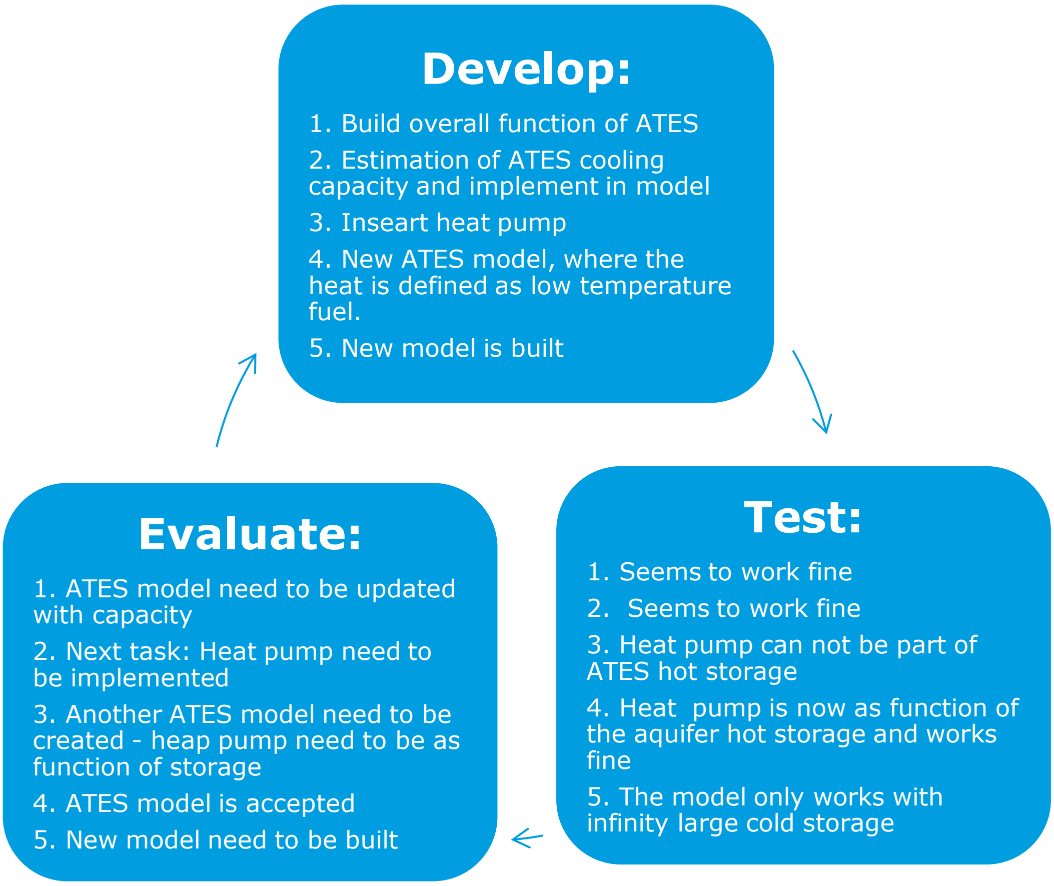


Figure 2.1 Example of the iterative process in this project.

2.1 Choosing a modelling tool

The idea of the project is to develop a model which can calculate the economy of a DC solution and the current solution. The tools evaluated for this purpose was:

- A proprietary linear or nonlinear optimization model
- EnergyPLAN
- energyPRO

A linear or nonlinear optimization model have the benefits that it provides a high degree of freedom to models exactly the way that it is desired. The disadvantages of such models are that they are very time-consuming to develop and it is difficult to find a solver that can handle enough constrains and decision variables.

EnergyPLAN, developed by Aalborg University, is a modelling tool to optimise the whole electrical system. Because this project is analysing the DC potential on project level and not a general level it does not make sense to use such a model.

energyPRO is a software for combined techno-economic optimization. energyPRO can handle optimization of cooling, heating and storage. energyPRO is only used on project level because of its degree of detail. The benefit of using energyPRO is that it provides building blocks of typical energy producing and consuming units such as CHP, electrical chiller and absorption chiller. It is easy to define custom units if required. energyPRO can generate reports of the cash flow and production, which makes it fast to conduct sensitivity analysis. The program can optimise given a user defined period, monthly or yearly, whereby seasonal storage also can be simulated. energyPRO is a deterministic model, whereby identical inputs give the same output and randomness is not implemented in the model.

The disadvantage of energyPRO is less flexibility than a linear or nonlinear optimization model.

energyPRO will be used to model the individual cooling solutions currently used at the potential DC consumers and DC solution in this project. The reason is that it will be faster than a proprietary linear or nonlinear optimization model and to avoid the problem by finding a solver than can handle enough constrains and decision variables. The losses of flexibility in energyPRO compared to a linear optimization model can be handled without it will affect the results.

2.2 From data collection to results

The process to calculate the individual/reference cooling production cost and the cost/benefit by changing to DC is based on a multi-phase model and is shown in the Figure below. First is all **data collected**. This is done by interviews, requesting offers on the cooling technologies and requesting data from companies.

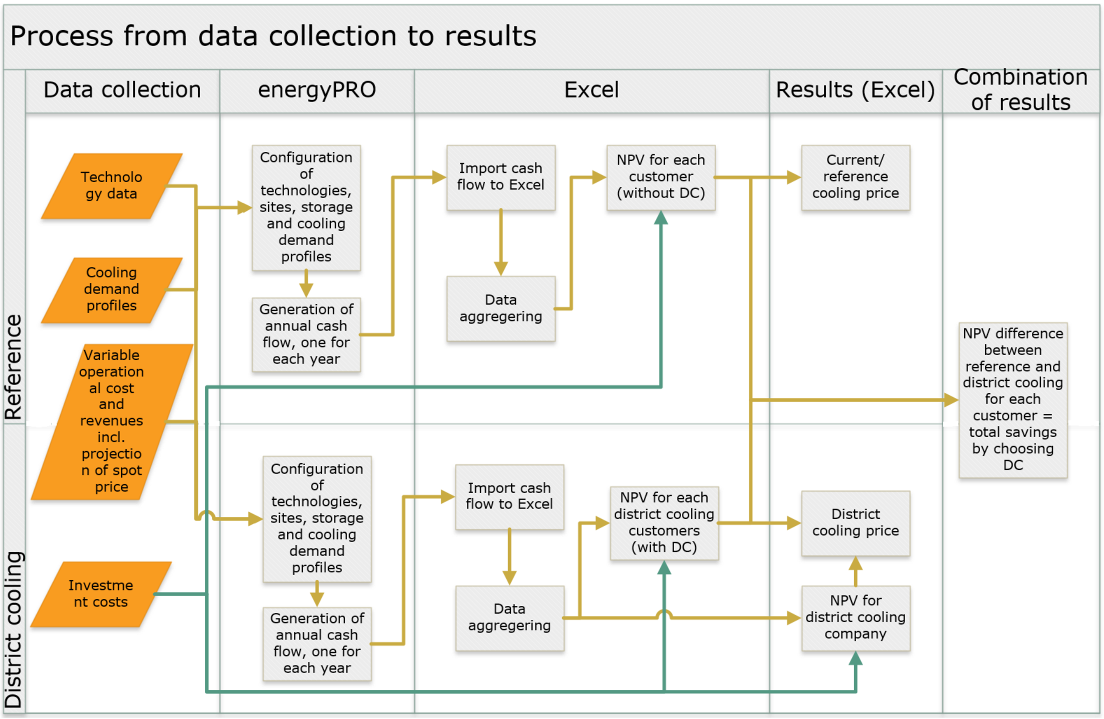


Figure 2.2 Flow chart of the process from data collection to the results. Larger version is placed in Appendix 15.16.

Secondly two **energyPRO**-models are configured. One model which simulate the individual consumers (reference) – without DC and one model which simulate the DC solution. The following objects are configured in energyPRO:

- The cooling production technologies as predefined objects or user defined objects.
- The storage size is defined (if storage is included in the given simulation)
- The yearly demand profiles are modelled or imported respectively

The output from energyPRO is the annual cash flow – one for each year in the simulation. Cash flows are generated for both the reference model and for the DC model.

Thirdly the cash flow is imported to **Excel**. Data aggregation is then used to combine the cashflows to one combined cash flow for each consumer and for the DC company in the reference situation and the DC situation.[8]

The individual investment costs, investment costs for the DC company and capital injections from the DC customers are inserted in the cash flows in Excel.

The Net Present Value (NPV) for the DC company, the NPV for the individual customers if they choose to invest in individual cooling production facilities and the NPV for the individual customers if they choose to invest in the DC solution are calculated.

The savings by choosing the DC solution is the difference between the NPV for the individual solution and the DC solution.

[8] In practices is the data aggregating done in Excel by introducing a "energyPRO jump factor" column. The "energyPRO jump factor" define, jumps in rows between the cash flow from each year. This make it possible to make a general formula to select the relevant numbers from the annual cash flow from energyPRO to the cash flow for the individual customer in the reference and DC situation and for the DC company.

3. TECHNOLOGY DESCRIPTION

This section introduces the theory behind the cooling technologies, which later will be considered in the energyPRO-model to find the cheapest DC production technology mix and to calculate the economy by establish an DC solution compared to the current individual cooling solutions. This section only introduces the theory behind the technologies, where economy, production curve and similar used for the energyPRO-model and economic calculation in Excel will be introduced afterwards. This section will introduce the individual technologies and afterwards a comparative analysis will be conducted.

3.1 Electrical chiller[9]

An electrical chiller works by absorb heat at low temperature and reject heat at high temperature (excess heat) with use of mechanical work from a compressor. The input and output of an electrical chiller is visualized in the Figure below to the left (Figure 3.1).

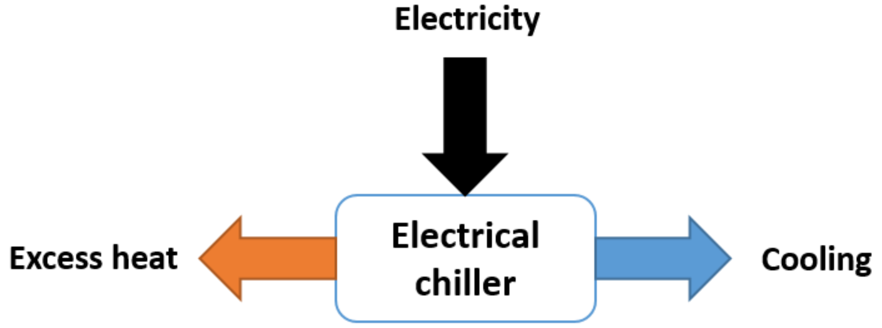


Figure 3.1 Input and output of an electrical chiller. The electrical chiller use electricity to produce cooling and as a buy product excess heating is produced.

An electrical chiller consists of four components as shown in Figure 3.1:

- Compressor
- Condenser
- Expansion valve
- Evaporator

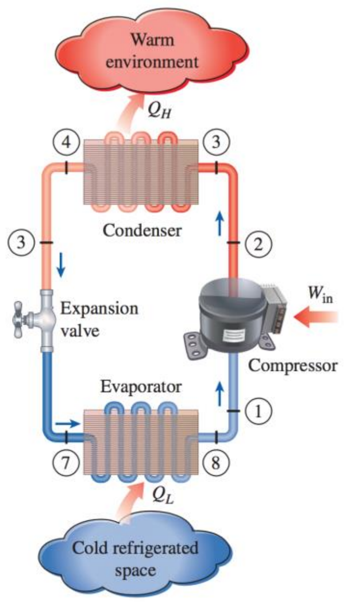


Figure 3.2 Schematics of electrical chiller. Figure from (Cengel & Boles, 2016, p. 610)

Electrical chillers are in general based on the vapour-compression refrigeration cycle.

[9] This section is based on (Lauritsen & Eriksen, 2017, pp. 178-185)

The states in an ideal vapor-compression refrigeration cycle is:

State	Description
1-2	Isentropic compression. The saturated vapor at step 1 is compressed and thus the pressure and temperature rise. The temperature rise to above the surrounding environment temperature.
2-3	Isobar heat rejection in the condenser creating a phase change from overheated vapor to saturated liquid.
3-4	The expansion valve reduces the temperature and pressure. The expansion valve ensures a pressure difference between the high and low pressure site in the process.
4-1	The evaporator absorb heat from the surrounding space and the refrigerant evaporate completely.

Table 3.1 States in an ideal vapor-compression refrigeration cycle

The temperature variation of a vapor-compression refrigeration cycle is shown in Figure 3.3 and the pressure variation is shown in Figure 3.4.

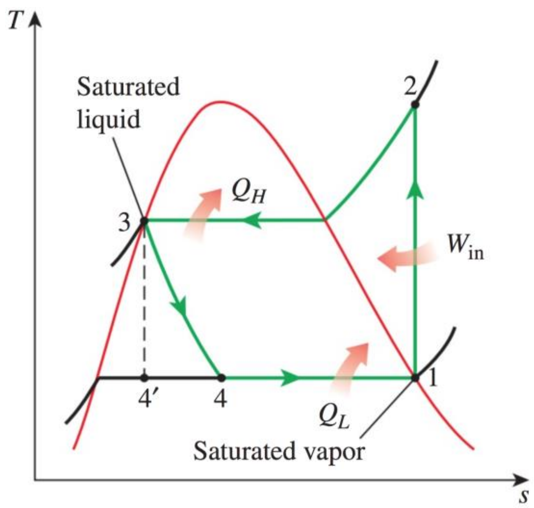


Figure 3.3 T-s diagram of a vapor-compression refrigeration cycle typically used for an electrical chiller. Figure from (Cengel & Boles, 2016, p. 610)

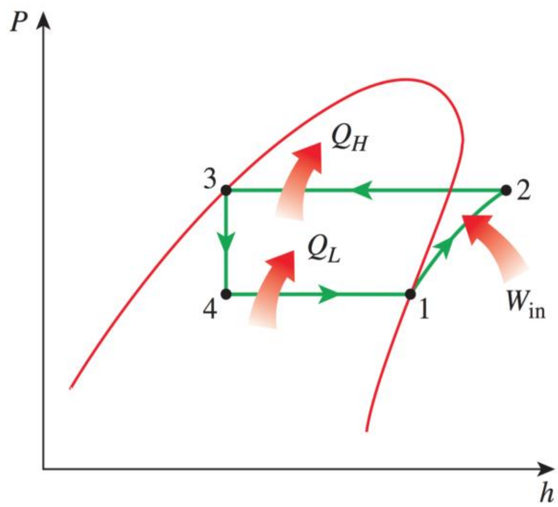


Figure 3.4 P-h diagram of a vapor-compression refrigeration cycle typically used for an electrical chiller. Figure from (Cengel & Boles, 2016, p. 610)

The COP-c (Coefficient Of Performance, Cooling – used for electrical chiller) value of an electrical chiller used in a DC solution compared to individual solutions is in general higher because the electrical chiller is larger (Smaller compressors are less efficient than larger compressors) and the partial load (partial load reduce efficiency) can be reduced by using a storage.[10] Furthermore, by using a storage the cooling can be produced cheaper, when the spot price is low.

3.2 Absorption chiller

The absorption chiller use heat as a fuel to produce cooling with lower grade heat as a waste product as shown in the Figure below. Absorption chillers are commonly used, where inexpensive excess heat is available, often operated in the temperature range of 100-200 ℃.[11]

[10] (Energiwiki, 2017)

[11] (Cengel & Boles, 2016, p. 633)

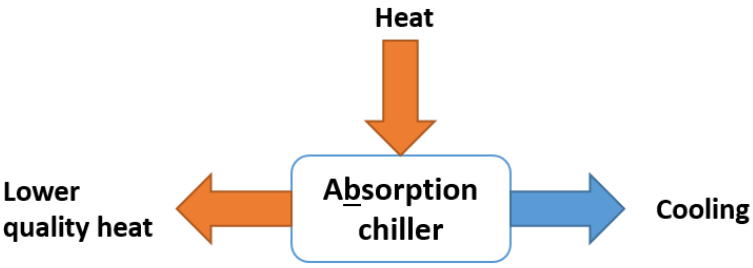


Figure 3.5 Input and output of an adsorption chiller. An absorption chiller used heat to produce cooling with lower quality heat as a buy product.

Absorption chillers are heat driven systems and different from vapour compression systems, as absorption chillers compress a liquid rather than a vapour. A liquid commonly used is a mixture of ammonia [NH_3] and water [H_2O], as ammonia dissolves very well with water at low temperatures.[12] This results in a very low work input from the pump of approximately 1 percent of the heat supplied to the system.[13] There is a significant production of waste heat for absorption chillers which requires space and ways to reject the excess heat. Given a complex setup compared to electric chillers, the absorption chillers are costly to service, partly due to the limited use in large installations.

The COP-a (Coefficient Of Performance, cooling used for absorption chiller or adsorption chiller) for absorption chillers is significantly lower than an electric chiller, which limits the scenarios for attractive business. For single stage absorption chillers the COP-a value is in the range of 0.65 – 0.70 with a heat source of 116 ℃.[14]

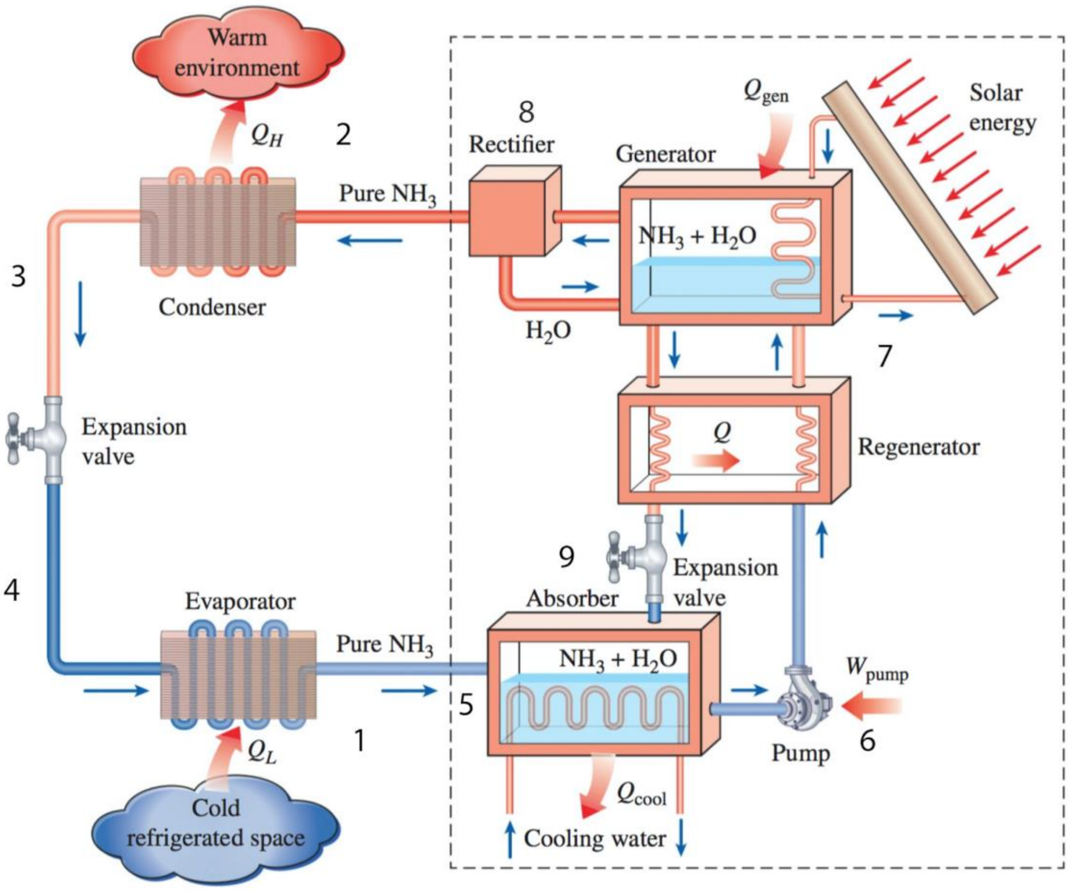


Figure 3.6 Refrigerant cycle for absorption chiller. Steps 1-4 are described in the electric chiller, section 3.1 page 12. Edited image from (Cengel & Boles, 2016, p. 634)

[12] (Cengel & Boles, 2016, p. 634)
[13] (Cengel & Boles, 2016, p. 634)
[14] (Cengel & Boles, 2016, p. 635)

Step no.	Description[15]
5-6	Exothermic reaction: Refrigerant liquid like ammonia from the evaporator is mixed with water in the absorber. Water and ammonia mixes very well at low temperature, so the absorber requires cooling.
6-7	Pressure is boosted by a pump, but the energy required is negligible. A 'strong' solution with high concentration of ammonia is pumped to the generator
7-8	Heat is added to the mixture in the generator. Ammonia has significantly lower boiling point than water.
8-2	Vaporized water at high pressure and temperature leaves the compression unit through a rectifier.
8-9	Water from the rectifier is passed through the expansion valve, thereby loosing pressure and temperature.
9-5	Water is mixed with ammonia in the absorber. Some cooling is necessary for the components to mix properly. The cycle is completed.

Table 3.2 Absorption chiller process steps, where step 5-9 describes.

3.3 Adsorption chiller

The adsorption chiller use low grade heat (~60 to 93℃) as input for producing cooling, with lower quality heat as a waste product.[16]

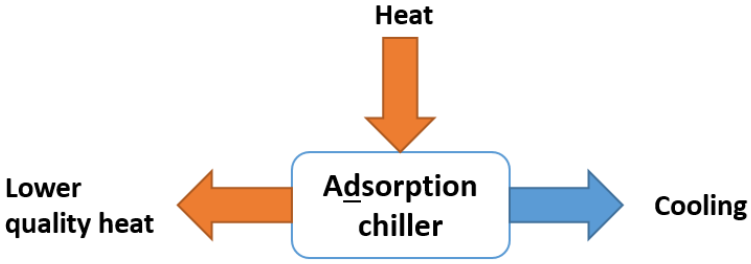


Figure 3.7 Input and output of an adsorption chiller. An adsorption chiller uses heat to produce cooling with lower quality heat as a waste product.

The adsorption chiller differ from the absorption chillers as water molecules adheres to a surface in the adsorption chamber opposed to the absorption chiller, where the water molecules are mixed with a refrigerant, as illustrated in Figure 3.8.

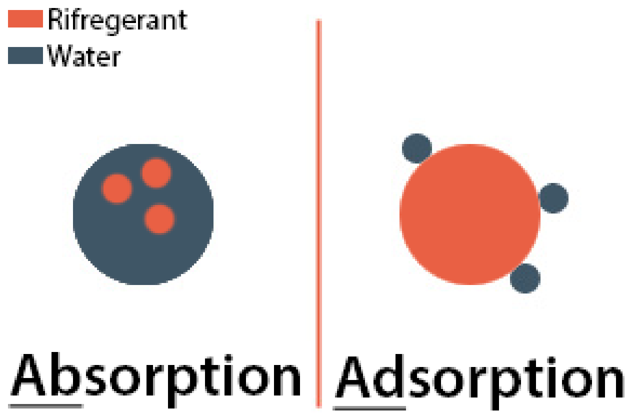


Figure 3.8 For absorption chillers the water molecules are mixed with a refrigerant. For the adsorption chiller the water molecules adhere to the adsorption surface. Figure edited from (chemistrytwig, 2017)

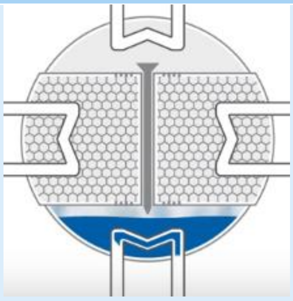
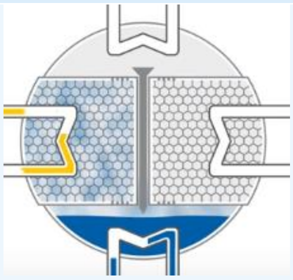
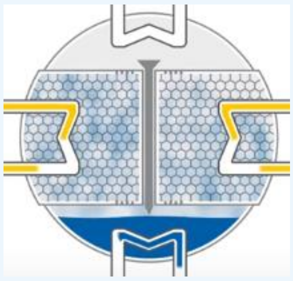
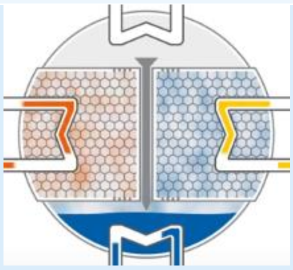
[15] Description based on (InvenSor, 2017) and Appendix 15.4 pp. 4-5

[16] Appendix 15.4 p. 6.

The adsorption chiller consist of four chambers:[17]

- One evaporator
- One condenser
- Two adsorption chambers

The adsorption chiller process is based on four steps:

Step no.	Description[18]	Visualisation[19]
1	The refrigerant (water) is in liquid form in the evaporator chamber, but the heat from the chiller inlet cause the water to evaporate due to low pressure in the evaporator chamber. During this evaporation, the chilled water is cooled down.	
2	A connection between the evaporator and one of the adsorption chambers is establish. The water vapor thereby enter the adsorption chamber, where the adsorption material (typical silica gel) attracts and binds the water vapor molecules – this is called adsorption as shown in Figure 3.8. Afterwards, a connection between the other adsorption chambers are establish by a heat exchanger.	 
3	When the adsorption materials are saturated, the hot water is used to dry the adsorption material through a heat exchanger. The adsorption material repels the water molecules as water vapor molecules – this is called desorption. The hot water temperature does not need to be high because the adsorption material creates an extremely low humidity condition, whereby water evaporates at a low temperature.[20] The desorption process is first started in one of the adsorption chambers and with some delay the process is started for the other adsorption chamber as well.	

[17] Appendix 15.4 / 15.1 B4, p. 4.
[18] Description based on (InvenSor, 2017) and Appendix 15.4 / 15.1 B4, pp. 4-5.
[19] Image is from the YouTube movie: (InvenSor, 2017)
[20] Appendix 15.4 / 15.1 B4, p. 4.

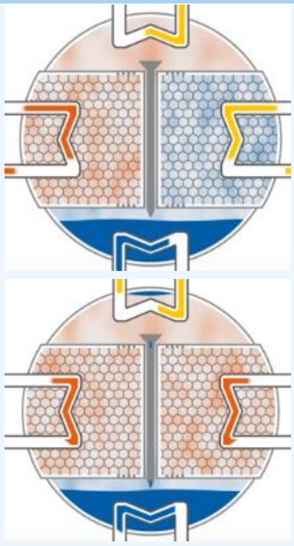
Step no.	Description[18]	Visualisation[19]
4	A connection between the condensing chamber and the adsorption chamber is established one-by-one. The vapor in the condensing chamber is condensed by cooling water. The condensed water is returned to the evaporator chamber. Step 1 can now begin again.	

Table 3.3 Adsorption chiller process steps.

3.4 Aquifer Thermal Energy Storage

An aquifer is an underground water-bearings permeable layer where water can be extracted. The temperatures in the Danish aquifers are 9-10 ℃ throughout the year. In areas where sand gravel and/or lime exist, the aquifer is useful for efficient storage of cooling and low temperature heat over long period such as a seasonal storage.[21]

ATES can be operated in dual mode depending on the season:

- **Summer**: In the summer period ground water is pumped from the cold well, where the temperature is 9-10 ℃. The cold water is sent through a heat exchanger, to be used for comfort cooling and/or process cooling. The heated return water is afterwards pumped down through the hot well. The thermal energy from the water is deposited in the surrounding structure of material. The water itself is only a transport medium.
- **Winter**: In the winter season is the pumping direction is reversed. The hot water from the hot well is extracted and passed through heat exchanger. The temperature can be further upgraded by using a heat pump. The heat may be used as space heating or added to the district heating (DH) network. If upgrading the heat is not economically feasible, an alternative is to use reject the heat through a dry cooler. The heat needs to be used to ensure thermal energy balance (the yearly removed heat from the aquifer is equal to the added heat including heat losses).

Please notice that the two described modes above is based on 2-flow ATES system because the pump direction is reversed when changing between the two modes. This ensures thermal energy balance in comparison with 1-flow ATES system, where thermal energy balance is not kept because the pump direction is not changed.[22] Thermal balance is a requirement by law.[23] The combination of a high COP-p (Coefficient Of Performance – used for the pump work in relation to ATES) value for the ATES technology and the possibility to sell the heat, when the demand is high, is a huge benefit for the ATES solution.

The summer and winter mode is shown in Figure 3.9 and the input and output of an ATES is shown in Figure 3.10.

[21] (Enopsol ApS, 2009, p. 5)
[22] (Enopsol ApS, 2009, p. 7)
[23] (Fødevareministeriet, 2015)

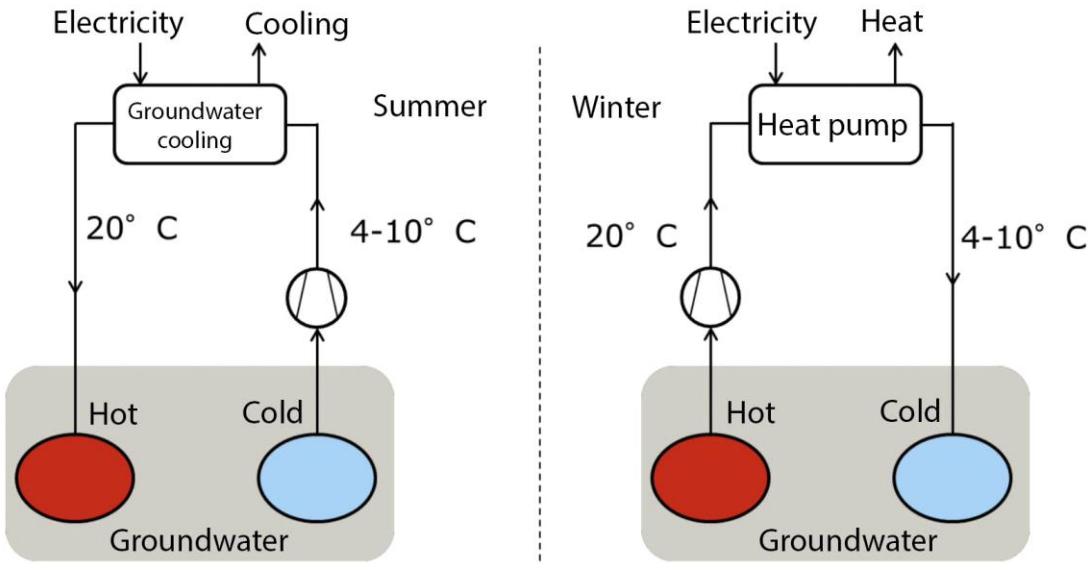


Figure 3.9 Show the two-typical operation mode of an ATES solution. Edited figure from (Rambøll, 2017, p. 14)

ATES wells always perform in pairs as shown in Figure 3.9. The capacity of the pair depends highly on the geological conditions.

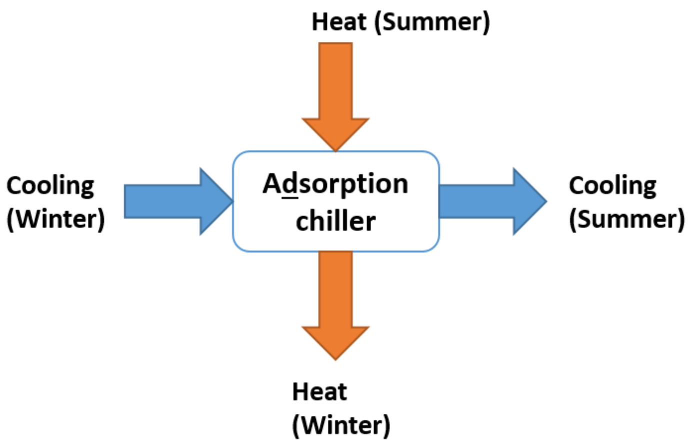


Figure 3.10 Input/output-diagram for ATES

3.4.1 Economy

The return on invest (ROI) of an ATES-system is in generally good if the geological conditions are favourable. In such cases the typical ROI is between 4 to 10 years.[24] Example of ROI for various project is placed in Appendix 15.18.1.

3.4.2 Operating framework

Act n heat recovery and ground water cooling (AHG) defines a lot of the legislation that affects the application process and the operation of an ATES-system[25]. To avoid conflict with areas with special drinking water interests (OSD) and "Extraction surrounding area outside OSD"[26], it is not recommended to plan for ATES in such places.[27]

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[24] (ENOPSOL, 2017)
[25] (Fødevareministeriet, 2015)
[26] In Danish: "Indvindingsoplande udenfor OSD"
[27] Mail from Gert Laursen, Odense municipality

The ATES-system can be used to store low temperature heat. It is only allowed to have a maximum average return temperature of 20 ℃ throughout a month with a maximum peak temperature of 25 ℃ cf. §14. This is in generally not a problem, when using the ATES in a DC network because the return temperature in general is below 20 ℃.[28] It is not allowed to boost the temperature with heat pumps before storing with ATES, even if this could be an advantage.

3.4.3 Heat pump

A heat pump is can be used to increase the hot water temperature stored in the hot well to DH forward temperature. §2 in AHG set the lower temperature allowed, which state that the minimum average allowed return temperature is 2 ℃ throughout a month cf. §2 in AHG. To avoid freezing in the heat pump, the temperature is kept above 4 ℃.[29]

3.4.4 Geological requirements

The geological requirements for ATES are waterborne layers in the underground. Most locations in Denmark have suitable layers within a depth of 100 meters[30], but the flow potential have local variations. Waterborne layers are characterised by large quantities of gravel or burst limestone. A well will usually consist of a topsoil followed by mixed layers of clay and sand. Locations on Funen and Sealand show layers of grey clay working as a barrier for conductive heat loss. Below the clay, layers of sand and gravel are potential waterborne layers. Burst limestone can also have good properties for water flow. Layers closer to the surface tends to have a gradient away from the boreholes, which lead to heat loss.[31]

It is required that the extraction and injection is to and from the same aquifer cf. §6 in AHG (Fødevareministeriet, 2015).

3.4.5 Losses in hot storage

The heat loss from ATES counts:[32]

- Convection loss: The natural water flow moves towards the sea or a nearby water stream with a slight gradient, resulting in a heat loss. The greater the water flow - the greater the loss.
- Conduction loss: Heat conduction from the aquifer to the surroundings layers.

The heat loss is typically around 20%.[33]

The potential of the aquifer can be explained by looking at a thermal image like Figure 3.11.[34]

- In the beginning of the cooling season (summer), the structures in the cold well will be cooled to the minimum temperature and have the maximum potential. The hot well has been exploited during winter and the remaining unused heat is identified as mushroom shaped formations, which are considered as heat loss. At this time, the temperature in the hot and cold wells are almost identical
- When the pump is reversed for winter operation in autumn, the structure in the hot well is fully charged. The cold well has no cooling potential left, apart from some heat loss located beyond operation area.

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[28] (Rambøll and Aalborg Univiersity, 2016, p. 20)
[29] (Niemi (ENOPSOL), 2017)
[30] (Enopsol ApS, 2017)
[31] (Jacobsen, 2017)
[32] (Jacobsen, 2017)
[33] (Enopsol ApS, 2009, p. 11)
[34] (Jacobsen, 2017)

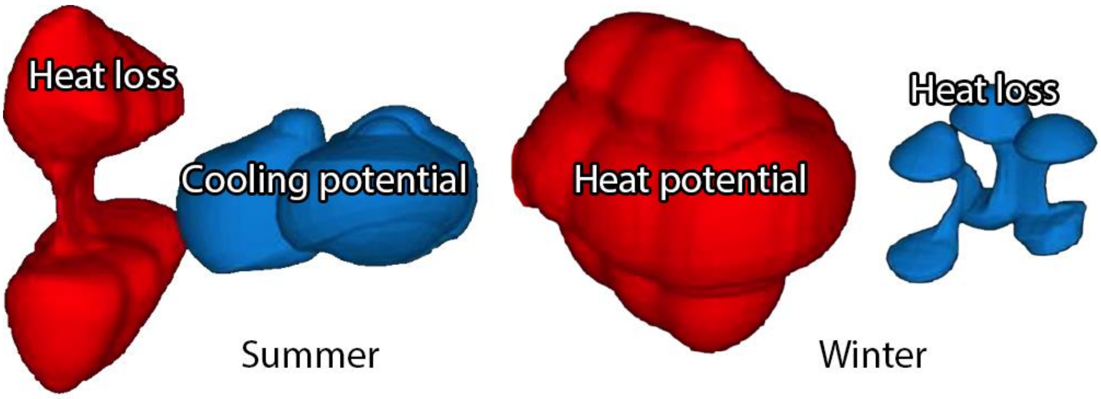

Figure 3.11 Edited figure from (Jacobsen, 2017). The blue area illustrates the potential of cooling in the structure to be used. In summer, cooling is distributed to the customers. The return water is stored in the aquifer (red area). The mushroom shaped areas illustrates heat loss.

More details on ATES are located in Appendix 15.18.

3.5 Comparative analysis

Parameter	Electrical chiller	Absorption chiller	Adsorption chiller	ATES
Cooling capacity range [kW][35]	2.4 to 6800 (depending on type)	4.5 to 5000	5.5 to approx. 1180	Capacity depends on the geological conditions and authorisation from the municipality. Typical capacity per dipole is between 400 kW to 1000 kW for areas where ATES is used.
COP (Coefficient Of Performance) cooling [-][36]	3-8	0.6-1.78 (depending on type and working condition)	0.4-0.6 (depending on working condition)	50-60 (cooling process / pump work)
Cooling chiller temperature output range [℃][37]	Depends on cooling capacity, type and work condition.	≥ 8.9	4.4 – 12.79	~ 9, but will vary over time. Dependent on the heat pump operation temperatures and whether heat pump is used to sub cooling

[35] Electrical chiller: (Green Riverside, 2017). Absorption chiller: (Bargman, 2017). Adsorption chiller: lower capacity cf. (Solair, 2017) and upper capacity found up to 1180 kW at (Bry-Air, 2017). ATES: (Rasmussen, 2017, p. 7)

[36] Electrical chiller: (Rambøll and Aalborg Univiersity, 2016). Absorption Chiller: lower COP-value (Sakradia, 2017) and upper COP-value (Kawasaki Thermal Eng.Co.,Ltd., 2017, p. 7). Adsorption chiller: (Reinholdt, 2017, p. 21). ATES: (Rasmussen, 2017, p. 6). The COP-value for absorption chiller and adsorption chiller is defined as the cooling output divided by pump work and the heat consumption cf. (Cengel & Boles, 2016, p. 633).

[37] Absorption chiller and adsorption chiller: (Bargman, 2017). ATES: (Rasmussen, 2017, p. 7)

Parameter	Electrical chiller	Absorption chiller	Adsorption chiller	ATES
Electricity consumption [kW]	See COP-value	Negligible	Negligible	See COP-value
Lifespan [year][38]	~ 30	20	> 30	~ 30 years. ATES consists of multiple technologies. Lifespan will be indicated by the heat pump, which is identical to an electric chiller.
Strengths[39]	Flexible and mobile technology. Uses only electricity to operate.	Use heat to drive the cooling process – cheap if heat is inexpensive. Only use marginal electricity. No moving parts equal silent operation.	Use heat to drive the cooling process – cheap heat can make good business case. Only use marginal electricity. No moving parts equal silent operation.	Return heat can be used for DH during the winter season.
Weaknesses[40]	Vulnerable to fluctuating electricity prices and taxation of electricity.	Low COP compared to alternative cooling technologies. Maintenance costs are high. Lifetime is 20 years.	Low COP compared to alternative cooling technologies	ATES can only be installed if the geological pre-requisites are available and OSD needs to be considered.

Table 3.4 Comparison of the various cooling technologies considered in this report.

[38] Electrical chiller cf. Appendix 15.10. Absorption chiller: Appendix 15.5. Adsorption chiller: (Bargman, 2017)
[39] Adsorption- and absorption chiller (Bargman, 2017), ATES: (Aquifer thermal energy storage, 2017)
[40] Adsorption- and absorption chiller (Bargman, 2017), ATES: (Aquifer thermal energy storage, 2017)

4. INTRODUCTION TO THE DISTRICT COOLING MARKET AND LEGISLATION

In this section, the necessary knowledge about the DC market and legislation in relation to this project is established.

The DC market differs from the DH market as the DC market is exposed to competition and no connection obligation exists. The typical DC customers do not include private customers, but companies with large cooling demand. Some examples of DC customers:[41]

Comfort cooling	Process cooling
• Supermarkets • Malls • Hotels	• Supermarket • Owners of large server farm • Cooling of machines in a factory

Table 4.1 Example of DC customers.

Currently, only cooling above the freezing point is delivered by Danish DC network. The reason is that water is used as the transport medium. If the temperature is below the freezing point another transport medium is needed such as glycol/water solution. Using such solutions as the transport medium has environmental impacts to consider and the cost of glycol is high. Furthermore, the loss in the network increases.[42]

The legislative rules for DC companies dependents highly on the ownership structure. The municipality can own or partly own the DC company or it can be operated privately.[43] The main differences in ownership structure is outlined as follows:

- **Synergy requirement with DH:** For municipality owned or partly municipality owned DC companies it is required that there is a synergy with DH cf. §2 in law about DC. This synergy can be obtained by operating an a<u>b</u>sorption chiller and/or a<u>d</u>sorption chiller (convert heat from DH to cooling) or an ATES solution (heat from cooling production is sold to DH company). It should be noted that: "The synergies can immediately (…) be attributed solely to cover part of the year".[44] This means that a free cooler or electrical chiller can be used as baseload and a<u>b-</u>sorption chillers only run a few hours. To use an electrical chiller only is not allowed. Energiklagenævnet, which examines complaints due to law about DC, have not yet made any decisions on whether synergy is present or not.[45]
- **DC in an independent company:** A municipality owned DC company need to be an independent and thereby possibly separated from a municipality owned DH company cf. § 3 in law about DC. Notice that it is allowed for an employee to work for both DH and DC companies, but the time register needs to be placed on the individual companies, which is used partly at HOFOR DC.[46]

Despite several restrictions that apply to municipality owned or partly municipality owned DH companies, there are many benefits of having cooperation between DH company and DC companies. Some of the benefits include:[47]

- Both systems in the same excavation
- Combined production of heat and cooling, using a<u>b</u>- or a<u>d</u>sorption chiller for cooling
- Many common components – possibly opportunities for joint procurement
- Similar professional skills to operate and maintain DH and DC.

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[41] (Pihl-Andersen (HOFOR DC), 2017) and (Rambøll and Aalborg Univiersity, 2016, pp. 19-20)
[42] (Rambøll and Aalborg Univiersity, 2016, p. 20)
[43] In the law municipally owned DC companies also cover partly municipally owned DC cf. 15.13
[44] Appendix 15.13. Translated from Danish to English.
[45] Appendix 15.13
[46] (Pihl-Andersen (HOFOR DC), 2017)
[47] (Rambøll and Aalborg Univiersity, 2016, pp. 9-10)

5. MODEL INTRODUCTION

In this project, the possible DC consumers are limited to five companies separated in a primary target group including Bilka, Rosengårdcentret and IKEA and a secondary target group including Nyt OUH and SDU. Common for all these cooling consumers are that they have a significant cooling demand and are closely located, thereby creating a DC potential cf. Section 4. Further, these companies are identified as interesting DC consumers in collaboration with Fjernvarme Fyn. Two energyPRO-models will be used to calculate the variable costs and revenues based on the simulated energy consumption for the various production units.

The first model (Model 1) simulates the reference / current situation and include both the primary and secondary target group.[48] The customers are not connected to each other. It is not possible to combine the cooling demand as they have different demand profiles and production units. The taxation depends on whether the cooling is used for process cooling or comfort cooling. By separating the cooling demand in energyPRO, the taxes can be calculated more accurately. The variation in the cooling profiles, makes it difficult to create an acceptable general cooling profile. This model will be used as reference, to determining the economic feasibility of a DC solution. The model is visualised in the Figure below.

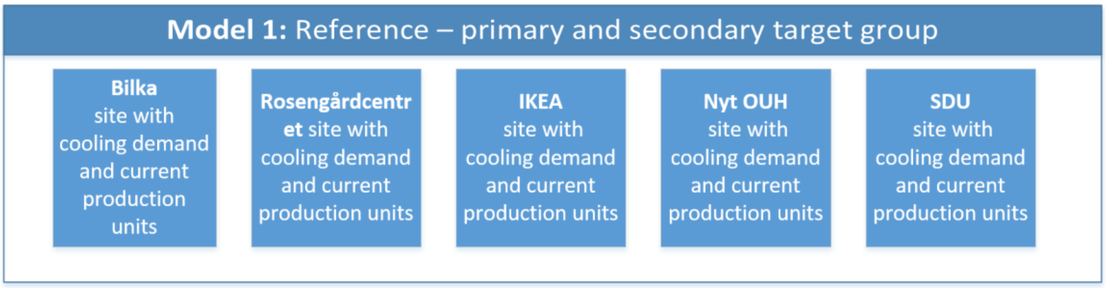

Figure 5.1 Simulation of the reference situation, where no DC solution exists. In model 1, the individual costs are calculated for both the primary target group (Bilka, Rosengårdcentret and IKEA) and the secondary target group (Nyt OUH and SDU).

Model 2 simulate the DC situation, where the model includes both the primary and secondary target group.[49] The DC solution is based on four cooling production units:

- Electrical chiller
- ATES
- Absorption chiller
- Adsorption chiller

The most cost effective production mix for model 2 will be found using energyPRO. Model 2 is visualised in Figure 5.2.

One of the things which can make a DC company economically competitive are production units with a high COP-c value. To ensure this an ATES solution is implemented as a base-load unit in the suggestion because it has a high COP-p value and a low payback time. The electrical chiller is chosen as a peak load unit and provide some economies of scale benefits in relation to the individual solutions as described in section 3.1 - Electrical chiller. The absorption chiller and adsorption chiller are modelled as they produce cooling, using heat and a negligible amount of electricity, thereby almost unaffected by increasing electricity prices.

[48] The energyPRO-file is in Appendix 15.1 A27.
[49] The energyPRO-file is in Appendix 15.1 A29.

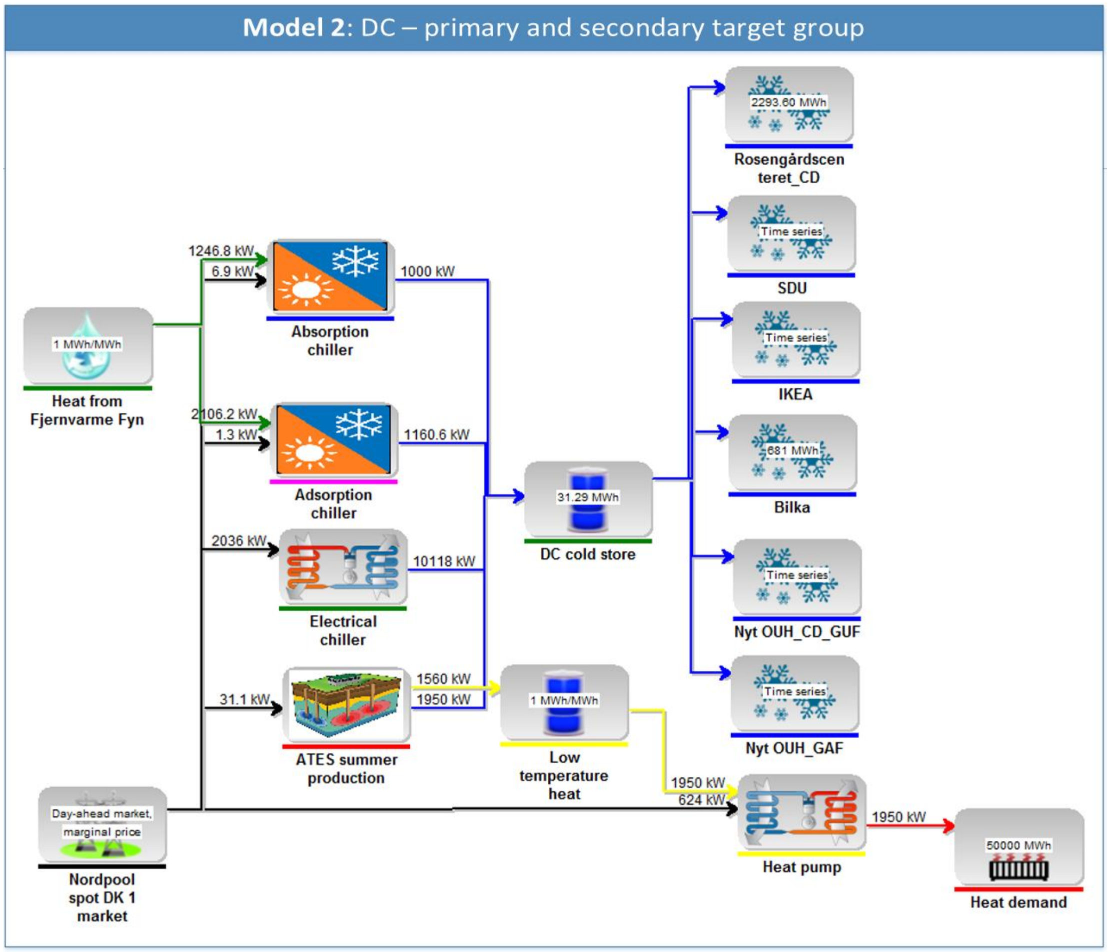

Figure 5.2 Simulation of DC solution. The model includes both the primary target group (Bilka, Rosengårdcentret and IKEA) and the secondary target group (Nyt OUH and SDU). The figure is from the energyPRO-file in Appendix 15.1 A32.

The **absorption chiller** and **adsorption chiller** use heat brought from Fjernvarme Fyn and a negligible amount of electricity. When configuring the model, "Heat from Fjernvarme Fyn" is omitted as a fuel in energyPRO. Instead the absorption chiller and adsorption chillers are modelled as an electrical chiller. The cost of heat is then defined as a cost per MWh cooling.

ATES consist of three components:
"ATES summer production" is effectively a heat exchanger and a pump, which produce cooling in the summer period. The return water from the customer is a by-product of excess heat.
This heat is stored in the "Low temperature heat", which is a storage. The low temperature heat can be upgraded during winter through a heat pump and then sent to the DH transmission network.

When modelling the heat recovery from the storage, the "low temperature heat" and heat pump is removed from the model because performance of the model is too time consuming.[50] The simulation time is reduced a lot by simulating the ATES as an electrical chiller instead - called "ATES summer production" in the figure below. As ATES production has

[50] The model takes around 1.5 days to run the model for each year (which give around 30 days because the simulation need to be run for 20-year period). The model has been sent to the producer of energyPRO (EMD International), but they have not provided any suggestion to optimise the simulation time.

thermal balance, the cooling production can be used to calculate the electricity used by the heat pump to upgrade the heat. Heat sales can then be calculated without being a part of the model, as the heat price is fixed. The downside is that an average spot price needs to be used, as the heat pump is not considering to operate when the spot price is low. This makes the production costs more expensive. The optimised model will run in less than a 1 minute, which enable more scenarios to be considered in the results section.

A **cold storage** is implemented in the DC solution as it enables the electrical chiller to produce cooling when the electricity price is low and the ATES solution to produce cooling at full capacity when the cooling demand is below the cooling capacity of ATES for some hours. A cold storage is able to boost the effect of the solution to deliver at peak demand, effectively reducing the required production capacity. The cold storage is also an advantage as none of the cooling customers currently have a cold storage, Nyt OUH have planned for one. This gives DC an economical advantage.

The optimised DC model that will be used is shown below. The model is the same as shown in Figure 5.2, but without "Low temperature heat", "Heat pump", "Heat demand" and "Heat from Fjernvarme Fyn".

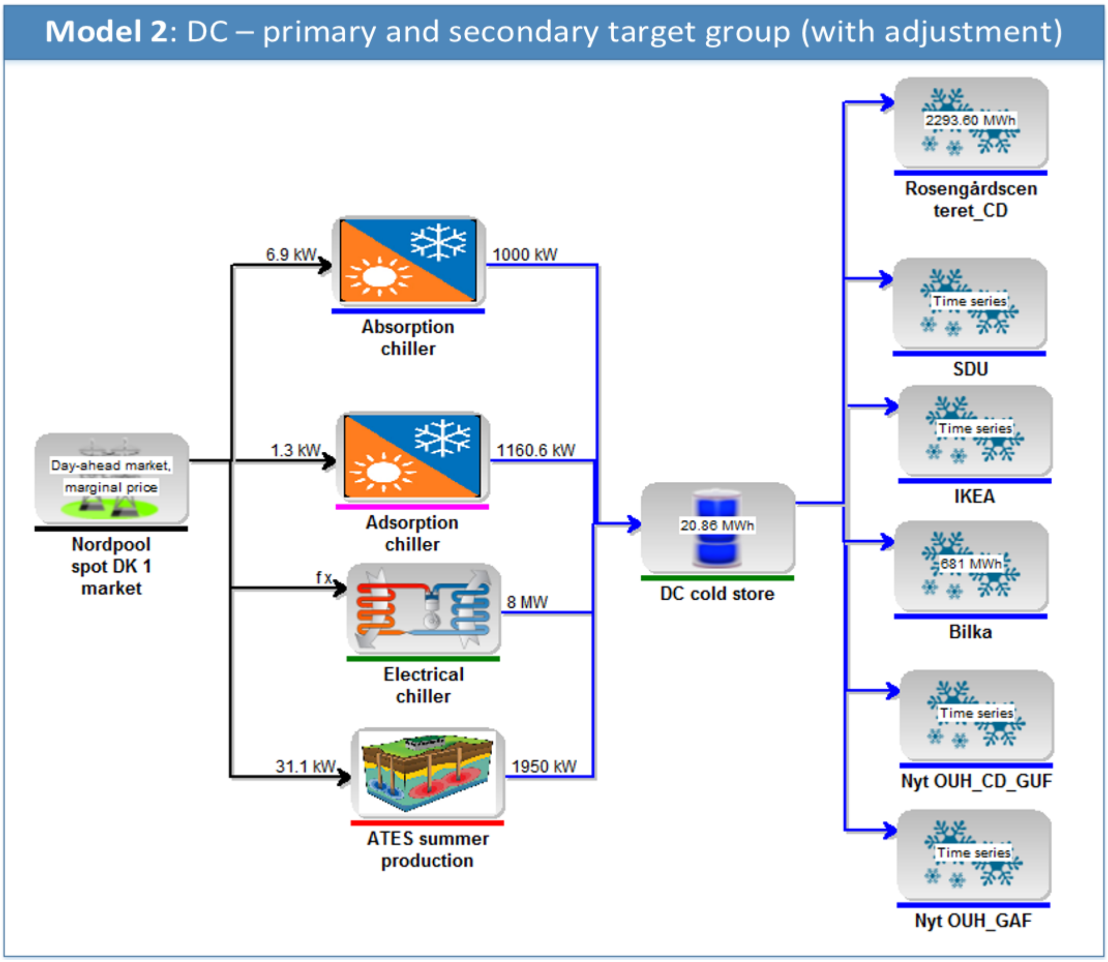

Figure 5.3 The energyPRO-model which will be used to simulate the DC network (located in Appendix 15.1 A29). The model has some simplification in relation to modelling ATES, a<u>b</u>sorption chiller and a<u>d</u>sorption chiller, but this simplification will only have smaller impact on the results. Black line is electricity and blue line is cooling.

The table below describes the connection between the report and the construction of the model.

Section in report	Model 1 (reference situation)	Model 2 (DC situation)
6 - Cooling customers	Cooling demand and individual production units.	Only cooling demand is used in the models
7 - Design of district cooling network	-	The temperature of DC network is chosen, which affect the performance of the cooling production technologies. The configuration of the DC cold storage is also described.
8 - DC production units	-	DC production units.
9 - Economy inputs	The cost of producing cooling at reference situation.	The cost of producing cooling at DC situation
10 - Verification of model	Verification of model.	Verification of model.

Table 5.1 Connection between the report and the energyPRO-models.

6. COOLING CUSTOMERS

This section establishes an overview of the customers cooling demand and important characteristics in relation to their production facilities. The result in this section is based on interviews and contacts with the companies. All cooling demand data is in general based on consumption data from 2016 apart from Nyt OUH which is based on estimates as Nyt OUH has not yet been built. A more detailed accounting for the individual cooling production facilities, construction of demand profiles and special individual characterises are placed in Appendix 15.2.

The location of the cooling demands and the individual yearly cooling demand in MWh is shown on a map in Figure 6.1, where blue house indicates a customer in the primary target group and grey house indicates a customer in the secondary target group.

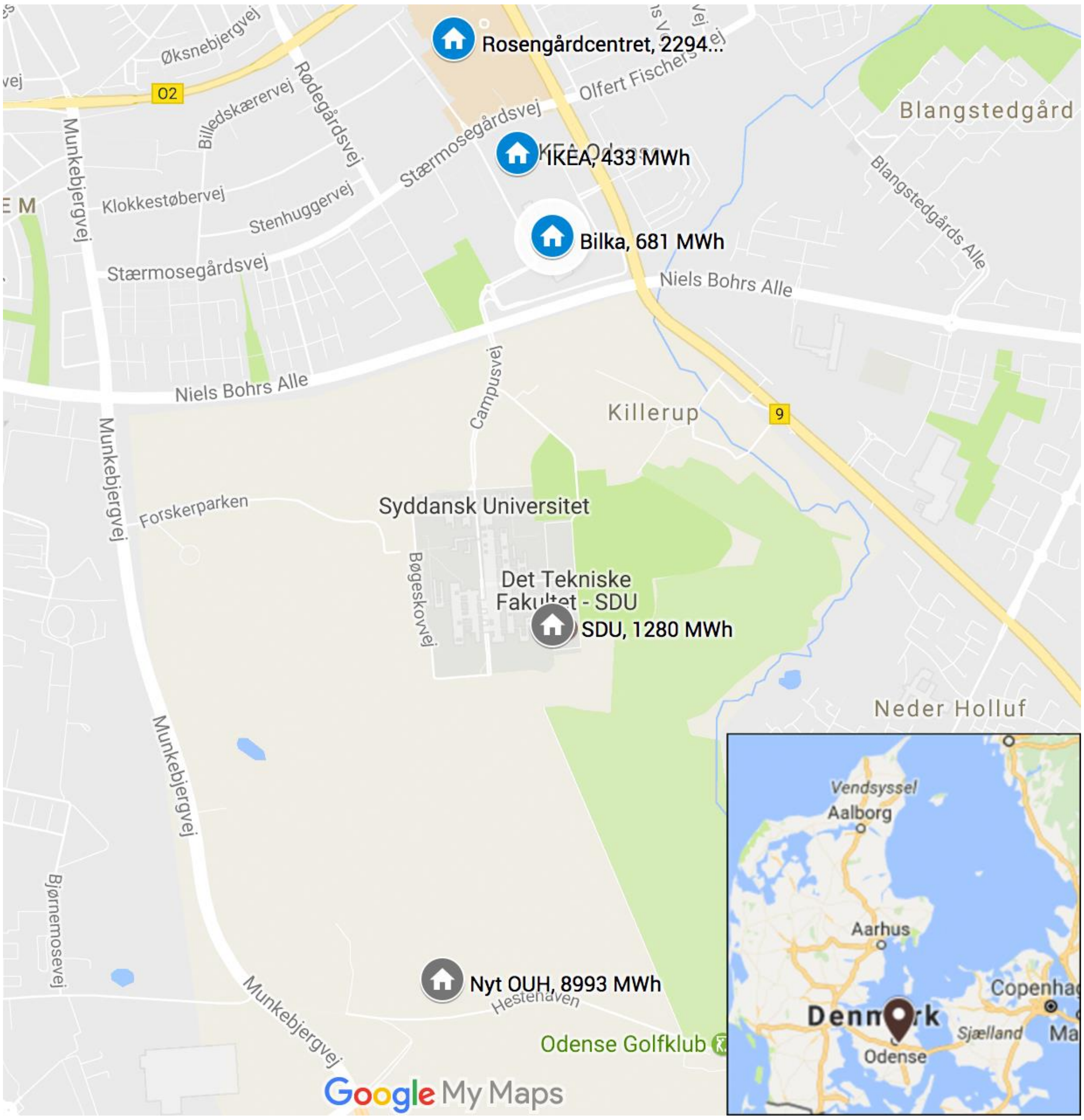

Figure 6.1 Map showing cooling demands for selected companies in this project. Group of primary customers are coloured in blue, secondary customers are coloured in grey. Source: Created by the author of this report in Google Maps and can be accessed by the website: www.goo.gl/TsK8Sn. This map also includes placement of the DC pipe and ATES drillings.

Table 6.1 shows a list of companies of particular interest to be connected to the DC network. They are separated in a primary target group (Rosengårdcentret, IKEA and Bilka) and a secondary target group (Nyt OUH and SDU). The primary target group only use comfort cooling, where Nyt OUH use both comfort and process cooling and SDU use process cooling only. This is quite important for the results as shown later. Please notice that server cooling is defined as process cooling in this report because the legislation percieves server cooling as process cooling.

Consumer no. [-]	Company [-]	Yearly cooling demand [MWh]	Cooling demand type [-]	Procentage comfort [%]
1	Rosengårdcentret	2,294	Comfort	100
2	IKEA	433	Comfort	100
3	Bilka	681	Comfort	100
A	SDU	1,259	Server Process	0
B	Nyt OUH	8,993 (estimate)	Process Comfort	36 (estimate)
Total, primary target group	**Rosengårdcentret, IKEA and Bilka**	**3,408**	**Comfort**	100
Total, primary and secondary target groups	**Rosengårdcentret, IKEA, Bilka, SDU and Nyt OUH**	**13,660**	**Comfort Server Process**	49

Table 6.1 List of the customers to the DC solution including their yearly cooling demand, cooling demand type/usages and the individual cooling technologies.

Figure 6.2 visualises the cooling demand in MWh/year.

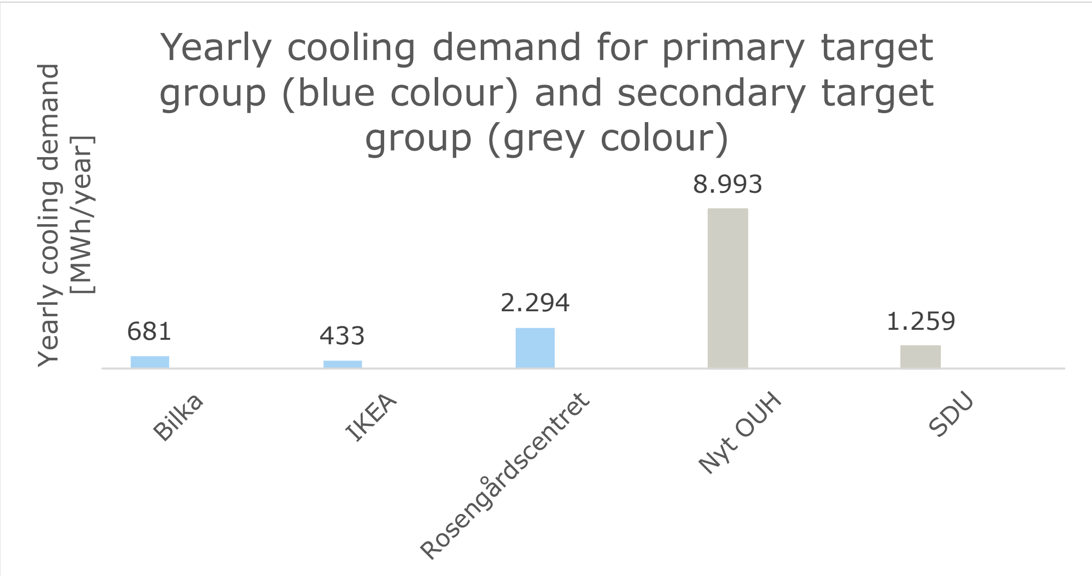

Figure 6.2 Yearly cooling demand for each possible DC consumer.

6.1.1 Duration curves

The duration curve for the primarily customer target group is shown in the figure below. Cooling demand [MW] as the function of time [Hours], sorted from the highest to the lowest cooling demand.

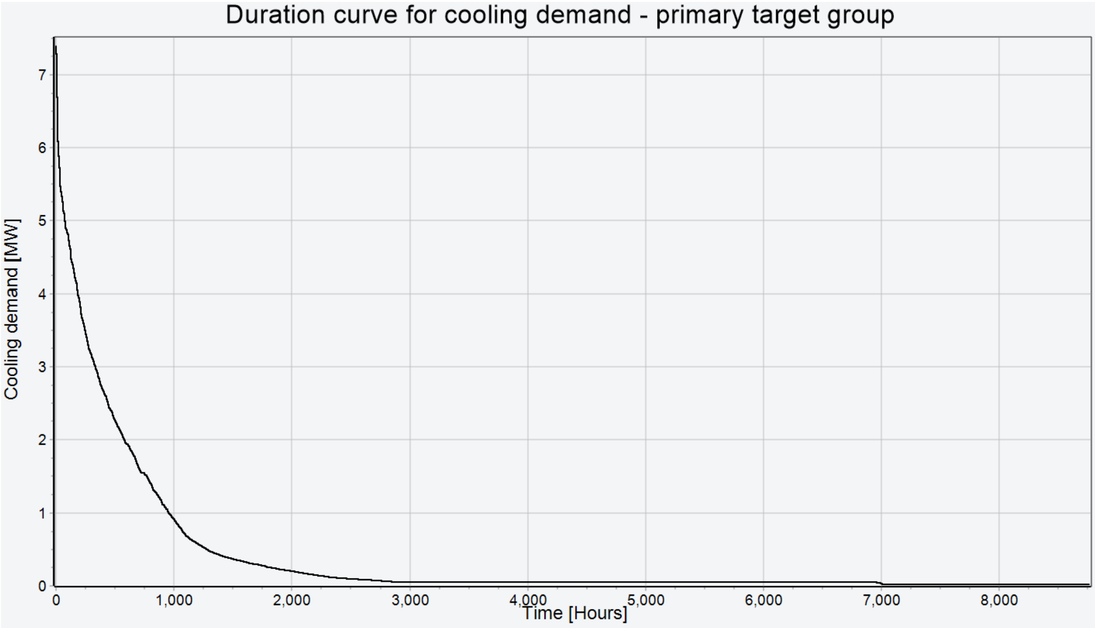

Figure 6.3 Duration curve for primary target group (IKEA, Bilka and Rosengårdcentret) generated by using energyPRO – energyPRO-model 1 with the primary target group (Located in Appendix 15.1 A28)

The duration curve for both the primarily and secondary customer target groups is shown in the figure below.

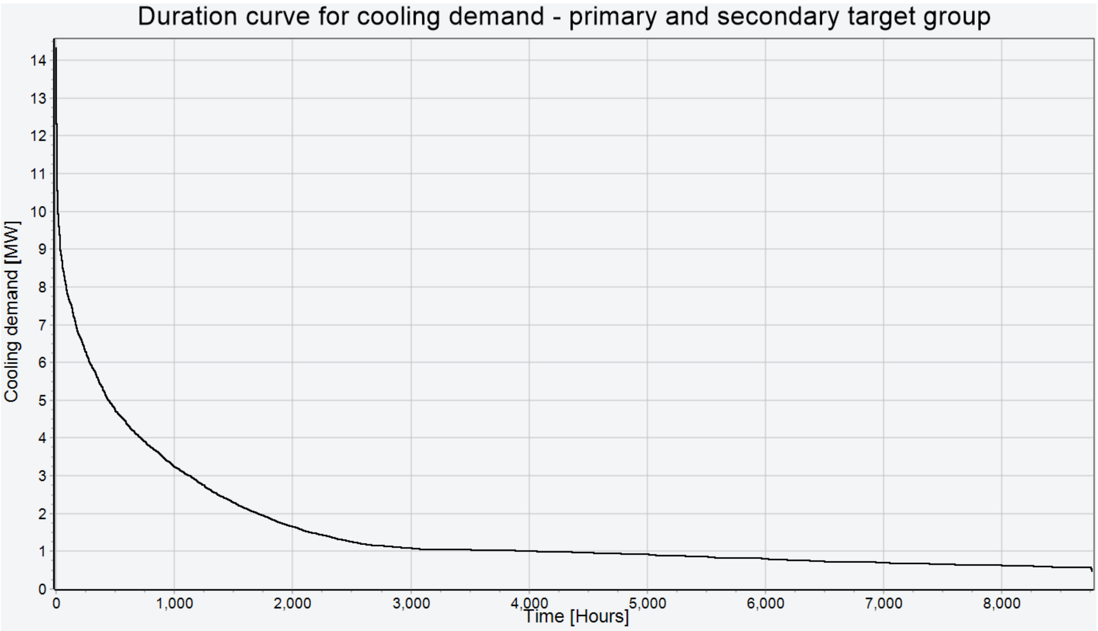

Figure 6.4 Duration curve for the primary and secondary target groups is generated by using energyPRO – energyPRO-Model 2: Reference – Primary and secondary target group (Located in Appendix 15.1 A27). The primary target group includes IKEA, Bilka and Rosengårdcentret. The Secondary target includes SDU and Nyt OUH.

6.2 Production facilities

All customers use electrical chillers for cooling production. In addition, Nyt OUH and SDU use dry coolers. All electrical chiller is assumed to have a COP-c value of 3.53 apart from Nyt OUH, where the COP-c value for the chiller is set to 4.97 due to a higher cooling demand, where better efficiency is expected. The dry cooler COP-c value is highly dependent on the ambient temperature and is assumed to be 17.5 for Nyt OUH and 16.8 for SDU. Both dry-coolers are assumed to run at the maximum capacity below 10 ℃.

7. DESIGN OF DISTRICT COOLING NET-WORK

7.1 Placement of production technologies

The electrical chiller, absorption chiller and adsorption chiller can be located at Fjernvarme Fyn. Maybe is it also possible to place the technologies near IKEA, where two electrical chillers already are installed. The absorption chiller, adsorption chiller, and ATES need to be connected to the DH transmission line. Adjacent to Fjernvarme Fyn is a DH transmission line located and can be used as a connection point for the three technologies. The pipe length used in the calculated is based on a connection to Fjernvarme Fyn.

7.2 DC supply and return temperature

It is desirable to have as high temperature difference between the supply and return temperature. From a network perspective, a high ΔT indicates that the maximum amount of energy has been delivered through the pipes and as a result, a smaller pipe diameter is required.[51]

The supply temperature is set to 9 ℃ as ATES deliver cooling at a natural temperature of around 9 ℃. The temperature in the aquifer can vary over time between 4 ℃ and 10 ℃. It is also possible to deliver at lower temperature if the water is processed by a heat pump, with an increase in costs as a result. Furthermore, the absorption chiller cannot be used below 9 ℃.

The return temperature is set to 18 ℃, which seems reasonable in relation to the current used temperature cf. Table 6.1. Please notice, that this project has not investigated whether this temperature set is optimal for the individual cooling coils.

7.3 Choice of district cooling pipes

The design load of the DC pipe is set equal to the maximum simultaneous cooling demand, which is 14.33 MW for both target groups and 7.5 MW for the primary target group cf. Figure 6.4 and Figure 6.3, respectively.

The pipe choice is based on the same criteria used in DH:[52]

- Transmission line maximum velocity 3-3.5 m/s
- Maximum pressure equal to 16 bar
- Pressure gradient between 50-200 Pa/m

The typical DC pipes are pre-insulated single pipe, series 1, or non-insulated PE pipes. The chosen pipe type in this analysis is series 1 from Logstor.[53] An Excel sheet is created to find the proper series 1 pipe based on the three criteria above and the data from the Logstor pipe catalogue. The Excel-spreadsheet can be found in Appendix 15.1 C2.

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[51] (Andersen, et al., 2015, p. 282)
[52] (Andersen, et al., 2015, pp. 281-288)
[53] (Logstor, 2017, p. 19)

The Excel-spreadsheet is built by using the following formulas:
The mass flow (q_m) is calculated by the formula:[54]

$$q_m = \frac{\Phi}{c_p * (T_r - T_s)} \tag{7.1}$$

Where Φ is the design load / cooling capacity in W, c_p is the specific heat capacity (based on a water temperature of the mean of the return and supply temperature, 4185 J/(kg*K), T_r is the return temperature ($18\,℃$) and T_s is the supply temperature ($9\,℃$).

The volume flow in $\frac{m^3}{s}$ is calculated by the formula:[55]

$$q_v = \frac{q_m}{\rho} \tag{7.2}$$

Where ρ is the water density equal to 999 $\frac{kg}{m^3}$ based on the mean temperature between the return and supply pipe.

The inner diameter in m is calculated as:

$$d_i = d_y - wt * 2 \tag{7.3}$$

Where d_y is the outer diameter in mm and wt is the wall thickness in mm.

The velocity in m/s is calculated by[56]

$$v = \frac{4 * q_v}{\pi * d_i^2} \tag{7.4}$$

Reynolds number is calculated as:[57]

$$Re = \frac{v * d_i}{v_{viscosity}} \tag{7.5}$$

Where $v_{viscosity}$ is the kinematic viscosity (based on a water temperature of the mean of the return and supply temperature $4.13 * 10^{-7} \frac{m^2}{s}$)

The Friction factor λ is calculated by the formula:[58]

$$\lambda = \frac{1}{4 \cdot \left(log\left(\frac{k}{3{,}7 \cdot d_i} + \frac{2{,}51}{Re \cdot \sqrt{\lambda}} \right) \right)^2} \tag{7.6}$$

Where k is the roughness assumed to 0.00006 m and λ is the friction factor.[59]

The pressure loss $\frac{Pf}{L}$ in Pa/m is calculated by the formula:[60]

$$\frac{pf}{L} = \frac{\lambda * \rho * v^2}{2 * d_i} \tag{7.7}$$

[54] (Andersen, et al., 2015, p. 281)
[55] (Andersen, et al., 2015, p. 288)
[56] (Andersen, et al., 2015, p. 282)
[57] (Andersen, et al., 2015, p. 287)
[58] (Andersen, et al., 2015, p. 287)
[59] The roughness seems reasonable cf. (Andersen, et al., 2015, p. 284)
[60] (Andersen, et al., 2015, p. 284)

7.3.1 Primary target group

The results from the Excel-spreadsheet (placed in Appendix 15.1 C4) where pipes coloured in green complies with the velocity, pressure gradient and total system pressure for the design load, when delivering DC to the primary target group:

Dimension	Inner diameter	Cross sectional area	Velocity	Pressure gradient
Unit:	m	m^2	m/s	Pa/m
DN 250	0.263	0.054	3.5	335
DN 300	0.313	0.077	2.5	137
DN 350	0.344	0.093	2.0	84
DN 400	0.394	0.122	1.6	42
DN 450	0.444	0.155	1.2	23
DN 500	0.495	0.193	1.0	13
DN 600	0.596	0.279	0.7	5
DN 700	0.695	0.379	0.5	2

Table 7.1 Velocity and pressure gradient of different pipes at design load for delivering DC to the primary target group. Pipes coloured green complies with the velocity, pressure gradient and total system pressure. Full sheet with formulas and result can be found in Appendix 15.1 C4.

The DN 300 will be used in calculating the pump work when delivering DC to the primary target group. The suggested pipe and digging costs are based on DN 400 as the most optimal pipe when delivering cooling to both target groups.

7.3.2 Secondary and primary target group

The results from the Excel-spreadsheet (placed in Appendix 15.1 C2), when delivering DC to the primary and secondary target group.

Dimension	Inner diameter	Cross sectional area	Velocity	Pressure gradient
Unit:	m	m^2	m/s	Pa/m
DN 250	0.263	0.054	7.0	1331
DN 300	0.313	0.077	4.9	544
DN 350	0.344	0.093	4.1	330
DN 400	0.394	0.122	3.1	166
DN 450	0.444	0.155	2.4	89
DN 500	0.495	0.193	2.0	51
DN 600	0.596	0.279	1.4	20
DN 700	0.695	0.379	1.0	9

Table 7.2 Velocity and pressure gradient of different pipes at design load for delivering DC to both the primary and secondary target group. Pipes coloured green complies with the velocity, pressure gradient and total system pressure. Full sheet with formulas and result can be found in Appendix 15.1 C2.

DN 400, DN 450 and DN 500 are the only three pipes which fulfil the pressure gradient criteria. The DN 400 will be used in calculating the pump work when delivering cooling to both the primary and secondary target group.

7.4 Cold storage

The cold storage capacity varies through the different scenarios which are simulated and will be described in each scenario. Storage loss is set to zero as the temperature gradient between the storage temperature and the outdoor temperature is low, resulting in a negligible heat loss.

8. DC PRODUCTION UNITS

8.1 Electrical chiller

Johnson control have sent an offer on an electrical chiller, which is in Appendix 15.10, 15.11 and 15.12. The offer is based on 2 MW modules, with a COP-cooling of 4.97 assumed to be when the temperature is above 10 ℃. The built in dry cooler starts operating at temperatures below 10 ℃ and the electrical chiller uses the dry cooler 100 % when the ambient temperature is below or equal to 2 ℃. An average COP-c value of 17.485 is used when the ambient temperature is between 2 ℃ and 10 ℃.

8.2 Absorption chiller

The cooling production, electricity consumption and heat input is based on 78 ℃ heat from DH, DC supply temperature of 9 ℃ and a return temperature of 18 ℃. Results for the absorption chiller models are listed in the table below based on Appendix 15.1 B1, 15.1 B2 and 15.1 B3, 15.1 B2 and 15.1 B3.

The COP-a value calculation for absorption chiller. Q_L is the desired cooling production, Q_{Gen} is the required heat input, W_{pump} is the electricity consumption by the pump.

$$\text{COP-a} = \frac{Q_L}{Q_{gen} + W_{pump}} = \frac{1000\ [kW]}{1246.8\ [kW] + 6.9\ [kW]} = 0.798 \quad (8.1)$$

Model	Cooling Production [kW]	Heat input [kW]	Electricity consumption [kW][61]	COP-a value [-][62]
5G 4K C	1000	1246.8	6.9	0.798
5G 6K C	2000	2485.5	18.1	0.799
5G 8N C	5000	6179.7	18.1	0.807

Table 8.1 Three absorption chiller units with a cooling capacity of 1 MW, 2 MW and 5 MW. The heat input and electrical consumption is also indicated for de three models. The data is based on the offer from Thermax (located in Appendix 15.1 B1, 15.1 B2 and 15.1 B3).

Only the 1 MW unit is implemented in the energyPRO-model, but can be changed to simulate the two other models by changing the production curve in energyPRO.

8.2.1 Waste heat

The heat received from the DH is reduced by around 10℃. The waste heat from the absorption chiller is fed back into the transmission line at Fjernvarme Fyn. There is no financial transaction related to this activity, as the heat is purchased for 100 $\frac{dkk}{MW}$. Feeding the waste heat back into the transmission line is an advantage, as the alternative could be to use a free cooler. This is possible, as the absorption chiller is only in operation during the summertime.

8.3 Adsorption chiller

The adsorption chiller used in this project is a Bry-Air F-330 adsorption chiller. Bry-Air have sent an offer for this adsorption chiller, which is attached in Appendix 15.3 and 15.4.

[61] Assumed 100 % active effect only - the offer give the electrical consumption as apparent effect.

[62] the COP-a value for absorption chiller and adsorption chiller is defined as the cooling output divided by pump work and the heat consumption cf. (Cengel & Boles, 2016, p. 633).

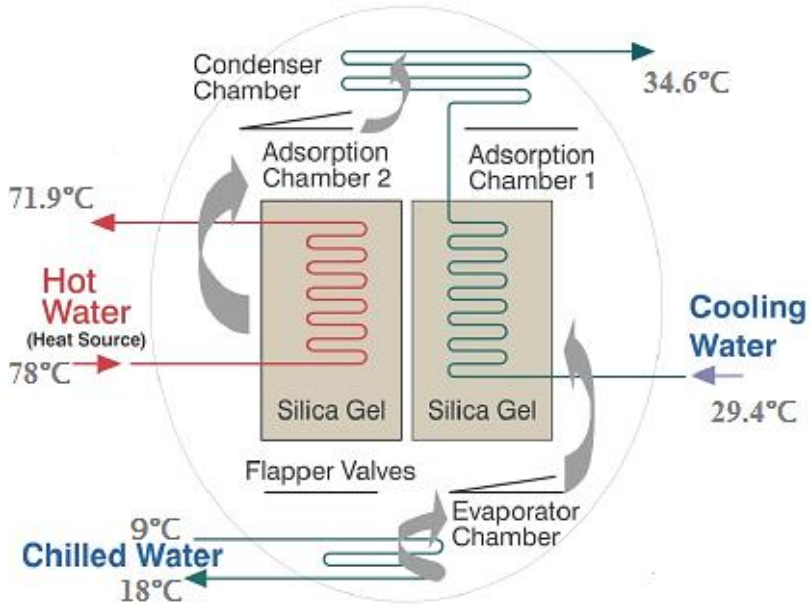

Figure 8.1 The working temperature for the adsorption chiller is used in the energyPRO-model. The image is a modified version of the image on page 4 in the offer located in Appendix 15.6.

The adsorption chillers cooling capacity is 1160.6 kW.[63] The electricity usage is 1.3 kW at the given working condition for the DC and DH network.

The heat input is not directly given in the datasheet, but can be calculated, by using the hot water temperature and volume flow. The hot water inlet is 78 ℃ and at the given working condition the hot water outlet temperature is 71.9 ℃ as visualized in Figure 8.1. The hot water flow is given in the datasheet as: $q_v = 304.3 \frac{m^3}{hr}$. The working fluid is water. Assuming a pressure of 1 atm. And use the average temperature equal to 74.95 ℃ give a density of 947.9 $\frac{kg}{m^3}$ and a specific heat capacity of 4.19 $\frac{kJ}{kg*K}$. The heat input is thereby:

$$Q = q_v * \rho * c_p * \Delta T = 304.3 \frac{m^3}{hr} * 974.9 \frac{kg}{m^3} * 4.19 \frac{kJ}{kg*K} * (78℃ - 71.9℃) = 2106\ kW \qquad (8.2)$$

Waste heat production from the adsorption chiller is returned to Fjernvarme Fyn given the same conditions as the waste heat from the absorption chiller see section 8.2.1 - Waste heat.

The COP-a value for the adsorption chiller is 0.55 and is lower than the three absorption chillers included in this project.

8.4 Aquifer Thermal Energy Storage

8.4.1 Design of Aquifer Thermal Energy Storage in energyPRO

energyPRO have no build-in ATES Energy Conversion Unit. ATES is modelled as an electrical chiller in energyPRO with the name “ATES summer production”. The electrical chiller is only allowed to produce cooling in the summer period, where ATES in the reality only produce cooling. This cooling production period is set to be from the beginning of May to the end of September roughly based on Figure 15.16 (in Appendix). This period has the highest demand for cooling.

[63] The Adsorption chiller have a cooling capacity of 330 TR (ton of refrigeration) / RT (refrigeration ton), which can be converted to kW by using the conversion factor 3.5168525 kW cf. (The Engineering Tooolbox, 2017) and (ME Subjects, 2017)

The return heat by-product from the cooling production and the aquifer hot storage operation will not be simulated in energyPRO. Instead all the economic figures will be calculated based on the cooling production such as the electricity consumption of the heat pump and the heat sold to Fjernvarme Fyn. This is due to the necessary simplifications as described in Section 5.

8.4.2 Cooling capacity

The ATES solution is located close to the primary target group to optimise the pipe cost for the target group. The area around the primary target group is outside the OSD-area and "extraction surrounding area outside OSD" as shown in Figure 8.2. The location then complies with the recommended guidelines for water injection and extraction in relation to ATES.

Figure 8.2 Map showing OSD, OD and "Extraction surrounding area outside OSD" in the area near Rosengårdcentret. Map from (Geodatastyrelsen, 2017) with "Drikkevand og grundvand" layer turn on.

The GEUS Jupiter database provides data on previous exploratory drillings.[64] The capacity of the drilling can be calculated by the formula:

$$Q = q_v * \rho * c_p * \Delta T \tag{8.3}$$

Q is the capacity of the drillings in kW, q_v is the volume flow / performance in $\frac{m^3}{hr}$, ρ is the density of the working fluid (water), c_p is the specific heat (of water) and ΔT is the temperature difference. The density of water is set to $1000 \frac{kg}{m^3}$ and the specific heat capacity is set to $4.184 \frac{kJ}{kg}$. The temperature difference is set to the difference between the supply and return temperature of the DC network (18/9 ℃) with a loss in the heat exchanger set to 1 ℃.[65]

[64] The database can be access through the website http://goo.gl/iBmQvb.

[65] (Jacobsen, 2017)

Table 8.2 list the three best GEUS drillings in the area around Rosengårdcentret, Bilka and IKEA.

Placement on map in Figure 8.3	Performance [m^3/hr]	Sinking [m]	Effect [kW]
Reference 1	25	1	234
Reference 2	28	0.5	524
Reference 3	13	Not measurable (assumed 0.1 m)	1216

Table 8.2 Three best GEUS drillings in the area around Rosengårdcentret, Bilka and IKEA. Based on data from GEUS drilling database – can be accessed though (Jupiter, 2017).

For the well at reference 3, the sinking is not measurable, according to the borehole report.[66] It is assumed that the sinking is 0.1 m, which defines the flowrate and thereby the potential of the well. In the sensitivity analysis, the potential of the well will be investigated. It seems reasonable to place ATES around reference 3 with a similar effect as the exploratory borehole. It is likely to find the same capacity from an exploratory drilling in around a 500 m radius.[67]

When calculating the potential effect of a well in relation to ATES, it is essential to include the storage conditions. The return water is pumped into the hot part of the dipole. The heat is transported by the water and stored in the waterborne layer. The heat is dispersed in a horizontal orientation away from the borehole. If the layer is not thick enough, the heat is contaminating the cold part of the dipole. The compulsory water model will identify the exact potential of the waterborne layers, but similar solutions have a total potential of 2 MW.[68] For this project, each of the 3 dipoles are set equal to 650 kW.

The first dipole is placed in the top corner of Rosengårdcentret. The typical drilling distance between the hot and cold drillings for ATES is around 100 m([69]) and the reason is that the legislation require that the two drillings are connected to the same aquifer cf. AGH § 6 piece 2. In this case the distance between the hot and cold drillings is 175 m.

The second dipole is located in the middle of the parking area, with a distance of approx. 260 m to dipole 1. The hot and cold boreholes are placed opposite of each other to for maximum effect of each borehole.

The third dipole is located in the south corner of Rosengårdcentret with a distance of around 500 m to the north dipole. The total capacity of the ATES wells is thereby 1950 kW.

[66] (Jupiter, 2017)
[67] (Jacobsen, 2017)
[68] (Jacobsen, 2017)
[69] (Jacobsen, 2017)

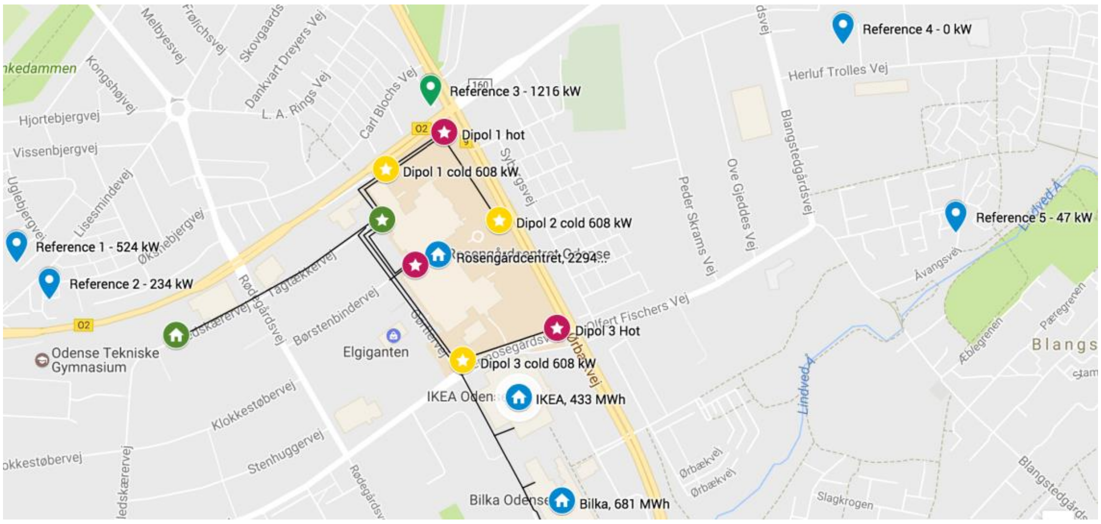

Figure 8.3 Map of GEUS drillings including their capacity. Blue 'drop' are reference drillings, green 'drop' is the closest located drilling, yellow and red stars are dipole pairs, blue houses are primary customers, green house is Fjernvarme Fyn, green star is location for technical installations related to ATES-

8.4.3 COP-value for pumping

The COP-p value for "ATES summer production" is the cooling or heating output in relation to the electricity consumed by the pump. The cooling or heating output can be calculated as:

$$W_{out} = q_m * c_p * \Delta T * \eta_{pump,total} = \dot{m} * 4185 \frac{J}{kg * °C} * (18°C - 9°C) * 50\% \quad (8.4)$$

Where q_m is the mass flow in kg/s, c_p is the specific heat capacity of the water (calculated based on the average temperature of the forward and return temperature of the DC network), ΔT is the temperature difference between the forward and return temperature of the DC network and $\eta_{pump,total}$ is the total efficiency of the pump. The total efficiency of the pump is set equal to 50 %, which is suggested as a typical value between 40 % and 60 % in (Enopsol ApS, 2009) and in this case the mean value is used.

The pump work equal the pressure loss in the heat exchanger and pump. The pump work can be calculated with the formula:[70]

$$W_{pump} = \frac{\Delta p * q_v}{\eta_{pump}} \quad (8.5)$$

Where the Δp is the pressure drop in $[Pa]$, q_v is the volume flow in $\left[\frac{m^3}{hr}\right]$ and η_{pump} is the pump efficiency. The pump efficiency is already included in $\eta_{pump,total}$, whereby η_{pump} is set equal to 1. The pressure loss is set equal to 3 bar as used in (Enopsol ApS, 2009). The volume flow is rewritten to an expression containing the mass flow instead by using the formula below

$$q_m = q_v * \rho = q_v * 1000 \frac{kg}{m^3} \quad (8.6)$$

Where q_v is the volume flow and ρ is the density set equal to 1000 $\frac{kg}{m^3}$. Combine Equation (8.5) and (8.6) give:

$$W_{pump} = \left(\frac{\dot{m}}{\rho}\right) \quad (8.7)$$

COP in this case is defined as:

$$\text{COP} = \frac{W_{out}}{W_{in}} = \frac{E_{out}}{E_{in}} \quad (8.8)$$

[70] (Andersen, et al., 2015, p. 288)

The COP-p value for pumping is thereby equal:

$$\text{COP-p} = \frac{\rho * c_p * \Delta T * \eta_{pump,total}}{\Delta p} = 62.7 \qquad (8.9)$$

The COP-pumping for delivering cooling is thereby 63. The heat delivering process include both the pumping process and the COP-h (Coefficient Of Performance – used for heat pump) value for the heat pump used to upgrade the temperature. The COP-pumping value seems reasonable in comparison to other projects:

- In a Grundfos and Bjerringbro DH ATES project the capacity of the wells is 1,850 kW and the COP value for cooling / pumping is 60.
- In an ATES project at Copenhagen Airport the COP-p value is 60.[71]

The electricity consumption by ATES summer production is thereby equal to:

$$W_{pump,ATES} = \frac{\text{Capacity of wells}}{COP_{pump}} = \frac{2432\ kW}{62.7} = 38.8\ kW \qquad (8.10)$$

The pump work from Equation (**8.10**) is inserted as the pump work in the ATES component in energyPRO. The total capacity of the three dipoles are inserted as the cooling output. The updated "ATES summer production" is shown in the Figure 8.4.

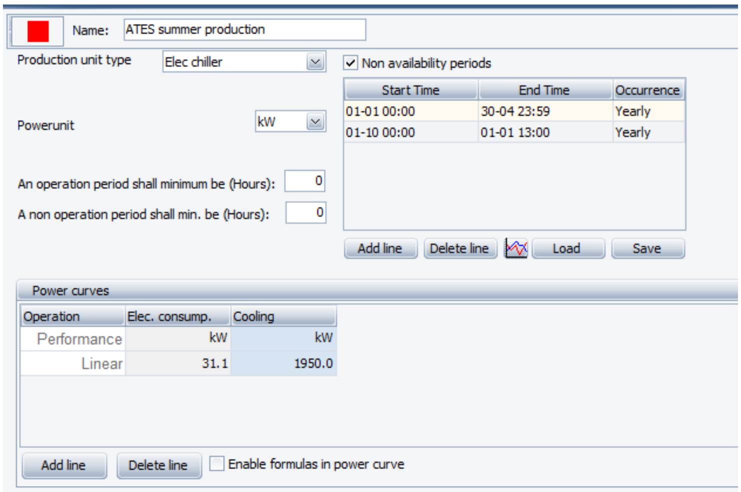

Figure 8.4 Configuration of "ATES summer production". This component only simulates the cooling production period of the ATES. The electricity consumption is equal to the electricity used by the pump. The cooling production is equal to the total capacity of the wells. The ATES is configured to only produce cooling from the beginning of May to the end of September by using the "Non availability periods" in energyPRO.

8.4.4 COP-value for heat pump

In the winter season from December to April, water from ATES is pumped from the hot well to the DH transmission line. As the temperature in the well is maximum 18 ℃, a heat pump is required to upgrade the temperature to DH temperature of 78℃.

The COP-h value for the heat pump is calculated by CoolPack (located in Appendix 15.1 C12 and 15.1 C13).[72] The Condensing temperature for the heat pump is the DH forward temperature which is assumed to equal 78 ℃ based on conversation with Fjernvarme Fyn.[73] The evaporating temperature is the temperature of the water pumped up from the aquifer. The temperature will decrease from the stored temperature of 18 ℃ at the summer to a lower temperature in the winter which is assumed to be 16 ℃. When the hot storage is used, cold water is pumped into the wells, whereby the temperature fall until the

[71] (Copenhagen Airport (CPH), 2017)

[72] The program is free to download at http://www.ipu.dk/Indhold/koele-og-energiteknik/CoolPack.aspx.

[73] (Andersen (Fjernvarme Fyn), 2017)

natural temperature of 9 ℃ is reached. To simplify the energyPRO-model the average temperature of the evaporator will be used for the COP-h.[74] An isothermal efficiency of 85 % is assumed, which seems reasonable cf. (Cengel & Boles, 2016, p. 625). Given the large temperature difference between the evaporator and condenser a Two-Stage Cascade Refrigeration Cycle is chosen to increase the COP-h value.

The Two-Stage Cascade Refrigeration Cycle for the condenser temperature of 78 ℃ and an evaporator temperature of 18 ℃ is shown in the figure below.

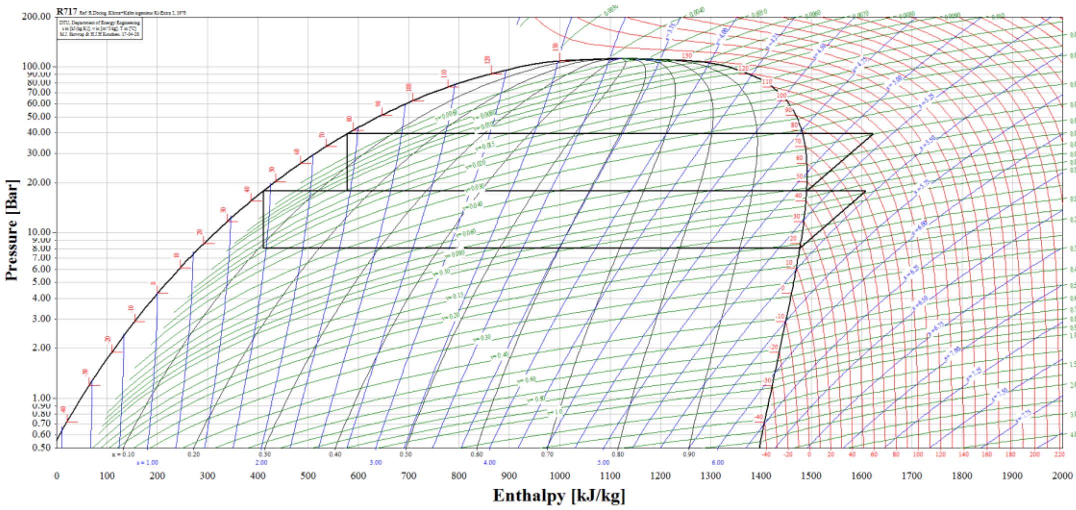

Figure 8.5 Log(P),h-plot of the heat pump used in relation to the ATES solution to upgrade the heat to DH temperature. This diagram is based on a condenser temperature of 78 ℃ and an evaporator temperature of 16 ℃. The Fluid used is R717 (NH_3, ammonia). The COP-h value for the temperature is set to 3.125. Larger figure in Appendix 15.1 C12 and 15.1 C13.

The COP-h value for the two-temperature set is shown below:

Condensing temperature [℃]	Evaporating temperature [℃]	COP-heating value [-]
78	16 (start of winter mode period)	3.35
78	9 (end of winter mode period)	2.90
Average		**3.125**

Table 8.3 COP-h value for different evaporating temperatures. The average COP-h of 3.125 will be used in the DC energyPRO-model for the heat pump used to upgrade the ATES hot water to DH forward temperature. Results from CoolPack – results is in Appendix 15.1 C12 and 15.1 C13.

8.4.5 Heat sales

The heat produced as a by-product of the cooling production needs to be used within the next cooling season as thermal balance in the aquifer is required. The heat by-product is 1:1 with the cooling production. The heat loss in the aquifer varies depending on the geological condition, but a reasonable heat loss in an aquifer is 15-25 % cf. (Enopsol ApS, 2009, p. 11) and in this case, it is assumed to equal 20 %. The heat sold to Fjernvarme Fyn is thereby:[75]

$$Q_{heat} = 1950kW * 80\% = \frac{1560kW}{1950kW \text{ cooling produced}} \quad (8.11)$$

[74] The temperature fall dependents on the cooling pump down to the hot wells and only a little bit of the time. This is very advance to implement in energyPRO.

[75] Defined in energyPRO-model 2 (Located in Appendix 15.1 A29) in the folder: Economy > Revenues > Heat soldt to Fjernvarme Fyn.

9. ECONOMY INPUTS

9.1 Operational cost

Table 9.1 Show an overview of the different tariffs when buying electricity. Electricity used by a company is considered process electricity unless it is used to space heating, domestic hot water or comfort cooling cf. (PwC, 2017, p. 13). Notice that comfort cooling does not include deep freezers or cooling of server facilities or similar cf. (PwC, 2017, p. 14). Table 9.1 will be used for the calculation electricity costs for the reference situation. It will also be used for the DC solution, but in some cases the electricity tax is based on process cooling independent of the cooling usage as described in Table 9.2.

Cost	Price [DKK / MWh electricity]	Remarks
Electricity tax[76]	- 910 + 505 (if comfort cooling) + 906 (if process cooling)	In some cases, the electricity tax perceived as "process cooling" independent of the usage. In this case it is mentioned in the report.
Energinet.dk grid tariff[77]	- 59	Based on the assumption, that all the customers have an electricity connection below 132/150 kV, which is reasonable cf. Appendix 15.9. If customer have their own 132/150 kV transformers the price is 57 DKK/MWh.
Energinet.dk system tariff[78]	- 24	
Distribution tariff	- 93.8	The tariff is based on the tariff type: "Net Tariff B-low with one transformer station", which is the typical setup for the cooling demand companies included in this project cf. Appendix 15.9.
PSO (Public Service obligation)	0	The PSO is completely abolished in year 2021. The simulation is based on year 2022, where the DC construction is completed. The PSO value is then set to zero.[79]
Total electricity tax	**- 581.8 – spot price (if comfort cooling)** **- 170.8 – spot price (if process cooling**	In some cases, the electricity tax is perceived as "process cooling" independent of the usage in this such case it will be mentioned in the report.

Table 9.1 Overview of tariff for buying electricity in 2017 prices.

[76] (PwC, 2017, p. 53) and (PwC, 2017, pp. 58-59)
[77] (Energinet.dk, 2017)
[78] (Energinet.dk, 2017)
[79] (Energi-, Forsygnings- og Klimaministeriet, 2016, p. 2)

The Table below lists the operational revenue and costs for using the different production units in the DC solution.

Cost and revenues	Price	Remarks
Electrical chiller		
Electricity incl. taxes	- 581.8 – spot price [DKK/MWh electricity] (if comfort cooling) - 170.8 – spot price [DKK/MWh electricity] (if process cooling)	See Table 9.1 for calculation of price.
ATES – summer production (pump work)		
Electricity incl. taxes	- 170.8 – spot price [DKK/MWh electricity]	The electricity tax is compensated as process cooling. This is independent of whether it is used as comfort or process cooling at the customer cf. conversation with PwC – located in Appendix 15.14. See Table 9.1 for calculation of price of electricity price incl. electricity tax based on process cooling.
ATES – winter production (pump work and usage of heat pump)		
Electricity incl. taxes for ATES pump work	- 170.8 – spot price [DKK/MWh electricity]	The electricity tax is compensated as process cooling. This is independent on whether it is used as comfort or process cooling at the cf. conversation with PwC – located in Appendix 15.14. See Table 9.1 for calculation of price.
Electricity incl. taxes for Heat pump	- 505 – spot price [DKK/MWh electricity]	The electricity purchased is taxed with compensation equal to space heating / comfort cooling cf. Appendix 15.8. This has been verified through a telephone conversation with Skat.[80] See Table 9.1 for calculation of price.
Heat sold to Fjernvarme Fyn	+ 298 [DKK/MWh heat]	This price is negotiated in collaboration with Fjernvarme Fyn.[81]
Excess heat tax	- 182.52 DKK/MWh heat, but no higher than 33 % of remuneration	The return heat is a product heated at the customer facility and as such does the COP 3 rule for a heat pump not apply cf. Skat.[82] See section 12.5 for more details.

[80] (Nielsen (Skat), 2017)
[81] (Andersen (Fjernvarme Fyn AS), 2017)
[82] (Nielsen (Skat), 2017)

Absorption chiller and adsorption chiller		
Electricity incl. taxes for ATES pump work	- 581.8 – spot price [DKK/MWh electricity] (if comfort cooling) - 170.8 – spot price [DKK/MWh electricity] (if process cooling)	The electricity tax is compensated depending on the usage (comfort cooling or process cooling) cf. telephone conversation with Skat.[83] See Table 9.1 for calculation of price.
Heat purchased from Fjernvarme Fyn	-100 [DKK/MWh heat] (Summer price)	This price is negotiated in collaboration with Fjernvarme Fyn.[84] Please notice that this price is only for the summer production, where the heat is produced on the waste incineration plant and thereby inexpensive.

Table 9.2 Operational cost and revenue depending of production units. Cost indicated with a minus sign and revenue is indicated with a plus sign. In 2017 prices.

The O&M cost for the electrical chillers and free coolers in the reference is assumed to half the cost of the O&M cost of the electrical chillers used in the DC solutions for each location.

The yearly administration costs are difficult to quantify and the costs are assumed unchanged from the reference to the DC solution.

Variable O&M costs are not considered for ATES and the electrical chiller because the value is unknown. Administration costs and labour costs are set to be unchanged in the DC solution in comparison with the existing solution.

Fjernvarme Fyn have offered cheap heat at 100 DKK/MWh to be used by the absorption chiller and adsorption chiller.[85] The offer is valid in the summer period only.

9.1.1 Projection of spot price

The electricity price is based on 2016 DK1 data for simulation of the dynamics of the electricity price.[86] The electricity price projections are made by the Danish transmission system owner (Energinet.dk) for the period of year 2022 to 2040.[87] The electricity price used in year 2041 is extrapolated based on the projections from Energinet.dk. The projection of the spot price is visualised in Figure 9.1.

[83] (Nielsen (Skat), 2017)
[84] (Andersen (Fjernvarme Fyn AS), 2017)
[85] (Andersen (Fjernvarme Fyn AS), 2017)
[86] The DK1 2016 electricity price is placed in Appendix 15.1 C7.
[87] (Energinet.dk, 2016, p. 45)

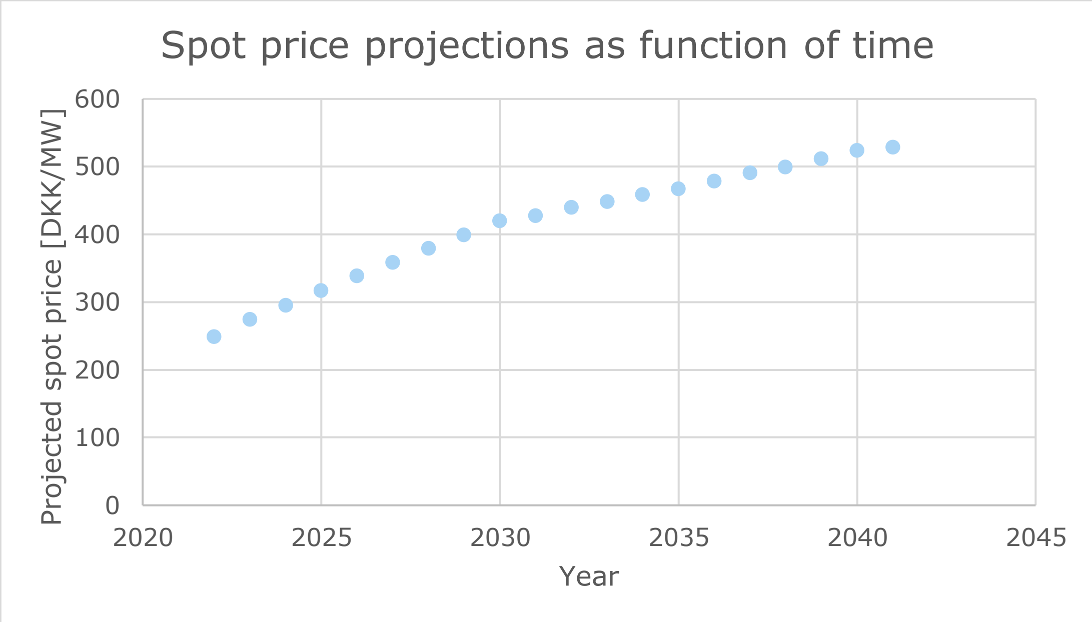

Figure 9.1 Projection of spot price in DKK/MW electricity.

9.1.2 Pump work

The pump work is calculated to equal:

Case	Pump work [kW]	Used pipe
Primary target group	7.1	DN 300
Secondary target group	7.8	DN 400

Table 9.3 Pump work used in calculation of the pump operational cost

The calculation is described in Appendix 15.22.

9.2 Investment costs[88]

9.2.1 Electrical chiller

Johnson Control have delivered an offer for the electrical chiller used in the DC. The offer is placed in Appendix 15.10 and Appendix 15.11. The expected lifetime for the chiller is about 30 years. The economical figures for the offer is shown in Table 9.4.

Cost	Price [DKK]
Yearly	
O&M	100,000
Lump sum	
Basic price[89]	15 million **if** above 6 MW 6 million **if** below 6 MW
Per electrical chillers	6 million / 2023.6 kW electrical chiller

Table 9.4 Offer on electrical chillers from Johnson Control

It should be noted that the offer price given by Johnson Control maybe is too expensive.[90]

[88] The conversion factor used to convert from US dollars to DKK is 7.01 and to conversion factor used to convert from euro to DKK is 7.44.

[89] Only the basis price for 2 MW and 10 MW is received.

[90] The two 750 kW electrical chillers and installation for the system at IKEA is 5.6 million DKK cf. Appendix 15.7. By linearly expend this value to a 2 MW solution give 7.5 million DKK.

9.2.2 Aquifer Thermal Energy Storage

The capacity for each dipole is set to 650 kW cf. section 8.4.2. The investment costs for ATES is estimated below and depends on the number of dipoles.

Cost	Price [DKK]
Groundwater system	4 million DKK per dipole[91]
Heat pump	2000 DKK/kW.[92]
Total lump sum	**5.3 million (for 1 dipole)** **10.6 million (for 2 dipole)** **15.9 million (for 3 dipole)**

Table 9.5 Investment cost for ATES

All ATES-system are subject to impact on the environment (EIA) screening duty cf. appendix 2 point 2c in the act on assessment of certain public and private installations EIA pursuant to the planning act.[93] However, ENOPSOL have never experienced any EIA obligation in all the projects they have contributed with.[94]

9.2.3 Absorption chiller

Cost	Price [DKK]	Comments / calculation method
Yearly		
O&M	37,200	Cf. Appendix 15.5.
Refilling the lithium bromide corrosion inhibitor	1,860	Cf. Appendix 15.5.
Total yearly cost	**39,060**	
Lump sum		
If 1 MW absorption chiller	0.93 million	Cf. Appendix 15.6 / 15.1 B1.
If 2 MW absorption chiller	1.637 million	Cf. Appendix 15.1 B2.
If 5 MW absorption chiller	3.869 million	Cf. Appendix 15.1 B3.

Table 9.6 Investment cost and yearly O&M for absorption chiller

The expected lifetime is around 20 years cf. Appendix 15.5.

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[91] Suggested value by Lars from Ingeniør huse

[92] (Enopsol ApS, 2009, pp. 11-12).

[93] Can be access though (Bekendtgørelse om vurdering af visse offentlige og private anlægs virkning på miljøet (VVM) i medfør af lov om planlægning, 2017)

[94] (Niemi (ENOPSOL), 2017). The price is estimated by Ramboll to be around 0.5-1 million DKK in case of EIA duty cf. Appendix 15.15.

9.2.4 Adsorption chiller

The lifetime for the adsorption chiller is around 25-30 years cf. Appendix 15.4 page 6. The investment costs and O&M cost for the Bry-Air F-330 adsorption chiller is listed in Table 9.7.

Cost	Price [DKK]	Comments / calculation method
Yearly		
Fixed maintenance cost	56,080	Cf. mail from Bry-air in Appendix 15.3.
Total yearly cost	**56,080**	Heat cost and electricity consumption will be calculated by energyPRO
Lump sum		
Bry-Air F-330	2.804 million	Cf. section 6 in the offer, Appendix 15.4 / Appendix 15.1 B4.
Supervision of Erection & Commissioning	21,030	Cf. section 6 in the offer, Appendix 15.4 / Appendix 15.1 B4.
Total lump sum	**2.825 million**	

Table 9.7 Lump sum and yearly cost for Bry-Air F-330 adsorption Chiller. All costs are based on the offer given by Bry-Air, which is placed in Appendix 15.4 / Appendix 15.1 B4 and a mail conversation with Bry-air placed in Appendix 15.5.

9.2.5 District cooling network

The DC network is set to 7200 DKK/m canal as suggested by Fjernvarme Fyn (See Appendix 15.8). The lengths of the DC pipes are calculated by using Google Maps and is indicated in the Excel-sheets for the individual calculations.

9.2.6 Other investments

The cold storage is assumed to have an investment price of 2000 DKK/m^3 up to 1000 m^3 and thereafter 1500 DKK/m^3 which is suggested by Fjernvarme Fyn (See Appendix 15.8).

The project planning costs are assumed to be equal to 15 % of the total investment costs, as suggested by Fjernvarme Fyn.[95]

[95] (Andersen (Fjernvarme Fyn AS), 2017)

9.3 Cost/benefit-analysis

DC is exposed to competition and it is difficult to receive the used Minimum Attractive Rate of Return (MARR) for an existing DC solution. The MARR is instead set to 4 % and an evaluation period of 20 years with reference to (Rambøll and Aalborg Univiersity, 2016, p. 44).

The MARR is maybe considered low in comparison with the MARR used in the DH sector. The risk is lower in the DC sector in comparison with combined heat and power production.[96] Some arguments for the lower risks:

- The electricity market will not provide an investment contribution to expensive production units such as a gas engine. On the other hand, the DC costumer can either invest in their own production units or invest in DC.
- "The gas combine heat and power is captured between electricity and gas prices (which We [Ramboll, editor of this report] know may be risky). While the price level for electricity for DH and individual refrigeration is the same except that DC can better takes advantage of price fluctuations by establishing storage".[97]

All the business economics will be calculated such that the Net Present Value (NPV)[98] with 4 % discount rate over a 20-year period equals zero. and thereby the maximum possible savings for the customer is calculated. If the cooling is sold to a higher price it will improve the DC economy, but is not necessary to be an attractive investment.

The price will be set such that all customers pay the same basis price and additional cost because of e.g. comfort cooling instead of process cooling is addressed to those customers who incur the additional cost.

No reinvestment in any of the DC production unit is necessary because the lifespan of all the production units is above the evaluation period of the DC project (20 years).

[96] (Rambøll and Aalborg Univiersity, 2016, p. 67)

[97] (Rambøll and Aalborg Univiersity, 2016, p. 67)

[98] "The net present value (NPV) of an investment project is the difference between the project's present value (PV), the value of a portfolio of financial instruments that track the project's future cash flows, and the cost of implementing the project. Projects that create value are those whose PVs exceed their costs, and thus represent situations where a future cash flow pattern can be produced more cheaply, internally, within the firm, than externally, by investing in financial assets. These are called positive NPV investments." (Hillier, Grinblatt, & Sheridan Titman, 2012, p. 312). More details in the abbreviations section.

10. VERIFICATION OF MODEL

10.1 Reference energyPRO model

John Christensen, Section manager, technical department in Bilka have told that the Bilka pay around 1 DKK/kWh electricity used.[99] The total electricity price from energyPRO is 194,615 DKK and the electricity used by the two electrical chillers is 192.9 MWh cf. Appendix 15.1 A27. The electricity price is thereby 1.009 DKK/kWh and the electricity price is thereby very close to the told electricity price.

The production curve is analysed and seems reasonable. E.g. In Figure 10.1 is SDU production curve seen. The free cooler should only produce, when the outdoor temperature is below 10 ℃ cf. section 15.2.5 - University of Southern Denmark (SDU), which is confirm by the production curve for the SDU site.

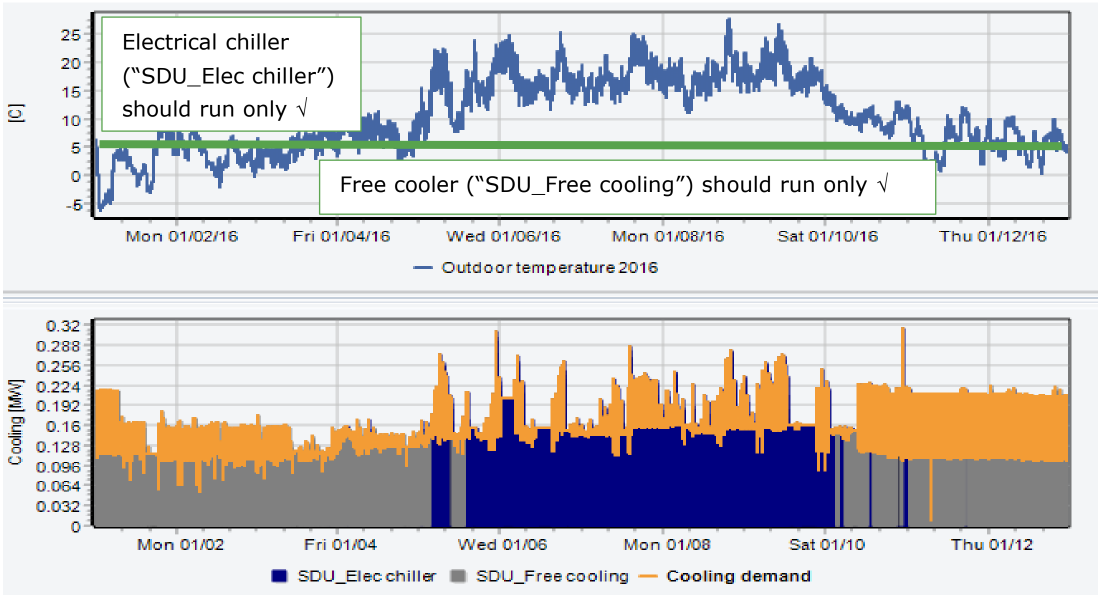


Figure 10.1 The top graph show the outdoor temperature in 2016 as function the year. The lowest graph show the production as function of the year. The combination of the two graphs show that the free cooler at SDU ("SDU_Free cooling") only produce when the temperature is below 10 ℃ as defined in the function for the free cooler.

A good validation of the model is to compared the cooling production with real cooling production data from the same year, but this data is not available for any of the consumers.

10.2 DC energyPRO model

The energyPRO-model 2 is verified by testing the model by changing different parameters and then ensure that the results are reasonable.

An example of such verification is the figure below. The electrical chiller is cheaper than the absorption chiller and adsorption chiller. The absorption chiller and adsorption chiller begin first to run when the capacity of the electrical chiller is exceeded as expected.

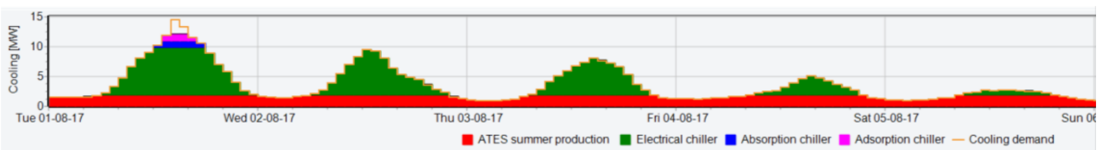


Figure 10.2 System is operated with a cold storage of 2 m³. The model has ATES, electrical chiller, absorption chiller and adsorption chiller available, where these technologies is sorted from cheapest to the most expensive production cost, where ATES is the cheapest.

[99] (Christensen (Bilka), 2017)

11. ECONOMIC RESULTS

11.1 Evaluation of technology potential

This section will identify the optimal production technology mix used for the DC solution. First is the potential of the absorption chiller and adsorption chiller is identified. Then the potential of the ATES solution is analysed.

11.1.1 Absorption chiller

Fjernvarme Fyn has agreed to provide heat at 100 DKK/MWh. The marginal cost for Fjernvarme Fyns production units shows, that the only unit which can provide heat at this price is the waste incineration plant.[100] The heat demand data in 2016 show that the heat is only available on the waste incineration plant in periods.[101] This indicates, that the absorption chiller is not ideal as a peak load plant because it is not certain that the heat is present when needed. It is relevant to analyse if the absorption chiller is feasible as an extra investment when the heat is available.

For analysing the potential of the absorption chiller, two simulations have been performed:

- One with 8 MW electrical chiller and 1950 kW ATES.[102]
- One with 8 MW electrical chiller, 1950 kW ATES and 1 MW absorption chiller.[103]

The analysis shows that the absorption chiller can save money in the operation, but due to the investment costs, it will decrease the total savings. It will not make sense to invest in an absorption chiller when the heat price is provided at 100 DKK/MWh. This is shown in the Figure 11.1. A positive value in the of the figure is equal to savings by investing in the 1 MW absorption chiller in addition to the electrical chiller. A negative value in the figure is equal to losses in savings by investing in the 1 MW absorption chiller in addition to the electrical chiller.

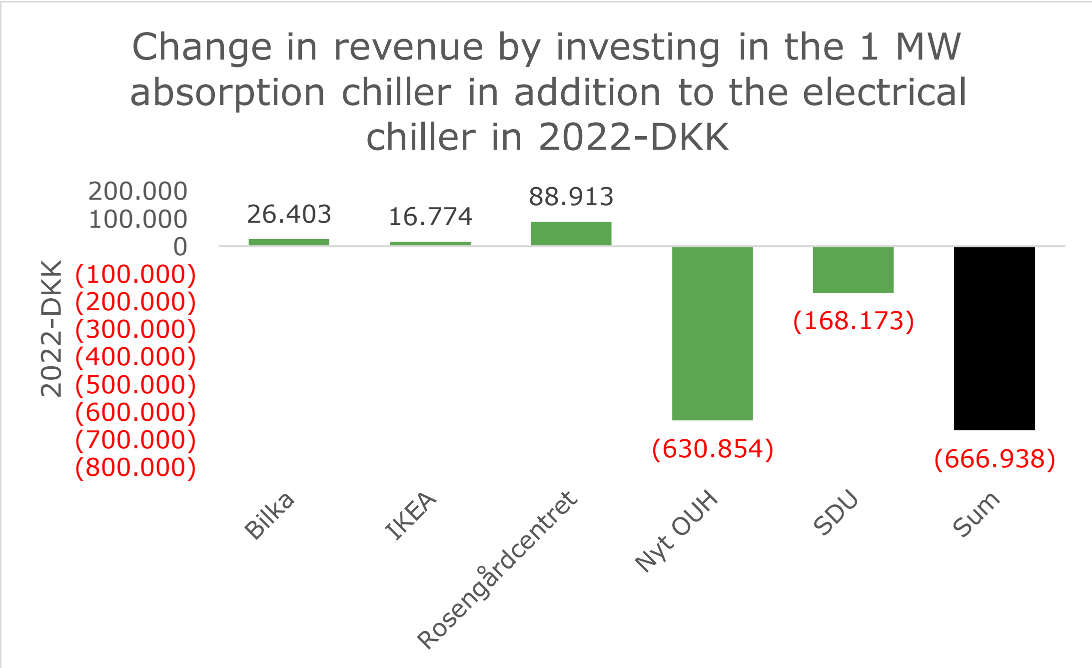


Figure 11.1 Change in revenue by investing in the 1 MW absorption chiller in addition to the electrical chiller in 2022-DKK. Figure from Appendix 15.1 A4, sheet: "DC results"

[100] Appendix 15.1 C15
[101] This is shown in Appendix 15.1 C16
[102] Based on energyPRO-file in Appendix 15.1 A29 and data processing in Appendix 15.1 A13
[103] Based on energyPRO-file in Appendix 15.1 A3 and data processing in Appendix 15.1 A4.

The reason that Bilka, IKEA and Rosengårdcentret saves money is due to savings in the electricity tax. Figure 11.2 show the effect on the cooling price.

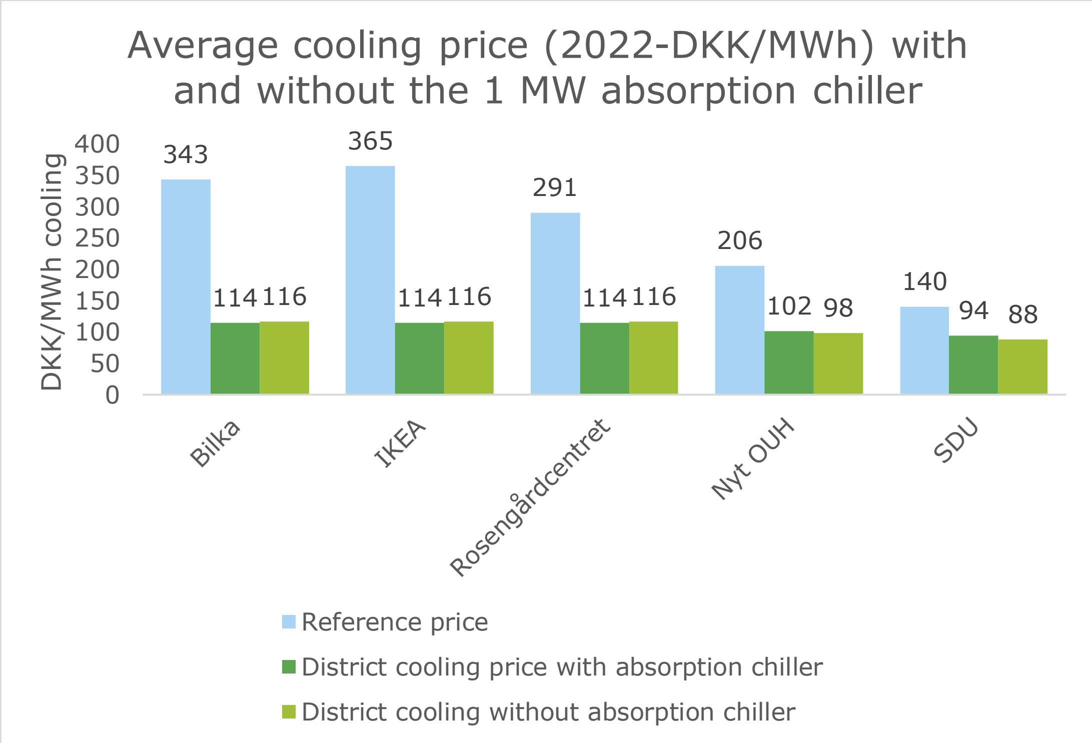


Figure 11.2 Change in cooling price by investing in 1 MW absorption chiller in addition to the 8 MW electrical chiller. Figure from Appendix 15.1 A3, sheet: "DC results".

11.1.2 Adsorption chiller

The adsorption chiller is more expensive to operate than the absorption chiller as the COP-a value is less for the adsorption chiller in comparison with the absorption chiller. Further, is the yearly O&M and investment costs higher. It does not make sense to choose an adsorption chiller instead of absorption chiller based on the given offers. It should be mentioned that the adsorption chiller is a relatively new technology. With further development, the adsorption technology may become more cost effective in the future.[104]

11.1.3 Aquifer Thermal Energy Storage

To analyse the potential of ATES, two simulations have been performed:

- One with 10 MW electrical chiller[105]
- One with 8 MW electrical chiller and 1950 kW ATES solution[106]

The change in the revenue is shown in Figure 11.3 with the 1950 kW ATES solution as the reference. A positive value in the figure is equal to savings by choosing the solution with 1950 kW ATES. A negative value in the figure is equal to loss by choosing the solution with 1950 kW ATES.

The figure shows that it is feasible for the DC company to invest in a 1950 kW ATES solution. The electricity used for producing the cooling on the ATES is defined as process electricity and it results in savings per unit electricity in comparison to comfort cooling. The reduction in the electricity tax will reduce the price for the customers in general, but because SDU use process cooling only, their price is increased.

[104] (Decentralized Energy, 2017)
[105] Based on energyPRO-file in Appendix 15.1 A41 and data processing in Appendix 15.1 A40.
[106] Based on energyPRO-file in Appendix 15.1 A29 and data processing in Appendix 15.1 A13

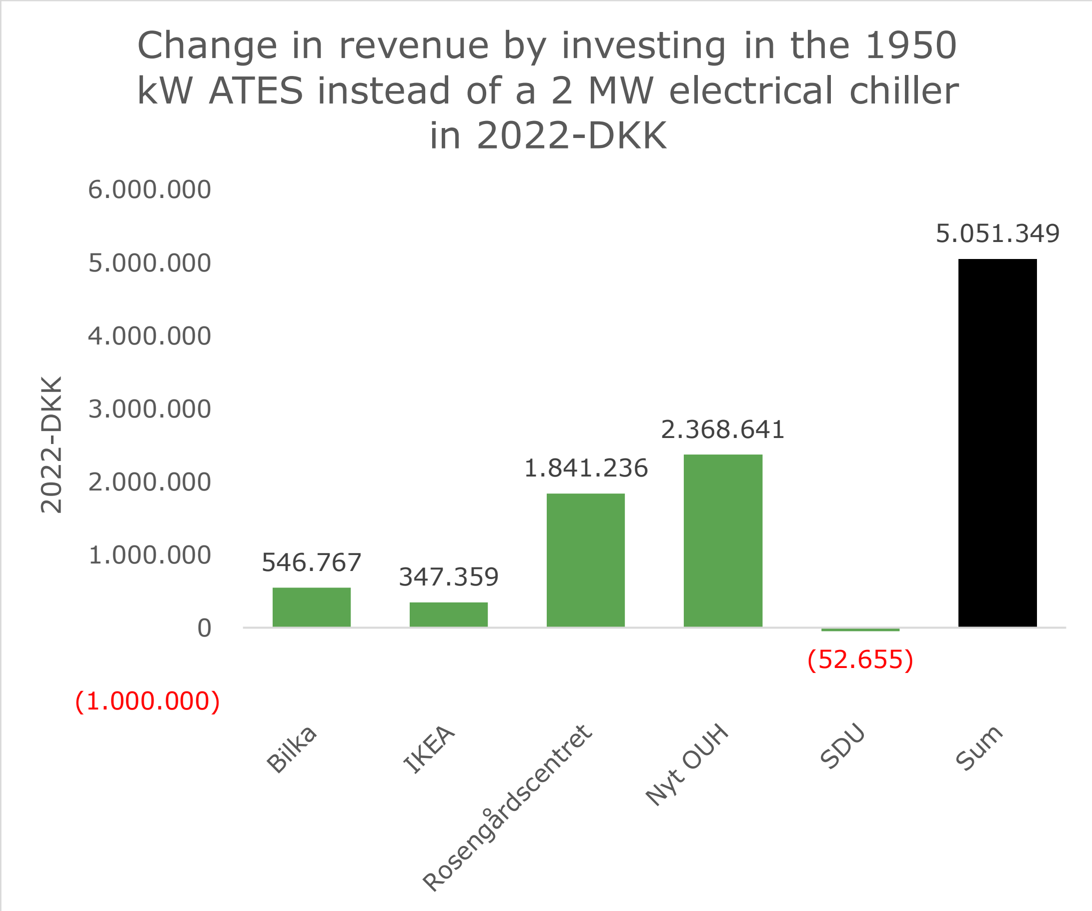


Figure 11.3 Change in revenue by investing in 1950 kW ATES in 2022-DKK price instead of a 2 MW electrical chiller. Figure from Appendix 15.1 A40.

The simulation shows that ATES is always prioritised, as a result of a high COP-p value of approximately 63. In comparison, the second best is the electric chiller combined with dry coolers, with a COP-c value of 17.5, when the outdoor temperature is below 10 ℃.

The business case is improved by selling the heat to Fjernvarme Fyn at a high price during the winter. The revenue by selling the heat is however reduced because of the excess heat tax. The revenue is reduced by 22 % in 2022 for selling the heat from the DC solution with both primary and secondary target group.[107] This excess heat tax will be discussed in more detail in section 12.5.

11.1.4 Suggested production mix for the DC company

The ATES solution should be used as a baseload plant due to the high COP-p value. Further, it is possible to sell heat to Fjernvarme Fyn. Fjernvarme Fyn can provide heat at 100 DKK/MW, but it is only available in periods. It is not feasible to have the absorption chiller and/or the adsorption chiller as an extra investment beside an electrical chiller. The savings in operation is not enough to compete with the electrical chiller and thereby will the electrical chiller be used as peak load plant.

The best production mix is settled by using ATES and electrical chiller in combination.

[107] Based on 1950 kW ATES (three dipoles), 4000 m3 cold storage, and 8 MW electrical chiller. The excess heat tax cost is equal to 346,794 DKK and the revenue by selling the heat to Fjernvarme Fyn is 1,545,427 based on the cash report in Appendix 15.1 A13 in sheet "District_cooling". The cashflow is based on the energyPRO-file Appendix 15.1 A29.

11.2 Reference (as is)

The current cooling price in 2022-DKK is shown in Figure 11.4 with and without fixed O&M for the electrical chiller.[108]

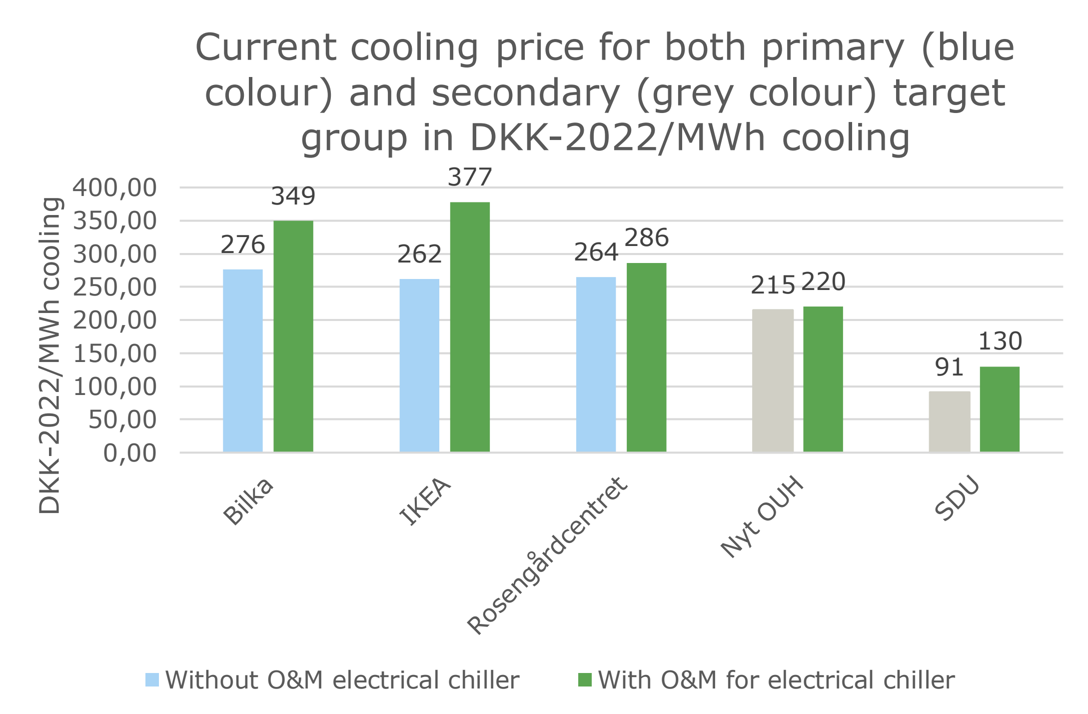


Figure 11.4 Current cooling price. Figure from Appendix 15.1 A12.

The reason that the cooling price is lower for SDU and Nyt OUH in comparison with the primary target group, is because the COP-c value for the dry cooler is higher than the COP-c value for the electrical chillers. Further, the COP-c value for the electrical chillers used at Nyt OUH is higher than for the primary target group. The electricity tax is also less expensive when the electricity is used as process cooling opposed to comfort cooling. Nyt OUH and SDU are the only customers which use process cooling. All electricity consumptions at SDU is based on process cooling. Parts of the electricity production at Nyt OUH is used for process cooling.

Rosengårdcentret has a cheaper cooling price than IKEA and Bilka as the cooling demand is higher, resulting in the fixed O&M for the electrical chillers being divided over a larger cooling demand.

The operational savings will never be able to pay back the investment costs in a DC solution on its own. This applies both when delivering cooling to the primary target group and when delivering cooling to both target groups.[109]

It is necessary for the DC customers to make a capital injection, assumed to be equal to the individual investment. This assumption will be discussed more in section 12.3. The individual cooling costs without DC is thereby set to include an investment in new individual production facilities expected to be in 2021, where Nyt OUH will be finished according to plan. The sensitivity analysis will consider the remaining lifetime of the existing production facilities.

[108] Based on the energyPRO-file in Appendix 15.1 A27, and data processing is in Appendix 15.1 A12.

[109] This is documented in Appendix 15.1 A12 (both primary and secondary target group) and in Appendix 15.1 A23 (primary target group only). The results is the Excel sheets is based on the two energyPRO-files in Appendix 15.1 A29 and Appendix 15.1 A36.

The individual cooling costs including the investment costs without DC is shown in Figure 11.5 based on energyPRO-model 1 (reference situation with both target groups).[110] As the spot price varies through the years, the average individual cooling price is shown in 2022 prices and is the average cooling price for a 20 year period. Prospectively the individual cooling price will refer to the individual cooling price with the investment cost included.

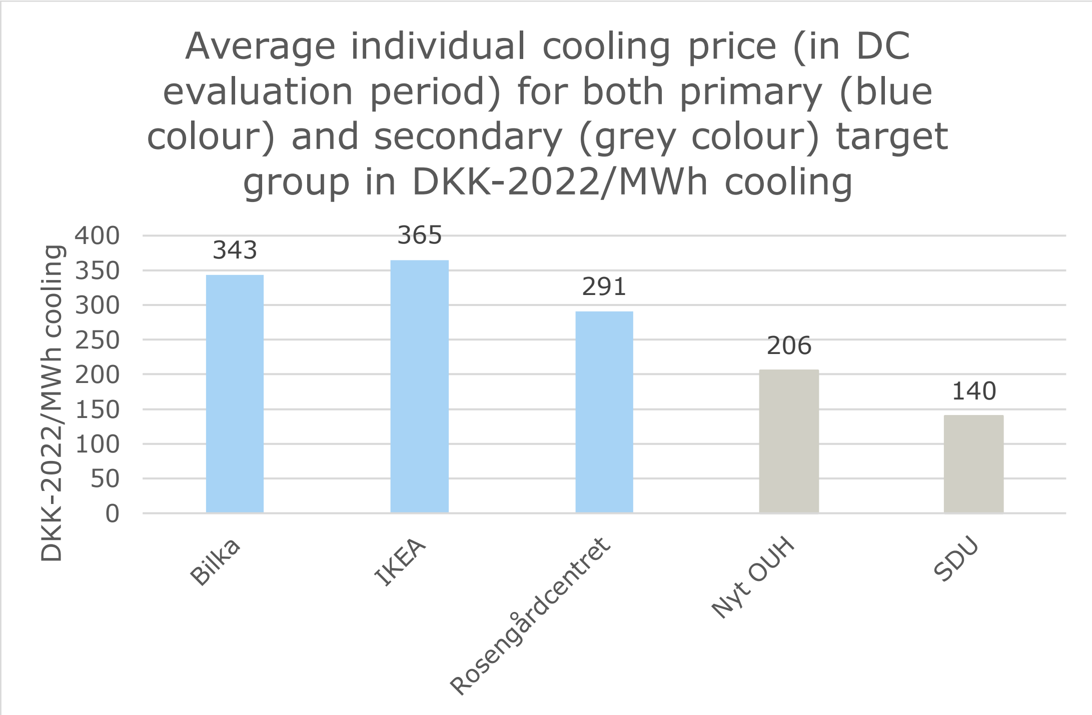


Figure 11.5 Show the individual cooling price without DC including investment costs in new individual production facilities in 2021. The graph is from Appendix 15.1 A12, Sheet: "Reference results - without OM".

11.3 District Cooling

This section will outline the production mix and show the yearly operation costs depending on the DC solution. Investigations on primary and secondary target group customers will be analysed. Afterwards, the economy by shifting to DC is presented for delivering DC to the primary target group and the secondary target group. This is done with reference to the individual solutions.

Calculations are based on implementation in year 2021. The results are independent of any strategy the customers may have with regards to re-investments in new individual cooling production units, based on lifetime. The consequence is that the cooling customers will not transfer to the DC solution at the same time. This situation is analysed in the sensitivity analysis.

11.3.1 Business case for the district cooling company focusing on the primary target group.

This section investigates the results if the primary target group invests in a DC solution in 2021. The results are based on the energyPRO-model 2 (DC with both primary and secondary target group) where the secondary target group is removed.[111]

[110] The energyPRO-file can be found in Appendix 15.1 A27 and Appendix 15.1 A12.

[111] The energyPRO-file can be found in Appendix 15.1 A36 and the data processing can be found in Appendix 15.1 A24.

The suggested production mix for the DC solution is:

- 1950 kW ATES (three dipoles)
- 5000 m^3 cold storage
- 2 MW electrical chiller

The yearly operational costs for the DC company is shown in Figure 11.6.

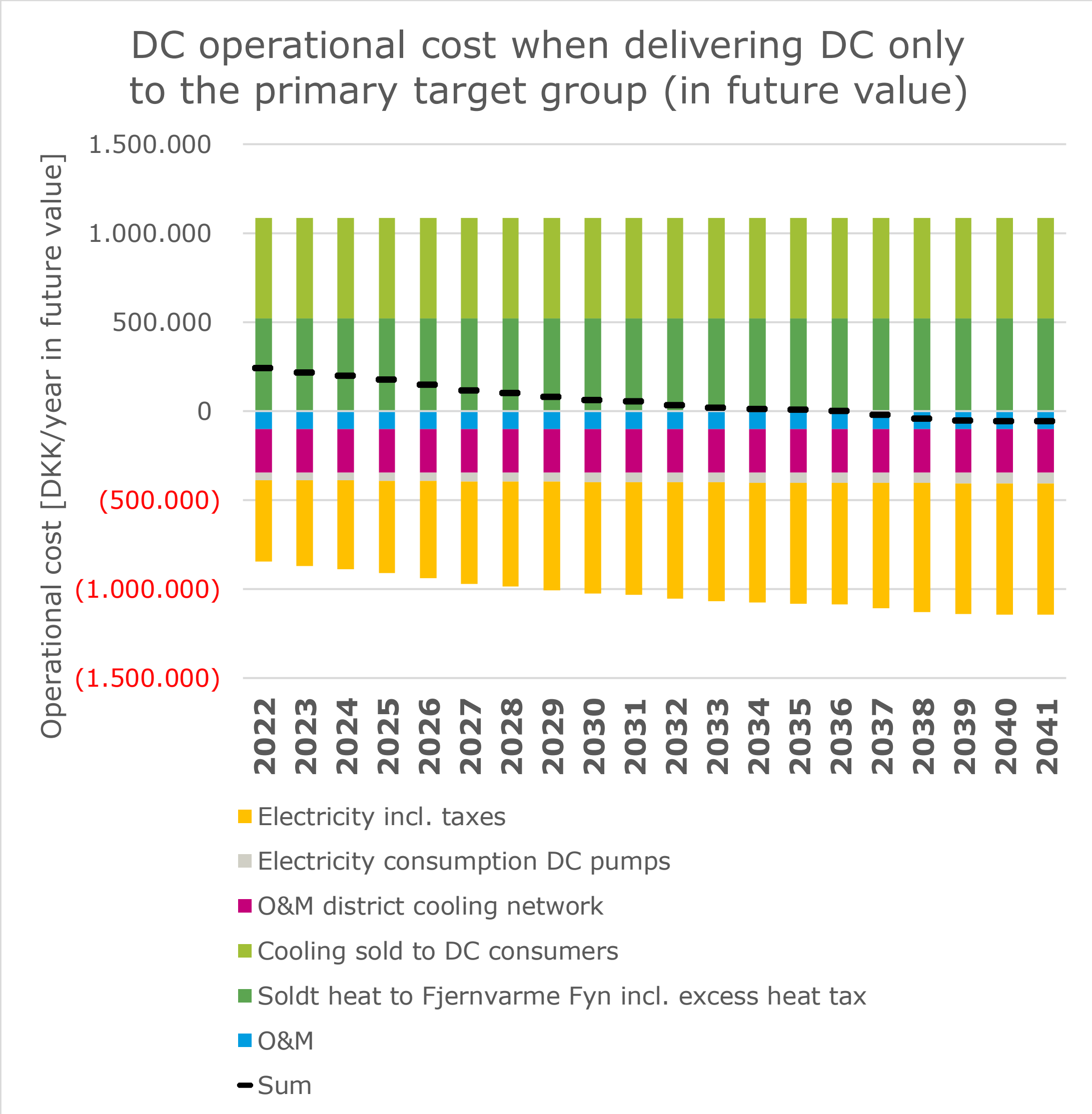


Figure 11.6 Show the operational costs for the DC company is separated in categories if the DC is delivering DC only to the primary target group. The graph is in future value. Figure from Appendix 15.1 A24, sheet: "DC results".

The operational costs are negative from year 2037. This can be avoided by increasing the cooling sales price. However, the goal is to calculate when the DC company's NPV is equal to zero, which provide a profit over the evaluation period of 20 year with a discount rate of 4 %.

The electricity costs increase due to the projected increase in the spot price as shown in Figure 9.1.

11.3.2 Business case for the district cooling company focusing on the primary and secondary target group.

This section investigates the results where the primary and secondary target group invests in a DC solution in 2021. The results are based on the energyPRO-model 2 (DC with both primary and secondary target group).[112]

The suggested production mix for the DC solution is:

- 1950 kW ATES (three dipoles)
- 4000 m^3 cold storage
- 8 MW electrical chiller

The yearly operational cost for the DC company is shown in the Figure 11.7.

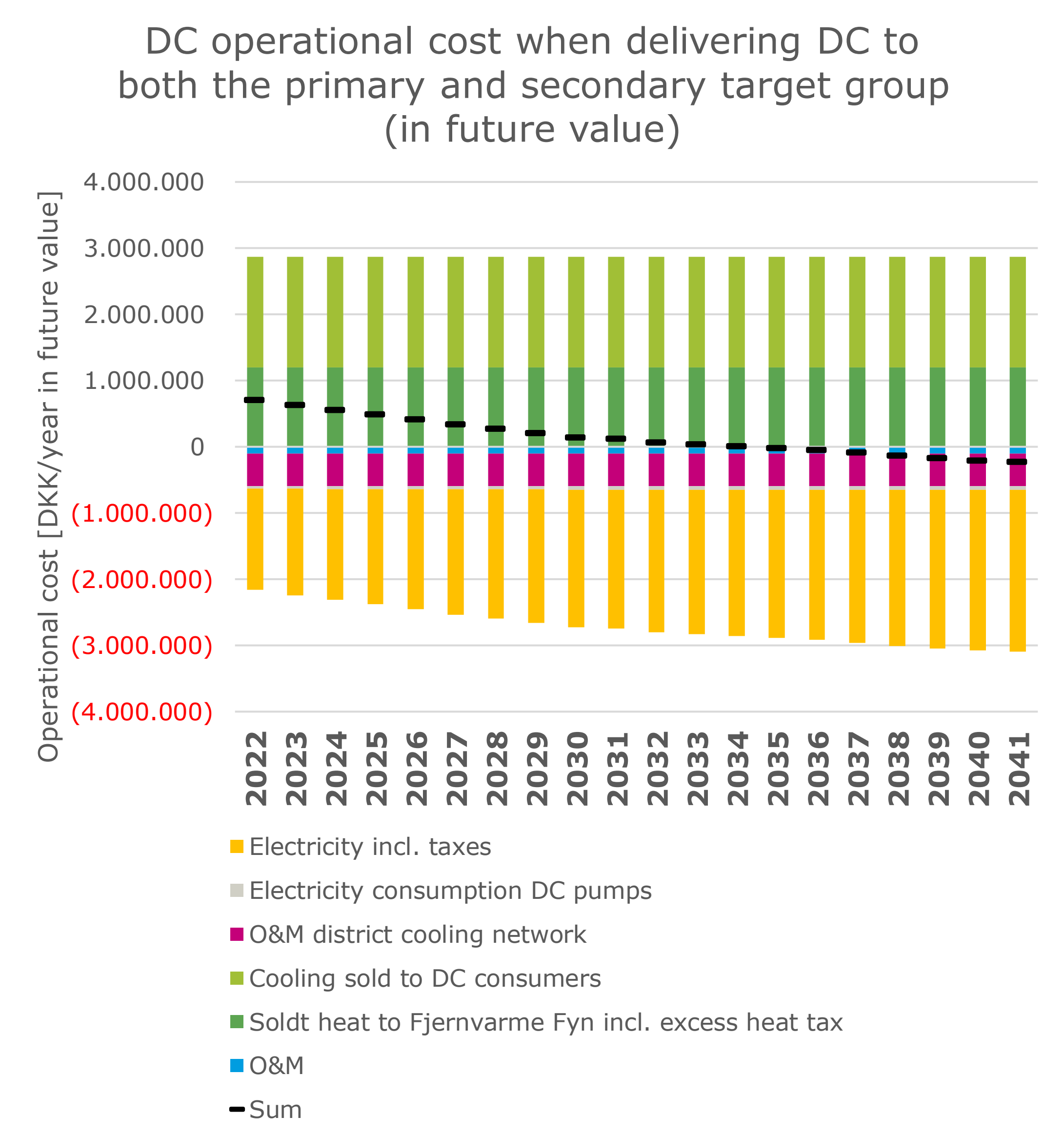


Figure 11.7 Show the operational cost for the DC company separated in categories if the DC company delivering DC to the primary and secondary target group. The graph is in future value. Figure from Appendix 15.1 A13, sheet: "DC results".

The results show the same trend as the results for the primary target group. From a DC company perspective, the increased investments to supply the secondary target group show a feasible business case. However, it cannot be concluded, if the customers find the cooling price attractive.

[112] The energyPRO-file can be found in Appendix 15.1 A29 and the data processing can be found in Appendix 15.1 A13.

11.3.3 Savings potential for the cooling customers

The unit cooling price for using DC in comparison with the individual solution is shown in the Figure below (Figure 11.8).[113]

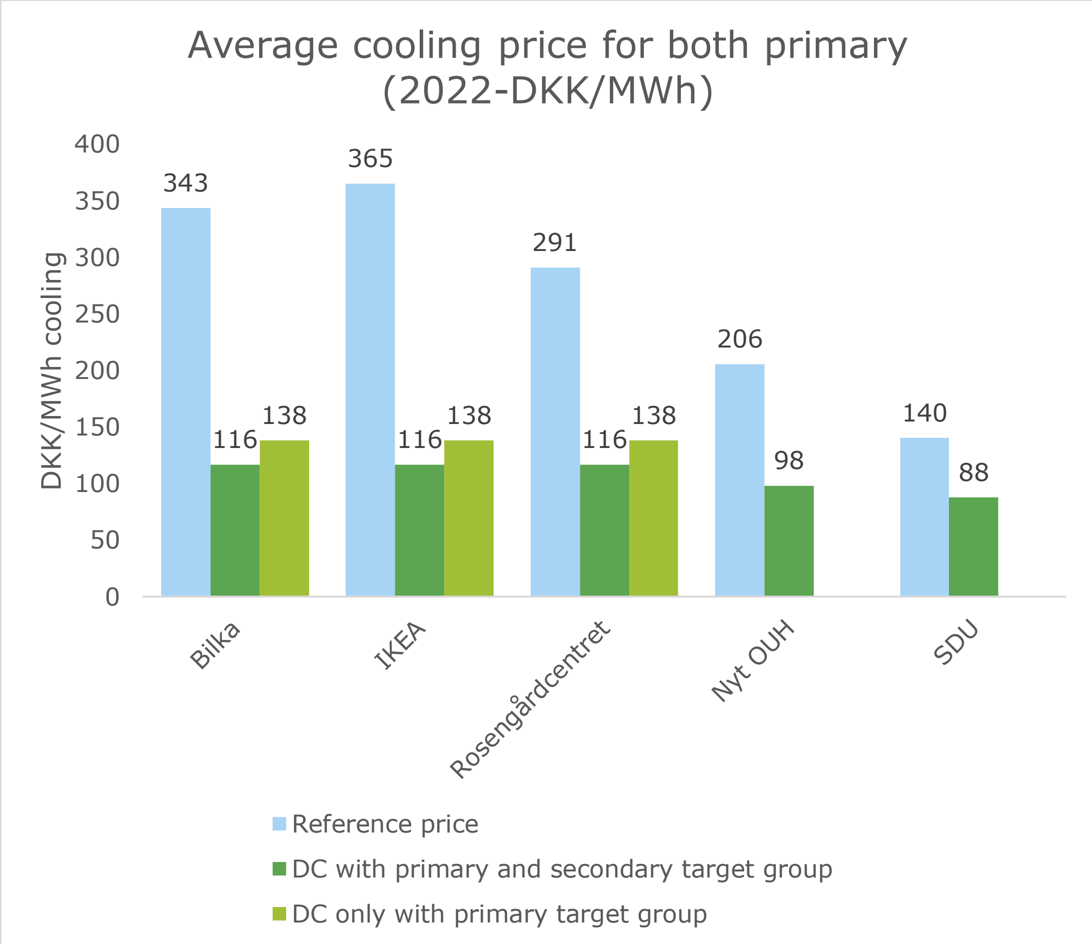
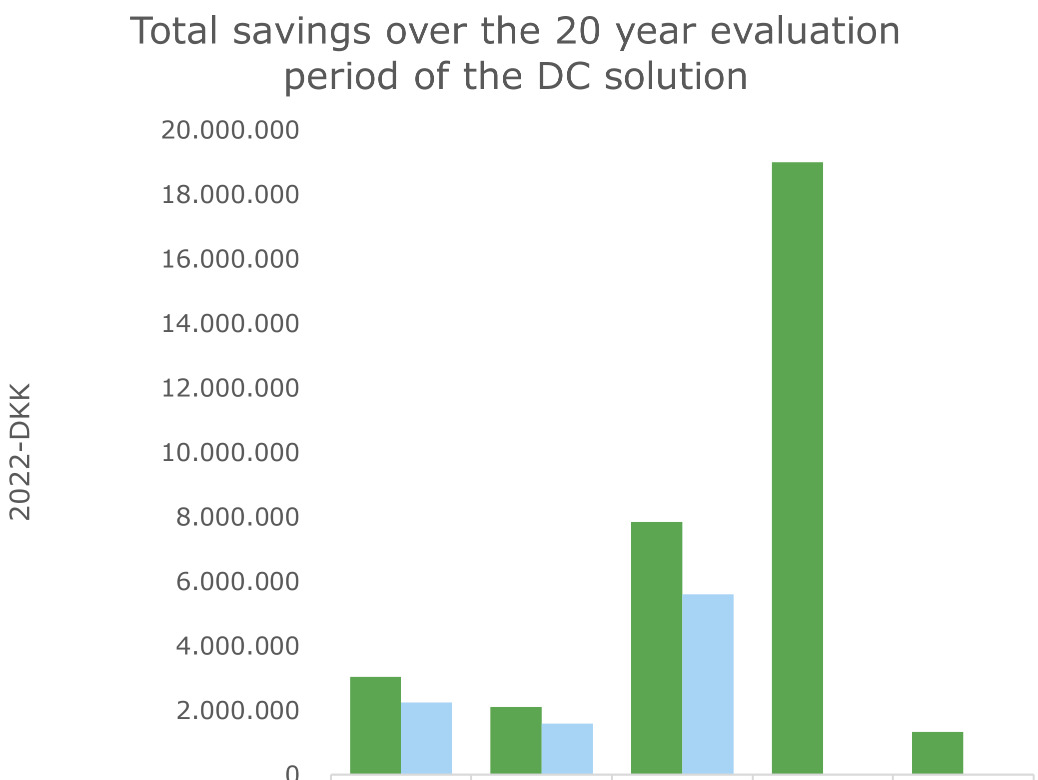


Figure 11.8 Average cooling price from year 2022 to 2041: Reference price for individual solution, with DC to the primary target group and with DC to both the primary and secondary target group. Figure from Appendix 15.1 A13, sheet: "DC results".

If the primary target group or the both target groups invests in DC solution in 2021, they will all the save money. The primary target group in particular will have savings given their use of comfort cooling. The ATES solution provides cooling with a high COP-a value, which decreases the impact of the electricity tax for comfort cooling.

Figure 11.3 show the total savings over the 20 year evaluation period of the DC solution, depending on whether the cooling is delivered to the primary target group or to both target groups. The savings for the secondary target group are attractive even if the they are not as pronounced as for the primary target group. The secondary group use process cooling which is not subject to a high electricity tax when produced on the electric chiller. The registered savings are the contribution of cooling from the ATES solution.

[113] The figure is based on the conditions described in section 11.3.1 and 11.3.2. The result is located in Appendix 15.1 A13, sheet: "DC results".



	Bilka	IKEA	Rosengårdcentret	Nyt OUH	SDU
DC with primary and secondary target group	3.028.975	2.108.405	7.835.033	19.003.811	1.315.817
DC with primary target group	2.243.695	1.578.887	5.589.144		

Figure 11.9 Total savings over the evaluation period of the DC solution. All customers save money by shifting to DC instead for individual cooling solutions. The savings for the primary target group increases when DC to the secondary target group is included. Figure from Appendix 15.1 A13, sheet: "DC results".

The savings for the primary target group increase when delivering DC to the secondary target group as well. This is caused by extra production on the ATES solution and thereby an increase of heat sales to Fjernvarme Fyn. Economy of scale and shared investment costs will also contribute to increased savings.

Even if Nyt OUH savings per MWh cooling is less than the primary target group the total savings is largest for Nyt OUH because of their large cooling demand.

12. DISCUSSION

This section will investigate the business case and provide some perspective to what can have an impact on the business case. The investigation will clarify if it makes sense to deliver DC and what risks apply. The discussion begins with some remarks to the calculations in section 11.3.3 of the savings by changing to DC. The business case is then challenged through different scenarios:

- A 20 % reduction of all the customers cooling demand
- Different possible MARR for the DC company
- Variations in the pipe and digging price
- Variation in the excess heat tax
- Customers transition time from individual solution to the DC solution

Finally, considerations on the role of the absorption chillers potential are made.

12.1 Discussion of results in general

There are several options to provide a better business case for the cooling costumers than calculated in this project. This include:

- The heat pump in energyPRO-model 2 (the DC solution) use the average electricity price when upgrading the heat from ATES to DH temperature. The aquifer is one large heat storage and the heat pump needs to be configured with a strategy to produce when the spot price is low, which will reduce the electricity cost.
- Calculations are based on standard offers from the suppliers. A general negotiation or active sourcing strategy will improve the business case for the DC company
- The ATES capacity is set to a lower capacity than the technical capacity of the wells to avoid the risk of thermal contamination between the aquifers. It is possible to operate with a higher capacity of the wells if the geology supports it.
- The ATES solution and more efficient operation of the electrical chiller results in a CO_2-reduction. This supports a better CO_2-accouting and improves the Corporate Social Responsibility (CSR) of the companies.
- Release of floor space at the customer site, where the current production units are located.

Aspects which challenge the business case of the proposed solution:

- Additional costs in relation to the location of the cooling production facilities at Fjernvarme Fyn or near IKEA is not included
- The ATES production units are placed on Rosengårdcentret property. This requires that Rosengårdcentret is compensated for the usage of the area or the used area is expropriated.

12.2 Cooling demand

Figure 12.1 shows the total savings over the 20 year evaluation period of the DC solution for the customers where their cooling demand is reduced by 20 %. The reduction is compared with the reference cooling demand estimated in section 6.[114] An increase in the customers cooling demand is not investigated because the business case is already feasible. The investment costs are kept constant for both the DC company and the DC customers to simplify the calculations. Figure 12.1 shows that the business case is still feasible for all customers and the DC company if the cooling demand decreases with 20 %.

[114] Based on the energyPRO-file in Appendix 15.1 A30. The data processing can be found in Appendix 15.1 A5.

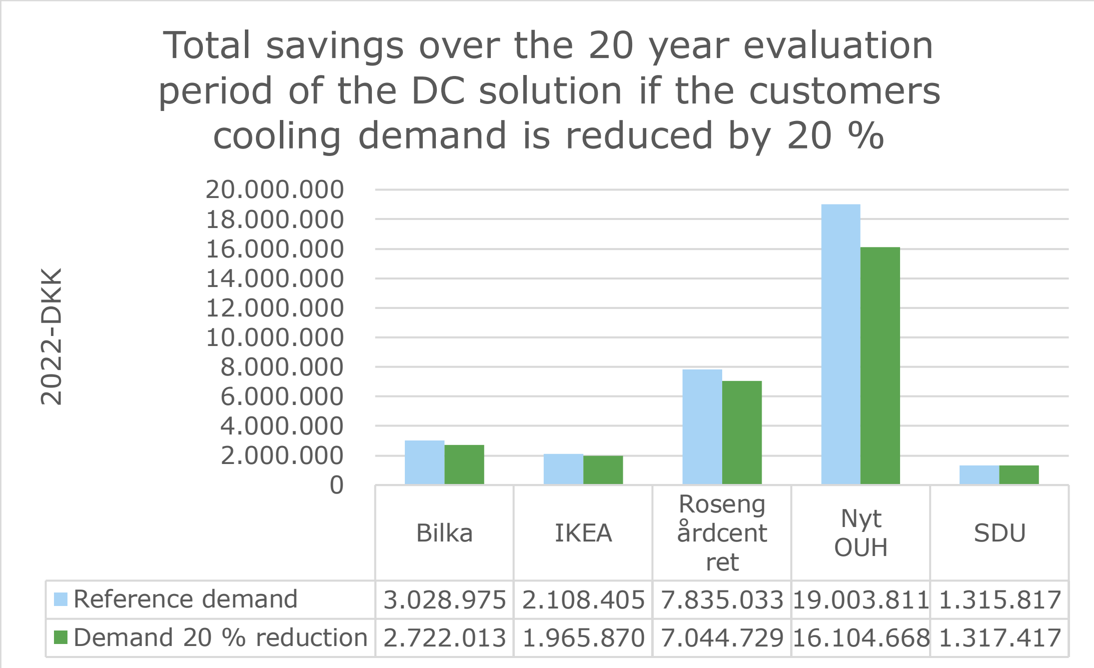


Figure 12.1 Total savings if all cooling demand is reduced by 20 % in comparison with the reference demand calculated in section 6. Figure from Appendix 15.1 A5.

12.3 MARR for district cooling company

The access to financial figures in relation to DC is limited, as DC is exposed to competition. It is difficult to identify a typical MARR for a DC project. The internal rate of return (IRR) is shown in Table 12.1. The calculation is based on the requirements, that the DC customer will have at least 0 % savings by migrating to DC.[115]

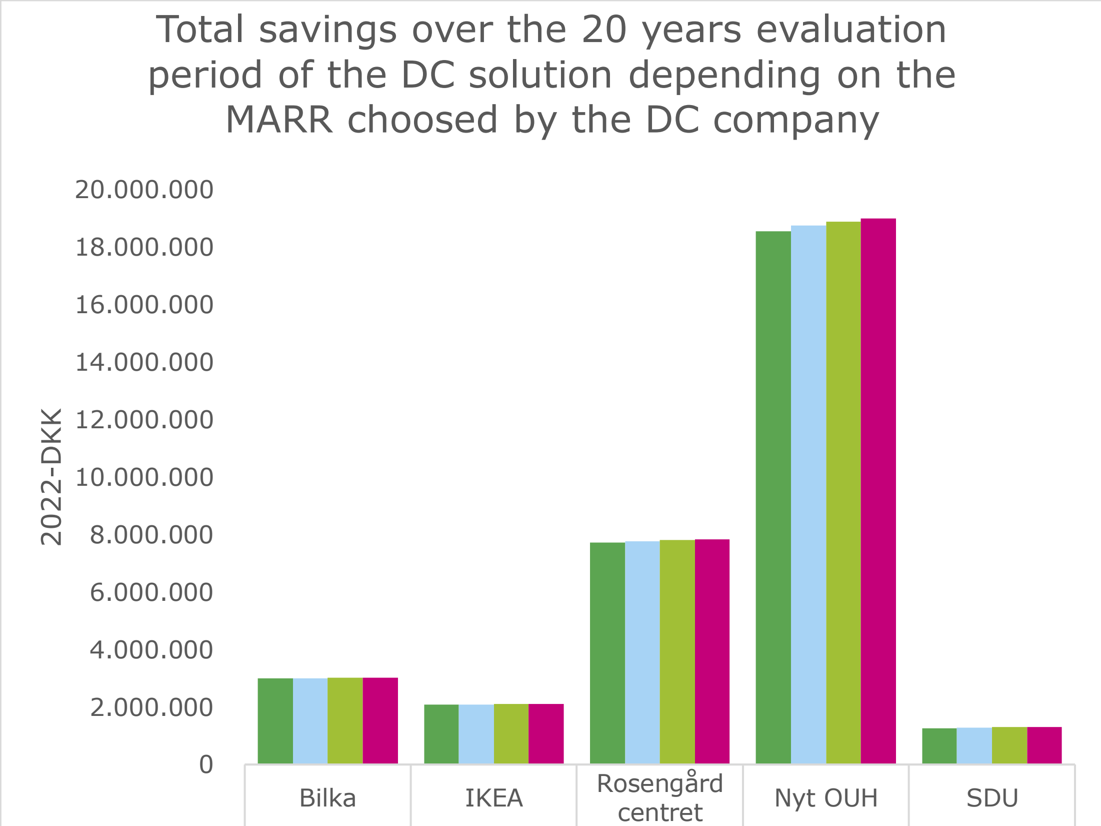
	DC to the primary target group only	**DC to both the primary and the secondary target group**
IRR, with at least 0 % savings for the customers by shifting to DC	~ 75 %	~ 48 %

Table 12.1 Maximum ROI for the DC company investment in the DC solution. Results from Appendix 15.1 A9 and A22.

The IRR is high in comparison to the 4 % MARR suggested by (Rambøll and Aalborg Univiersity, 2016, p. 36). This means that there is room for risks. Figure 12.2 show the total savings for the DC customers over the 20 year evaluation period for the DC solution depending on the MARR chosen by the DC company. [116] Figure 12.2 show that the revenue for the customers is marginally decreased for a MARR in the range of 4 % to 10 %.

[115] The results is based on the energyPRO-file in Appendix 15.1 A29 and 15.1 A28, where the data processing is in Appendix 15.1 A9 (IRR when delivering DC to both the primary and secondary target group) and Appendix 15.1 A22 (IRR when delivering DC to the primary target group only)

[116] The results are based on the energyPRO-file in Appendix 15.1 A29 and A27. The data is processed in Appendix 15.1 A6, A8, A10 and A13.



	Bilka	IKEA	Rosengård centret	Nyt OUH	SDU
DC 10 %	2.994.805	2.086.696	7.719.965	18.551.997	1.251.590
DC 8 %	3.009.717	2.096.170	7.770.182	18.749.176	1.279.620
DC 6 %	3.021.141	2.103.427	7.808.650	18.900.219	1.301.091
DC 4 %	3.028.975	2.108.405	7.835.033	19.003.811	1.315.817

Figure 12.2 Total savings over the 20 year evaluation period of the DC solution depending on the MARR choose for the DC company. Figure from Appendix 15.1 A8.

12.4 Pipe and digging price

The price for pipes and digging, specified by Fjernvarme Fyn, can be assumed to contain uncertainties. The synergy effect in relation to building the Nyt OUH, could lower the price. Similarly, the planned construction of a tramway (Odense Letbane) can provide synergies that will create savings or construction complications that will increase the price. Figure 12.3 show the cooling price depending on the digging and pipe price.[117]

The figure show if the price of the pipe and digging increase to 10,000 DKK/meter channel then will DC still be an interesting business case for all consumers apart from SDU. This could be solved by the other customers paying the cost for delivering to SDU. SDU could also be deselected. In that case, the business case for all the consumers and the DC company will have to be re-calculated.

[117] The results are based on the energyPRO-file in Appendix 15.1 A29 and A27. The data is processed in Appendix 15.1 A10, A11 and A13.

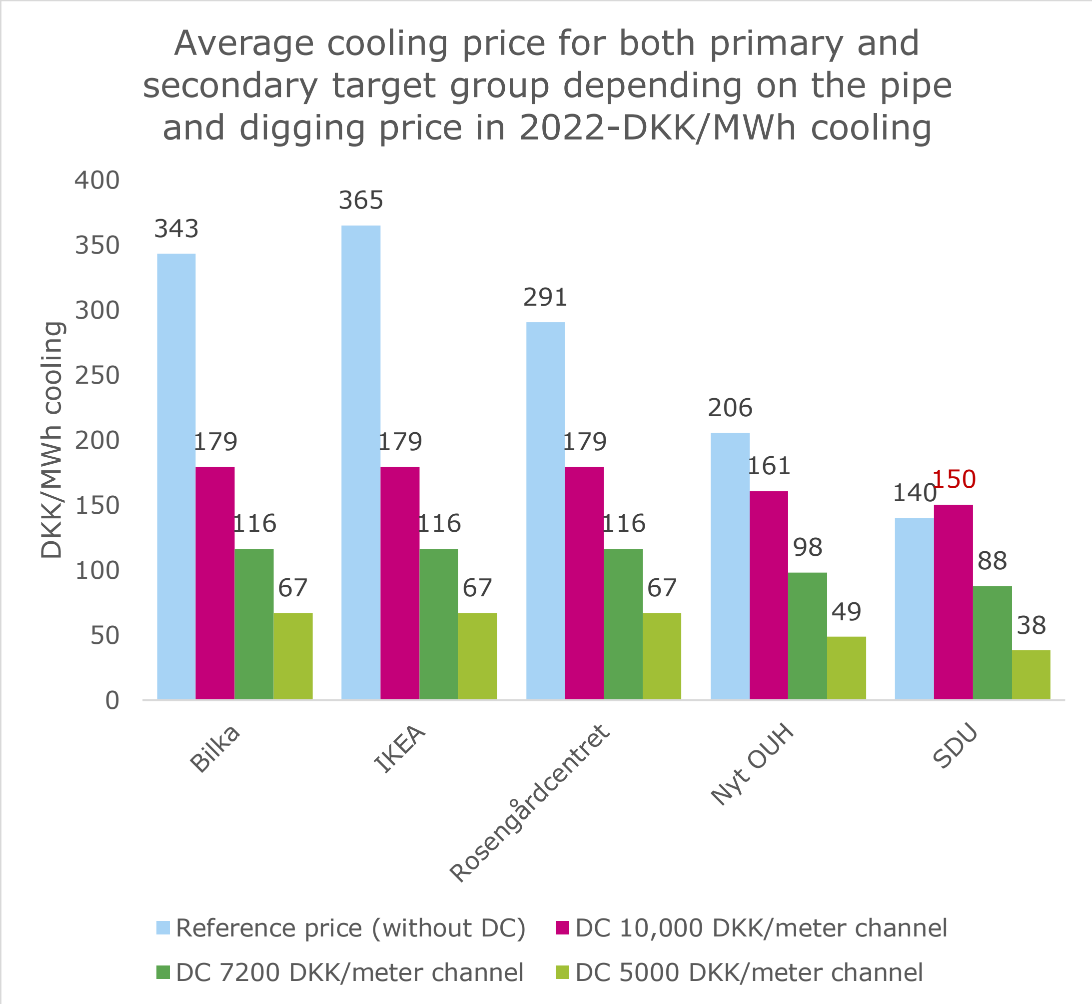


Figure 12.3 Cooling price for the DC consumers depending on the pipe and digging price. Figure from Appendix 15.1 A10.

12.5 Excess heat tax

A company that install an individual ATES solution is required to pay excess heat tax for the heat above COP 3. However, a DC company is required to pay excess heat tax of all the heat produced except for the electricity that goes into the heat. The reason is, that the heat is not produced at the DC company. The heat is produced at the customer site cf. Skat.[118]

The two excess heat scenarios are shown in Table 12.2. The DC company has to pay 2/3 excess heat tax for a COP-h value of 3, where an individual solution does not pay any excess heat tax. The DC company paid 4/5 excess heat tax for a COP-h value of 5, where an individual solution pay 2/5 excess heat tax.

The impact on the cooling price depends on the excess heat tax shown in Figure 12.4. The total savings over the 20 year evaluation period of the DC solution depends on the excess heat tax is shown in Figure 12.5. The two Figures shows that the excess heat tax conditions have a considerable impact on the unit cooling price.[119]

To avoid full taxation of excess heat, it is relevant to explore company structures that can bypass the requirement of paying full excess heat tax.

[118] (Nielsen (Skat), 2017)

[119] The results are based on the energyPRO-file in Appendix 15.1 A29 and A20. The data processing is in Appendix 15.1 A21.

Scenario	Reduced excess heat tax (individual solution)		Full excess heat tax (DC solution)	
COP-h	3	5	3	5
Consumption				
Electricity consumption	1	1	1	1
Heat production	3	5	3	5
Tax distribution				
- Electricity tax	1	1	1	1
- Excess heat tax	0	2	2	4
- Tax free excess heat	2	2	0	0
Additional tax for DC company	-	-	**2**	**2**

Table 12.2 Excess heat and electricity tax depending on COP-h value and whether there is paid excess heat tax for a COP above 3 or full excess heat tax. Table with the reduced excess heat tax is from (Sekretariatet for afgifts- og tilskudsanalysen på energiområdet, 2017, p. 30), where the full excess heat tax is added by the author of this report.

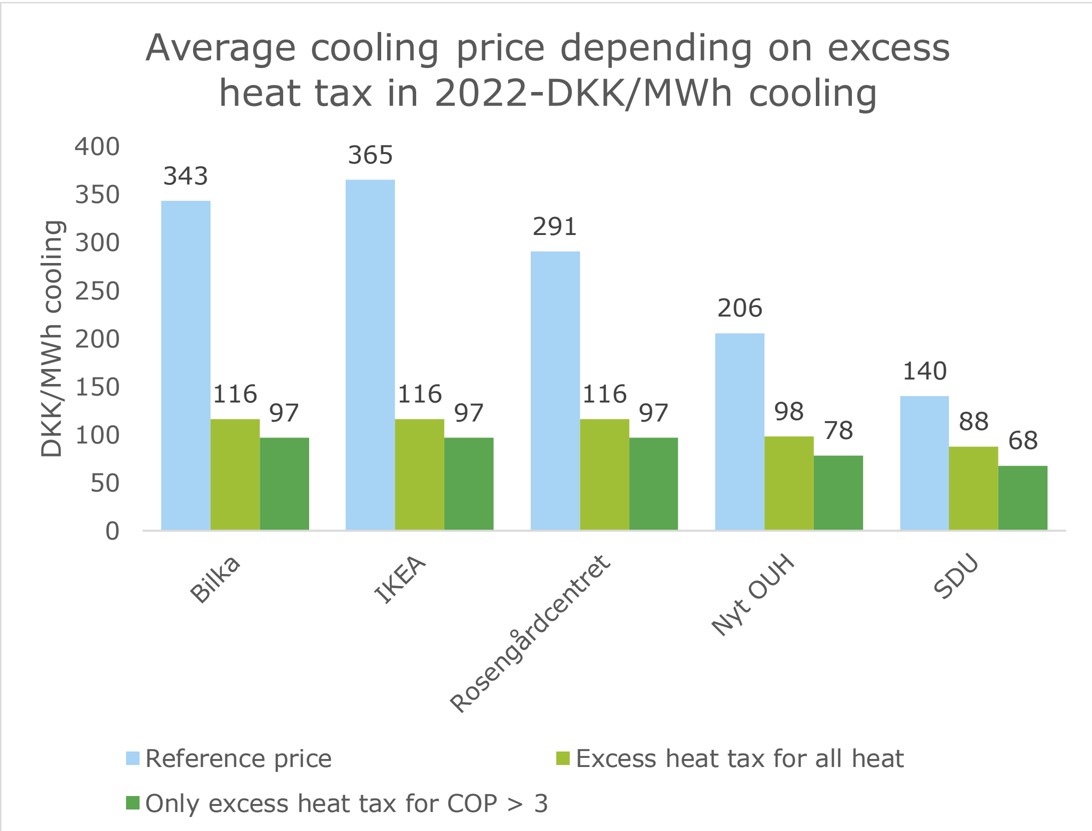


Figure 12.4 Cooling price, where the excess heat tax is payed for all the heat produced by the heat pump in relation to ATES except the electricity their goes into the heat pump and where the excess heat tax only is payed for the heat produced above a COP 3. Figure from Appendix 15.1 A21.

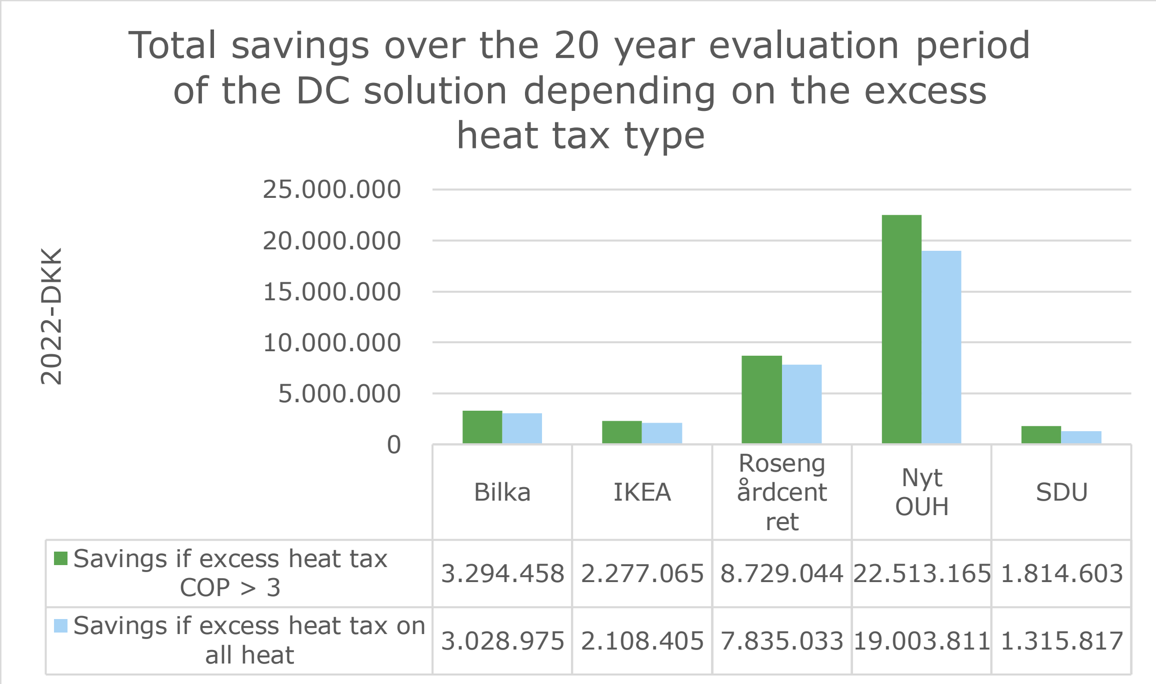


Figure 12.5 Total savings over the 20 year evaluation period of the DC solution depending the type of excess heat tax. Figure from Appendix 15.1 A21.

12.6 Absorption chiller potential - Heat price

The marginal heat price for the two cheapest production units owned by Fjernvarme Fyn are shown in Figure 12.6 (Block 8 (straw) plant and waste incineration plant).

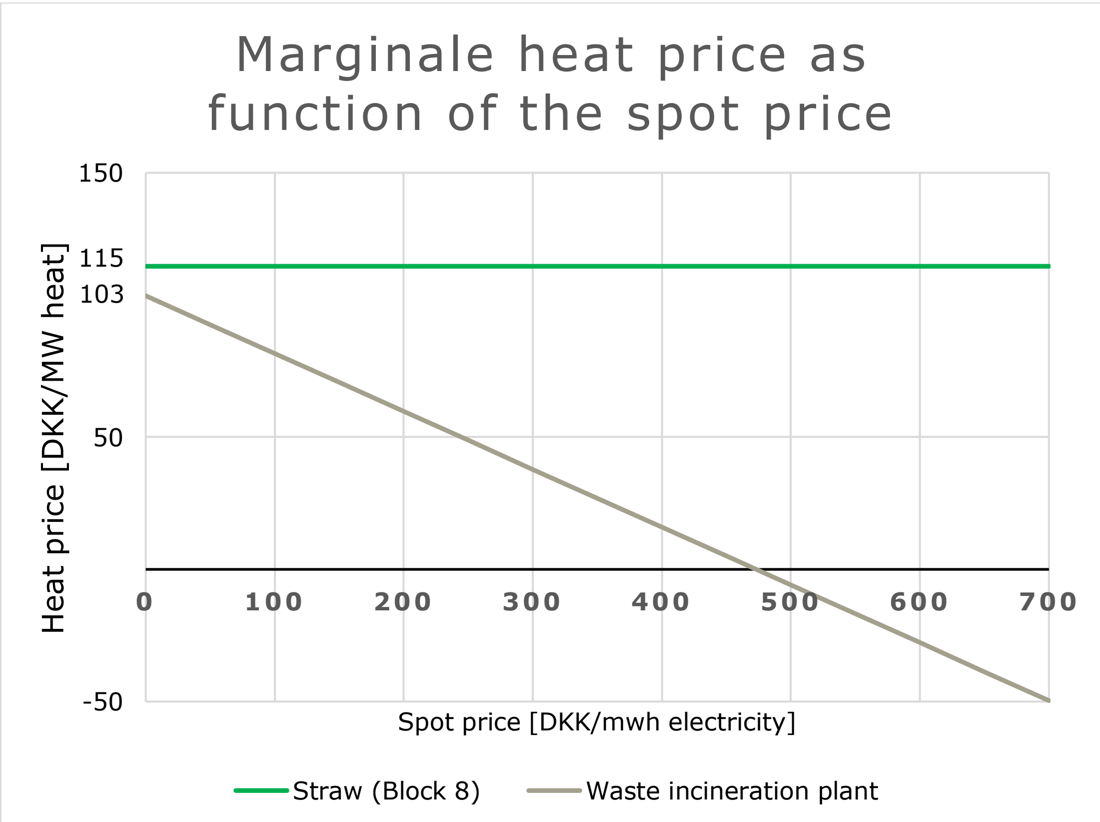


Figure 12.6 Marginal heat price for the straw (Block 8) and waste incineration plant. Edited figure from Fjernvarme Fyn – Appendix 15.1 C15.

Figure 12.6 show that heat can be purchase at 50 DKK/MWh when the spot price is above 250 DKK/MWh if the contribution margin for Fjernvarme Fyn is removed. A calculation with the heat costs of 50 DKK/MW results in an increased cooling price. The business case is still unattractive.[120]

It does not seem that the absorptions chiller provide a good business case for the DC company given the heat available from Fjernvarme Fyn. Other sources of heat could be investigated, but with increasing storage capabilities is the potential for high temperature heat to use in an absorption chiller probability declining.[121]

12.7 Transition time from individual solution to DC solution

One of the challenges with DC compared to DH is that no connection obligation exists cf. section 4 - Introduction to the district cooling market and legislation . The potential customers have already invested in individual production facilities. It is unlikely that they will commit to a new investment of a magnitude similar to the existing investment. An exception is Nyt OUH, which is under construction. They have not finalised their investment in cooling equipment.

It is difficult to estimate the lifespan of the customers' existing production facilities and this topic is discussed in this section.

An estimation of the lifespan of the existing individual cooling equipment is estimated below:

Consumer	Time to new investment in refrigeration equipment [Years]
Bilka[122]	2-10
IKEA[123]	25
Rosengårdcentret[124]	15
Nyt OUH[125]	4-5
SDU[126]	15-25

Table 12.3 Estimated time before the customers need to invest in cooling equipment

The time for a new investment will be reduced if any of the costumer use refrigerants that not are allowed to refill such as R22 (Freon). [127] It has only been identified that Bilka use a refrigerant that is not allowed to refill.[128] A positive indication for Bilka to invest in DC is considerable.

12.7.1 Within a 5 year period: Nyt OUH, IKEA and Bilka

Nyt OUH and Bilka will within a 5 year period have incentive to be connected to a DC solution. It is assumed that the electrical chillers at IKEA is purchased to a price of DKK 3.73 million. The value is a linear depreciation, based on the lifetime of the electrical chiller and

[120] This result is based on the energyPRO-file in Appendix 15.1 A2 and the data processing in Appendix 15.1 A1.
[121] (Rambøll and Aalborg Univiersity, 2016, p. 18)
[122] (Christensen (Bilka), 2017)
[123] The electrical chiller was used for the first time in year 2010 cf. 15.7. if the maximum lifetime of an electrical chiller is around 30 years (cf. 15.10), then the electrical chiller has 25 years left
[124] Appendix 15.20.
[125] Nyt OUH is expected to be finish in year 2022 cf. (Nyt OUH, 2017)
[126] Guess value. The maximum lifetime of an electrical chiller is around 30 years cf. Appendix 15.10.
[127] "As of 31 December 2014 refrigerant systems with refrigerant R-22 (Freon) much no longer be repaired in Denmark and the rest of the EU if it requires interference with refrigerant or refrigerant filling" (PACCO, 2017)
[128] (Christensen (Bilka), 2017)

the investment costs given by Peer Andersen from Fjernvarme Fyn.[129] The electrical chiller can then be used to reduce the investment costs. The chosen production mix:

- 5.4 MW electrical chiller
- 1,950 kW ATES (three dipoles)
- 4,000 m^3 cold storage.

The new cooling price is shown in Figure 12.7.[130]

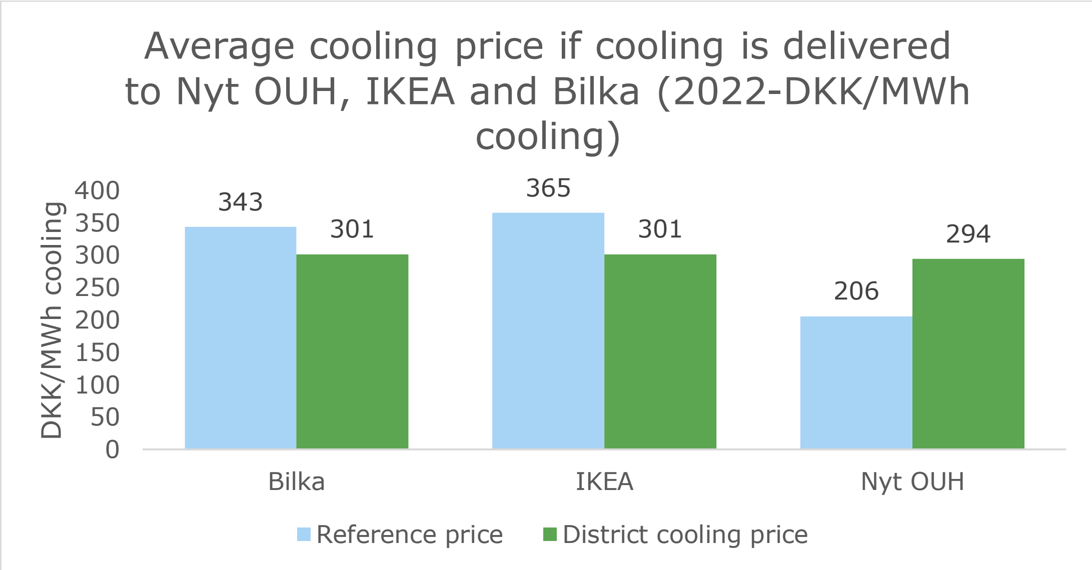


Figure 12.7 Comparison of cooling prices from DC in relation to individual solution, if cooling is delivered to Nyt OUH, IKEA and Bilka from 2022. Figure from Appendix 15.1 A19, sheet: "DC results".

The yearly savings is shown in the Figure 12.8.

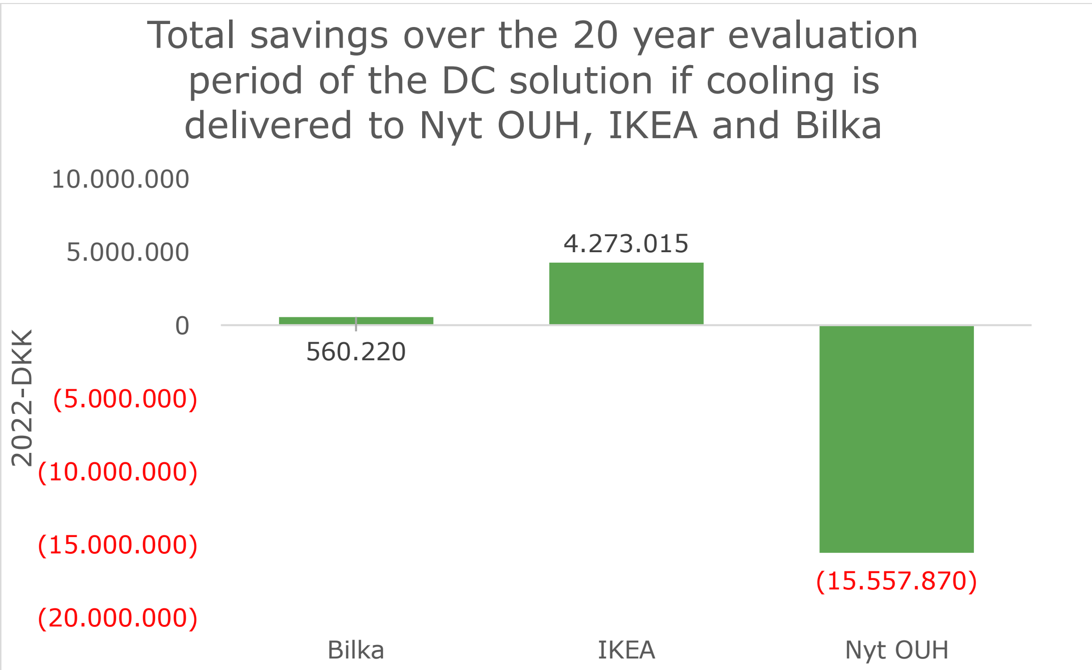


Figure 12.8 Total savings over the evaluation period of the DC solution if DC is delivered to Bilka, IKEA and Nyt OUH from 2022. Figure from Appendix A19, sheet: "DC results".

[129] Investment cost is from Appendix 15.7. It should be noted that this investment cost is for the overall project and thus is the price for the electrical chiller lower – without knowing who much. The chosen depreciation method is unknown and therefor is the linear depreciation model chosen. The depreciation period is set to be over the lifetime of an electrical chiller – in this case set to 30 years as the lifetime given for the electrical chiller used in the DC solution.

[130] The results are based on the energyPRO-file 15.1 A33 and A27. The data processing is in Appendix 15.1 A19.

The savings for Nyt OUH are negative and it is a infeasible business case for Nyt OUH to migrate to a DC solution based on the given assumptions.

Possible events that can make the business case feasible are analysed in the following subsection.

12.7.1.1 Increased demand by 20 percent

It is possible that the cooling demand of Bilka and Nyt OUH is higher than the used demand in energyPRO-model 1 and 2. Bilka have informed, that their electrical chiller is undersized and Nyt OUH is based on estimations. To analyse the possibilities at Bilka and Nyt OUH, the cooling demand is increased with 20 %. The data from IKEA is more reliable and therefore is IKEA cooling demand not increased. The total savings by the change in the cooling demand over the 20 year evaluation period of the DC solution is shown in Figure 12.9.[131] The Figure shows that it still is an unfeasible business case for Nyt OUH to choose DC.

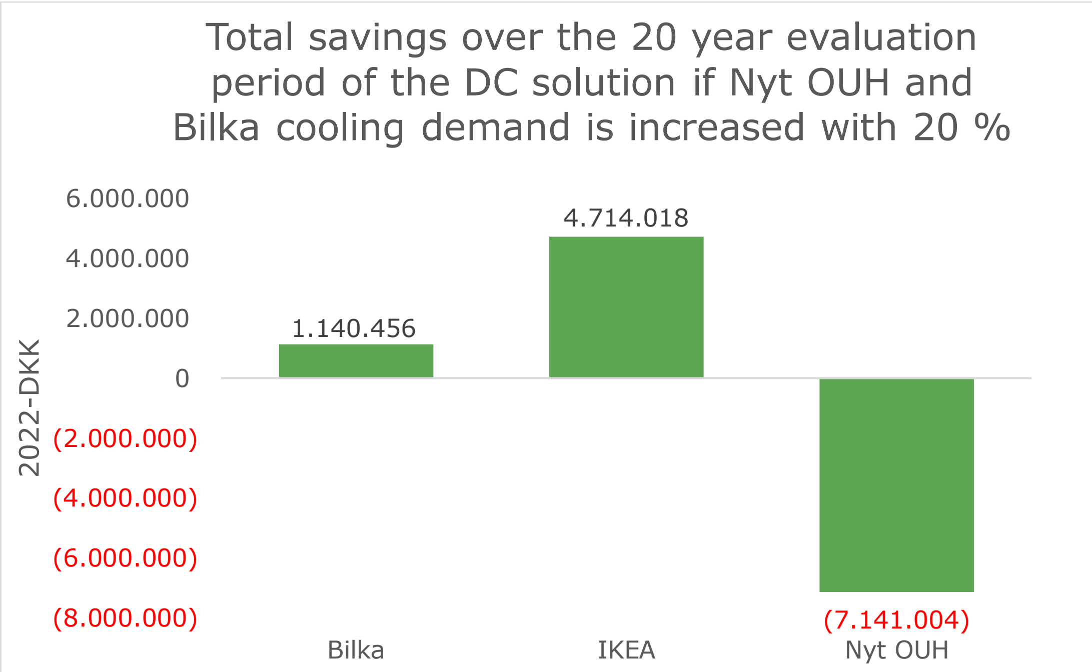


Figure 12.9 Total savings over the 20 years' evaluation period of the DC solution if Nyt OUH and Bilka cooling demand is increased with 20 %. Figure from Appendix 15.1 A16 sheet: "DC results".

12.7.1.2 Increase in ATES capacity

It is possible that the ATES solution can deliver a larger cooling production than estimated depending on the real geological conditions. If the thermal contamination between the well is not a problem, each dipole can deliver a cooling capacity of 1,216 kW. By increasing the cooling capacity of the ATES solution, it is possible to reduce the capacity of the electrical chiller from 5.4 MW to 4 MW including the 1.4 MW electrical chiller from IKEA.[132] The total savings if the technical capacity of the ATES solution is higher than expected is shown in Figure 12.10 and it is still an unfeasible business case for Nyt OUH.

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[131] The results are based on the energyPRO-file 15.1 A34 and 15.1 A26. The data processing is in Appendix 15.1 A16.
[132] The results are based on the energyPRO-file 15.1 A31 and 15.1 A27. The data processing is in Appendix 15.1 A14.

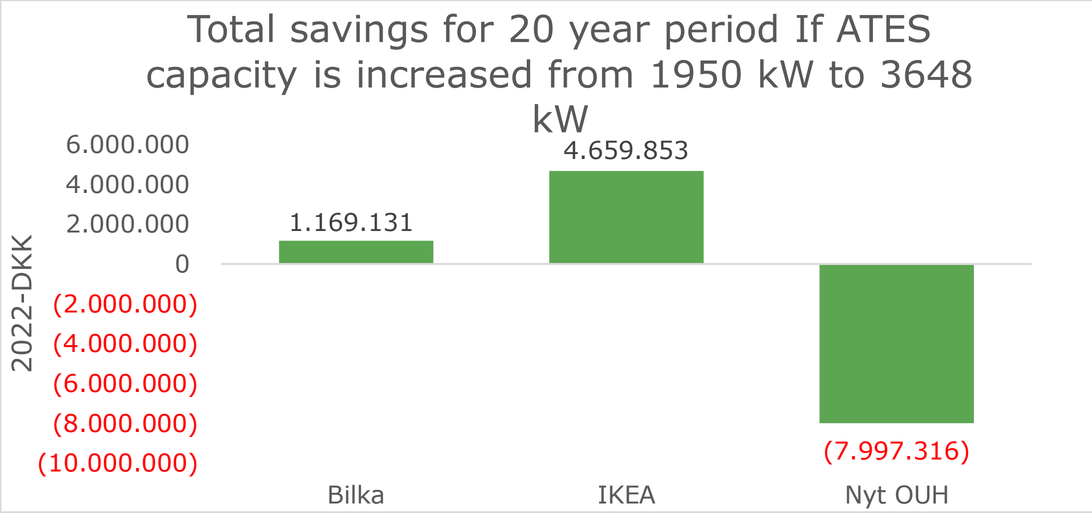


Figure 12.10 Total savings over the 20 year evaluation period of the DC solution if DC is delivered to Bilka, IKEA and Nyt OUH, where the ATES cooling capacity is increase from 1950 kW to 3648 kW. Figure from Appendix 15.1 A14 sheet: "DC results".

12.7.1.3 Shared digging costs

The synergy effect with the tramway could possibly reduce the pipe and digging costs. Figure 12.11 show that if the digging and pipe price is reduced from 7,200 DKK/meter channel to 5,175 DKK/meter channel then is the business case is feasible for all customers.[133] The effect on the cooling price is shown in Figure 12.12.

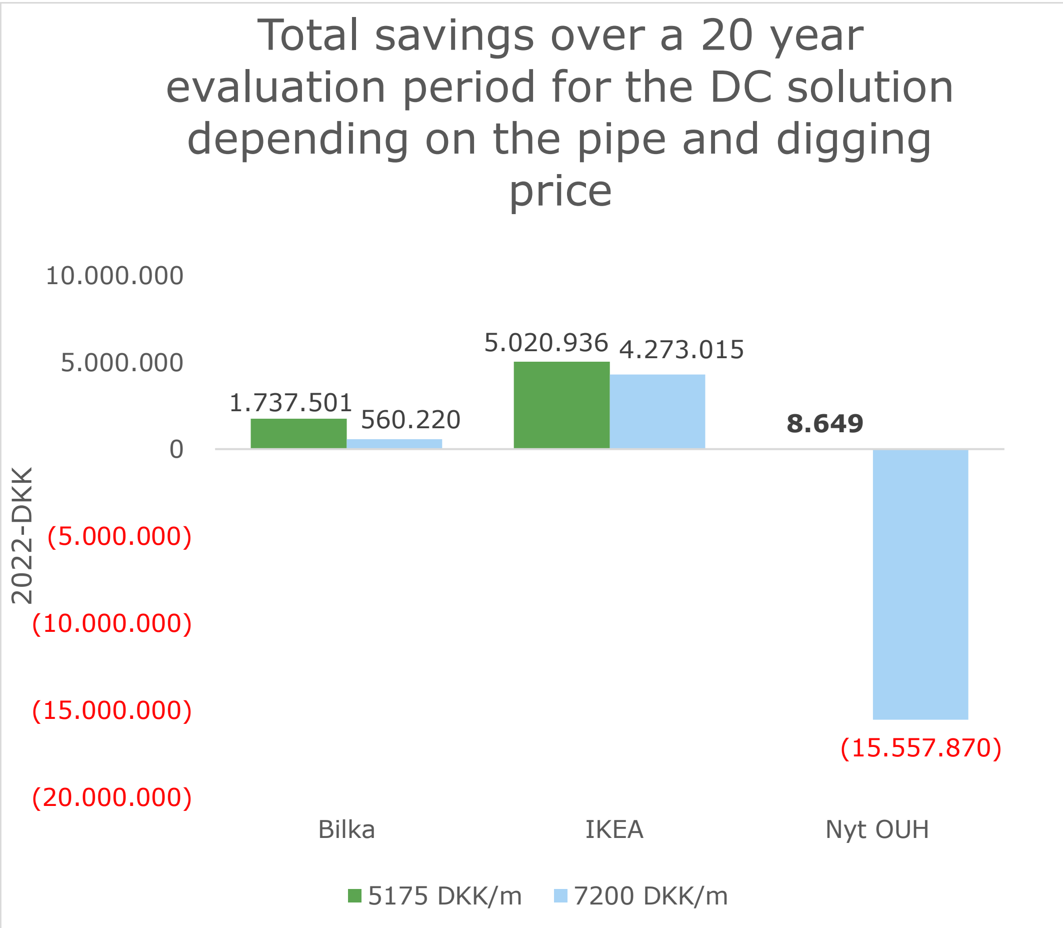


Figure 12.11 Total savings over a 20 year evaluation period for the DC solution depending on the pipe and digging costs. Figure from Appendix 15.1 A42 sheet: "DC results".

[133] The results is based on the energyPRO-file in 15.1 A33. The data processing is made in the two Excel files in Appendix 15.1 A19 and A42.

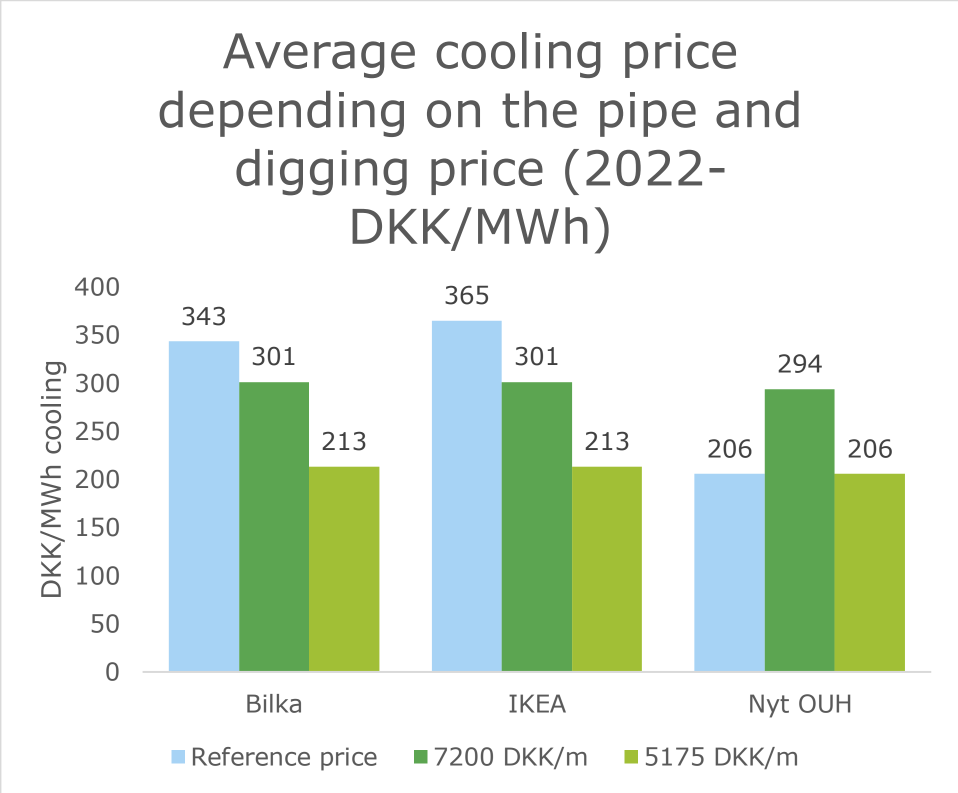


Figure 12.12 Cooling costs with reduced costs for digging and pipe. Figure from Appendix 15.1 A42 sheet: "DC results".

To finally conclude whether the business case by delivering DC to Bilka, IKEA and Nyt OUH is feasible, additional analysis needs to be conducted. The most critical analysis is to source the best price for the pipe and digging. Skat needs to be consulted for a binding answer in relation to the excess heat tax. It is possible that a company structure exists, that will work around the full excess heat taxation related to the heat. The more advanced and time consuming energyPRO model which simulate the heat pump with the corrected spot price should be performed.[134]

[134] This is not done in this project because the model takes around 1.5 days from each report and such for simulating the 20 year period does it take a total time of around 30 days to run.

13. CONCLUSION

The cooling demand is estimated by receiving historic cooling consumption data from the investigated companies. Nyt OUH has not been built yet and the estimations are conducted by Medico OUH. The yearly estimated cooling demand in MWh is shown below.

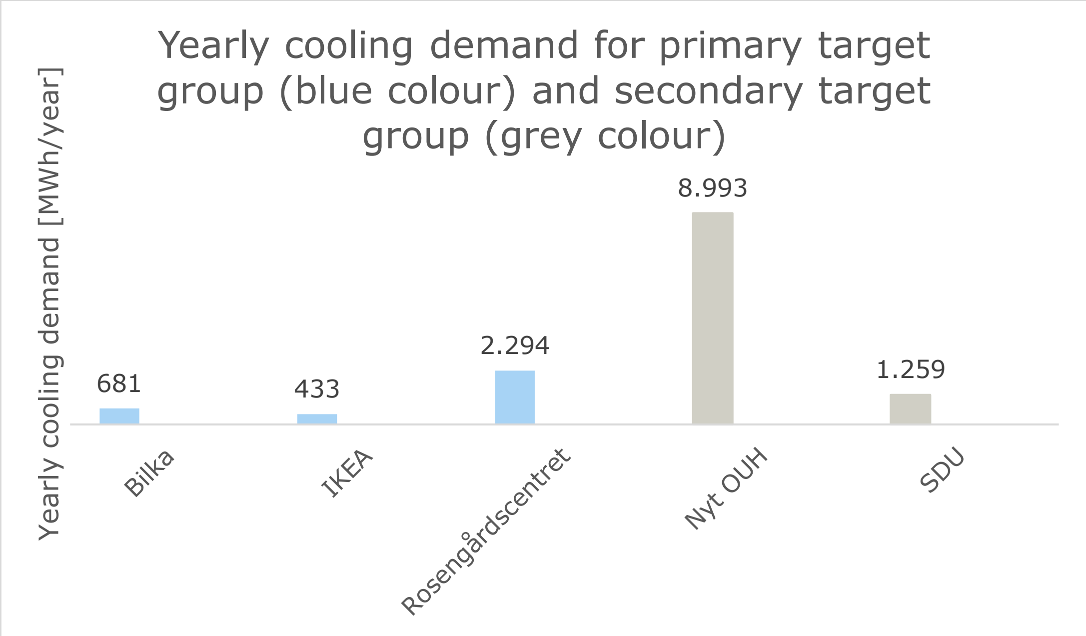


Figure 13.1 Yearly cooling demand for each potential DC customer. Figure described in more detail in section 6.

In the area near Rosengårdcentret is an aquifer located, which have a potential of 1,216 kW cooling or heat storage depending on the operation of the Aquifer Thermal Energy Storage (ATES). The technical potential is reduced to a lower capacity to minimize the risk of thermal contamination to adjacent wells. The potential is estimated equal to 650 kW. The ATES solution will be used as a baseload plant because:

- The high COP value of around 63 results in a more cost effective cooling production than an electrical chiller
- The electricity tax for the cooling production by ATES is based on process cooling, which reduce the electricity costs for comfort cooling customers
- The heat by-product from the cooling production can be sold to Fjernvarme Fyn

An energyPRO-model of the district cooling (DC) solution with all the selected technologies implemented, is conducted including all operational costs. The selected technologies include:

- ATES
- Ab<u>s</u>orption chiller
- A<u>d</u>sorption chiller
- Electrical chiller

The a<u>b</u>sorption chiller is cheaper in some hours during summer, in comparison to the electrical chiller, given a heat price of 100 DKK/MWh as agreed with Fjernvarme Fyn. The savings in operation are not adequate to pay back the investment cost.

The a<u>d</u>sorption chiller COP value is 31 % smaller than the a<u>b</u>sorption chiller and furthermore are the investment costs and O&M higher. The a<u>b</u>sorption chiller is thereby more attractive at the current technology state. None of the two technologies results in savings compared to using an electrical chiller.

The savings in operation at the DC company are not adequate to cover the investment cost. The business case for the DC company is feasible if the DC customers pay a capital injection. For the district cooling solution to be a success, the customers have to invest in the district cooling company at the end of the lifespan of their existing production facilities.

The technical lifespan of the production facility for some of the customers are uncertain or unknown. The analysis is split into two parts:

- One where all customer investments are done in 2021, including Nyt OUH.
- One which is based on an estimation of the remaining technical lifespan.

The first analysis shows a feasible business case independent on whether the district cooling is only delivered to the primary target group (Bilka, IKEA and Rosengårdcentret) or to the secondary target group (Nyt OUH and SDU). The savings of the primary target group are increased if district cooling is also delivered to the secondary target group.

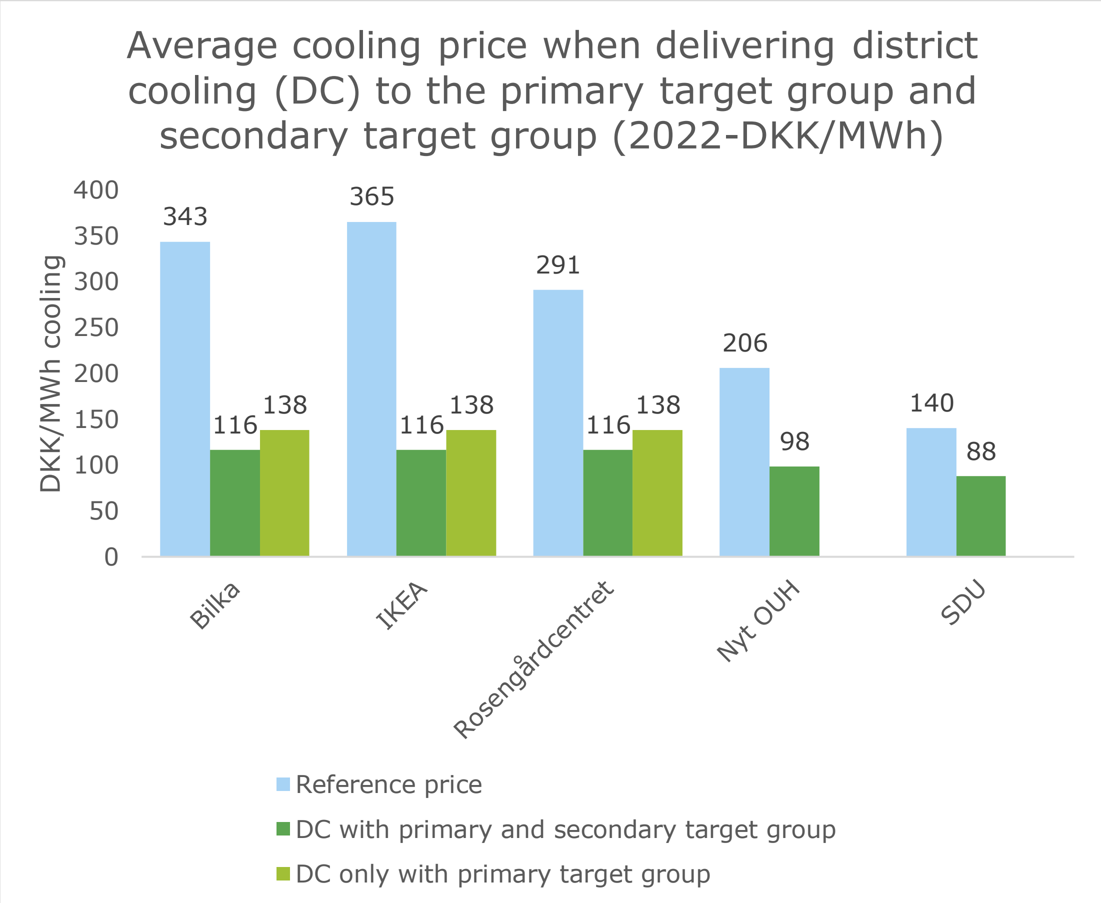


Figure 13.2 Cooling price if the DC company deliver cooling only to the primary target group (Bilka, IKEA and Rosengårdcentret) and to the secondary target group (Nyt OUH and SDU).

The secondary analysis shows that within a 5 year period, Bilka and Nyt OUH are ready to invest in new production facilities. Fjernvarme Fyn desire to expand from IKEA and it is chosen that the DC company purchase their electrical chiller. The business case for delivering to these three companies is not feasible as the cooling price will be unattractive to Nyt OUH.

The tramway (Odense Letbane) is built in the exact same route as the DC pipe. It may be possible to make a synergy effect with the construction of the tramway. The business case is feasible for Bilka, IKEA and Nyt OUH if the digging and pipe price is reduced from the suggested value from Fjernvarme Fyn on 7200 DKK/meter channel to 5175 DKK/meter channel.

14. BIBLIOGRAPHY

Algers, A. (2017, April 13). *Stage 3: Development*. Retrieved from Strategic new product development: http://qpc.adm.slu.se/SNPD_ver2/page_31.htm

Andersen (Fjernvarme Fyn AS), P. (2017, April 05). Status meeting 2. (K. J. Vinstrup, Interviewer)

Andersen (Fjernvarme Fyn), P. (2017, February 13). First meeting about bachelor project. (M. G. Vinstrup, & K. K. Jespersen, Interviewers)

Andersen, N. B., Andersen, B., Buhl, L., Drivsholm, C., Ellehauge, K., Frederiksen, J., . . . Wit, J. (2015). *Varme ståbi.* Odense: Praxis - Nyt Teknisk Forlag.

Aquifer thermal energy storage. (2017, May 5). Retrieved from Wikipedia: https://en.wikipedia.org/wiki/Aquifer_thermal_energy_storage

Bargman, R. (2017, March 09). *Hubpages*. Retrieved from Adsorption vs. Absorption Chillers: Applications and Use Overview: https://hubpages.com/education/Adsorption-vs-Absorption-Chillers-Applications-Use-Overview

Bekendtgørelse om vurdering af visse offentlige og private anlægs virkning på miljøet (VVM) i medfør af lov om planlægning. (2017, May 20). Retrieved from Retsinfomation: https://www.retsinformation.dk/Forms/R0710.aspx?id=184472

Bry-Air. (2017, March 09). *Bry-air*. Retrieved from Adsorption Chiller: http://www.bryair.com/product/adsorption-chiller-17/adsorption-chiller-40?categoryID=17

Cengel, Y. A., & Boles, M. A. (2016). *Thermodynamic - An Engineering Approach* (5th ed.). USA: McGraw-Hill Education.

Center for Klima og Energiøkonomi. (2016). *Forudsætninger for samfundsøkonomiske analyser på energiområdet.* Copenhagen: Energistyrelsen.

chemistrytwig. (2017, April 21). *WHAT'S THE DIFFERENCE BETWEEN ABSORPTION AND ADSORPTION?* Retrieved from Chemistrytwig: http://chemistrytwig.com/2013/09/18/whats-the-difference-between-absorption-and-adsorption/

Christensen (Bilka), J. (2017, February 22). Bilka cooling production technologies, strategy, and data agreement. (M. G. Vinstrup, & K. C. Jespersen, Interviewers)

Copenhagen Airport (CPH). (2017, April 23). *Københavens Lufthavn*. Retrieved from ATES - Grundvandskøling: https://www.cph.dk/om-cph/miljo-og-energi/klima-og-energi/ates---grundvandskoling/

Decentralized Energy. (2017, March 09). *Decentralized Energy*. Retrieved from Adsorption and other thermal chillers making trigeneration systems work: http://www.decentralized-energy.com/articles/print/volume-10/issue-5/features/adsorption-and-other-thermal-chillers-making-trigeneration-systems-work.html

Dincer, I., & Rosen, M. A. (2011). *Thermal Energy Storage System and Application* (2nd ed.). United Knigdom: WILEY.

ECE. (2013, November 01). *Rosengårdscentret.* Retrieved from Rosengårdscentret: http://rosengaardcentret.dk/wp-content/uploads/2016/02/Roseng%C3%A5rdcentret.pdf

Energi wiki. (2017, March 01). *Energiwiki*. Retrieved from Graddage, energisignatur: http://energiwiki.dk/index.php/Graddage,_energisignatur

Energi-, Forsygnings- og Klimaministeriet. (2016). *Aftale om afskaffelse af PSO-afgiften.* Copenhagen: Energi-, Forsygnings- og Klimaministeriet. Retrieved from http://efkm.dk/media/7912/elementer-i-aftale-om-pso.pdf

Energinet.dk. (2016). *Energinet.dk's analyseforudsætninger 2016.* Fredericia: Energinet.dk. Retrieved from

http://www.energinet.dk/SiteCollectionDocuments/Danske%20dokumenter/El/Energinet.dk%27s%20analyseforuds%C3%A6tninger%202016,%20juni%202016.pdf
Energinet.dk. (2017, March 11). *Energinet*. Retrieved from Aktuelle tariffer og febyrer: http://www.energinet.dk/DA/El/Engrosmarked/Tariffer-og-priser/Sider/Aktuelle-tariffer-og-gebyrer.aspx
Energiwiki. (2017, March 12). *Energiwiki*. Retrieved from Køling: http://energiwiki.dk/index.php/K%C3%B8ling
ENOPSOL. (2017, March 16). *ENOPSOL*. Retrieved from Økonomi: http://enopsol.com/dk/okonomi.html
Enopsol ApS. (2009). *ELFORSK PSO F&U 2007 - Grundvandsvarmepumper og –køling med grundvandsmagasiner som sæsonlager - BILAG 7.* Copenhagen: Enopsol ApS. Retrieved from http://enopsol.com/onewebmedia/bilag_7_beregningsvaerktoej.pdf
Enopsol ApS. (2017, May 4). Retrieved from Undergrunden: http://enopsol.com/dk/ates-losningen/undergrunden.html
ENOPSOL ApS. (2017, April 23). *Tekniske Data.* Retrieved from Nordiske medier: https://f.nordiskemedier.dk/2ve8msfsbx9gd0ya.pdf
Fjernvarme Fyn. (2017, May 04). *Yumpu.* Retrieved from Fjernkøling i odense: https://www.yumpu.com/da/document/view/32445642/fjernkling-i-odense
Fødevareministeriet, M. o. (2015, December 15). *BEK nr 1716 af 15/12/2015 (Gældende)*. Retrieved from Retsinformation: https://www.retsinformation.dk/pdfPrint.aspx?id=176576
Geodatastyrelsen. (2017, May 17). *Danmarks miljøportal*. Retrieved from Danmarks miljøportal: http://arealinformation.miljoeportal.dk/distribution/
Goldman Energy. (2017, May 4). Retrieved from HOW DOES AN ABSORPTION CHILLER WORK?: http://goldman.com.au/energy/company-news/how-does-an-absorption-chiller-work/
Green Riverside. (2017, March 10). *Green Riverside*. Retrieved from Efficient Electric Chillers: http://www.energydepot.com/rpucom/library/hvac013.asp
Heggland, N.-O. (2013, April 02). *Fields's udvider med stor biografcenter.* Retrieved from Business: http://www.business.dk/detailhandel/fields-udvider-med-stort-biografcenter
Hillier, D., Grinblatt, M., & Sheridan Titman. (2012). *Financial markets and corporate strategy.* UK: McGraw-Hill Education.
InvenSor. (2017, March 12). *YouTube*. Retrieved from InvenSOR Chiller Adsorption Process Animation - YouTube: https://www.youtube.com/watch?v=u9cXit_jhbA&t=26s
Investropedia. (2017, May 18). *Investropedia*. Retrieved from Net Present Value - NPV: http://www.investopedia.com/terms/n/net-internal-rate-of-return.asp
Jacobsen, L. H. (2017, March 22). (K. J. Vinstrup, Interviewer)
Jensen, P. (2013, January 12-13). Danmarks nye supersygehus Nyt OUH. *Fyens Stiftstidende, Fyns Amts Avis, JydskeVestKysten, Vejle Amts Folkeblad, Nordvestnyt, Dagbladet, Sjællandske*. Retrieved from http://www.nybygsdu.dk/Nyheder/~/media/sdusites/Nybyg/Filer/Nyheder/Ny%20OUH%201213%20januar%202013.ashx
Jupiter. (2017, May 15). Retrieved from GEUS: http://data.geus.dk/geusmap/?mapname=jupiter
Kawasaki Thermal Eng.Co.,Ltd. (2017, March 01). *District Energy.* Retrieved from Absorption Chiller Applications and Efficiency: http://www.districtenergy.org/pdfs/07CoolingSymposium/Proceedings/Monday/Awn_Murai_Absorption_Chiller_Applications.pdf

Lading, H. J. (2017, March 05). *Dokumentation og forklaring til energisignatur ved DRY-data.* Retrieved from Dropbox: https://www.dropbox.com/s/peudk8oja0l0e8i/DRY_Data_Beskrivelse%2020130610.docx?dl=0

Lauritsen, A. B., & Eriksen, A. B. (2017). *Termodynamik, teoretisk grundlag - praktisk anvendelse* (3th ed.). Copenhagen: Nyt teknisk forlag.

Logstor. (2017). *Product Catalogue.* Løgstør: Logstor. Retrieved from https://www.logstor.com/media/5571/product-catalogue-uk-201703.pdf

ME Subjects. (2017, March 10). *ME Subjects*. Retrieved from * Unit of Refrigeration–Ton of Refrigeration: http://www.mesubjects.net/unit-of-refrigeration-ton-of-refrigeration/

Midwestern Regional Climate Center. (2017, March 05). *Degree Day Description*. Retrieved from CliMate: http://mrcc.isws.illinois.edu/CLIMATE/Station/Daily/degreeday_description.html

Moran, M. J., Shapiro, H. N., Boettner, D. D., & Bailey, M. B. (2011). *Fundamentals of Engineering thermodynamics* (6th ed.). USA: Wiley.

Nielsen (Skat), N. H. (2017, April 28). Taxes in relation to the used district cooling production technologies. (M. G. Vinstrup, & K. C. Jespersen, Interviewers)

Niemi (ENOPSOL), S. S. (2017, March 13). General questions about Aquifer Thermal Energy Storage. (M. G. Vinstrup, & K. C. Jespersen, Interviewers)

Nyt OUH. (2017, May 07). *Nyt OUH tilbage på sporet*. Retrieved from Nyt OUH: http://www.nytouh.dk/om-hospitalet/nyt-ouh/nyheder/tilbage-paa-sporet

Odense Municipality. (2017, May 04). *Energiprojekter*. Retrieved from Odense kommune: http://www.odense.dk/erhverv/miljoe-for-erhverv/klima/energiplan/energiforsyning/koling

PACCO. (2017, 05 17). *PACCo*. Retrieved from Udfasning af Froen - kølemiddel R-22. Freon er forbudt efter 2014: http://www.pacco.dk/ydelser/freon-r-22-udfasning/

Petersen, S. A. (2014). *Fjernkøling - En energisystem- og bariereanalyse af fjernkøling i dansk kontekst.* Aalborg: Aalborg University.

Pihl-Andersen (HOFOR DC), J. O. (2017, March 08). Visit at HOFOR DC. (M. G. Vinstrup, & K. C. Jespersen, Interviewers)

PlanEnergi. (2012). *Projektforslag for udnyttelse af overskudsvarme fra ATES-anlæg hos VIVA Odense.* Århus C: PlanEnergi.

Power knot. (2017, March 10). *Power Knot*. Retrieved from What is a ton of refrigeration: http://www.powerknot.com/what-is-a-ton-of-refrigeration.html

PwC. (2017). *Afgiftsvejledning 2017 - Samlet overblik over afregning og godtgørelse af afgifter.* Hellerup: PwC.

Rambøll. (2017, May 09). *Køleplan 2016 pixi udgave.* Retrieved from Fjernvarme industrien: http://fjernvarmeindustrien.dk/wp-content/uploads/2013/12/K%C3%B8leplan-Danmark_pixi-udgave.pdf

Rambøll and Aalborg Univiersity. (2016). *Køleplan Danmark 2016.* Copenhagen: Rambøll. Retrieved March 09, 2017, from http://download.ramboll-environ.com/ramboll/Koleplan-Danmark-2016-Rapport.pdf

Rasmussen, P. (2017, March 09). *Ajourererhvervskonference.* Retrieved from Grundvandskøling - Fordele, udfordringer og økonomi: http://www.ajourerhvervskonference.dk/imgdb/docs/Pia_Rasmussen_2329.pdf

Reay, D. A., & Macmicheal, D. (1998). *Heat pumps.* (2th, Ed.) UK: Pergamon Press.

Reinholdt, L. (2017, March 10). *Teknologiske Institut.* Retrieved from Køling: https://www.google.dk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwixjI7ygprSAhUH2ywKHcL1CJsQFggZMAA&url=http%3A%2F%2Fwww.teknologisk.dk%2F_root%2Fmedia%2F30570_K%25F8l%252006-3%2520Alternativ%2520k%25F8ling.pdf&usg=AFQjCNGog2zySaT3Z

Sakradia, V. A. (2017, March 10). *ES Engineered Systems*. Retrieved from Basics For Absorption Chillers: http://www.esmagazine.com/articles/82307-basics-for-absorption-chillers

Sekretariatet for afgifts- og tilskudsanalysen på energiområdet. (2017). *Afgifts- og tilskudsanalysen på energiområdet.* Copenhagen: Skatteministeriet. Retrieved from http://www.skm.dk/media/1452402/afgifts-og-tilskudsanalysen-delanalyse-5.pdf

Solair. (2017, March 09). *Solair*. Retrieved from Adsorption Chillers: http://www.solair-project.eu/142.0.html

Tang (Dansk Fjernvarme), J. (2017). *Overskudsvarme.* Odense: IDA. Retrieved May 19, 2017, from https://universe.ida.dk/meetupfiles/download/?meetupNumber=313778&filename=313778_EGNO_4_Indl%C3%A6g%20af%20John%20Tang%20-%20Dansk%20Fjernvarme.pdf

The Engineering Tooolbox. (2017, March 10). *The Engineering Toolbox*. Retrieved from Calculating Cooling Loads: http://www.engineeringtoolbox.com/cooling-loads-d_665.html

TV2 Fyn. (2008, March 10). *Rosengårdscentret bliver landets største.* Retrieved from TV2 Fyn: http://www.tv2fyn.dk/node/24461

Contact details of people who have been interviewed are in Appendix 15.22 on page 152.

15. APPENDIX

15.1 Online content

energyPRO-models, data processing, offers and more are located online. The material from the list below can be accessed though: https://goo.gl/ciRWkU.

Content ID (name used when referred to the report)	File name	Description
Folder: energyPRO results		
A1	Absorption potential_Absorption chiller 1 MW_50DKKMWh.xlsx	Results processing of potential of absorption chiller if the heat price is available at 50 DKK/MWh heat and only when the spot price is above 250 DKK/MWh electricity.
A2	Absorption potential_Absorption chiller 1 MW_50DKKMWh.epp	energyPRO-model of potential of absorption chiller if the heat price is available at 50 DKK/MWh heat and only when the spot price is above 250 DKK/MWh electricity
A3	Absorption potential_Absorption chiller 1 MW_Summer.epp	EnergyPRO-model of potential of 1 MW absorption chiller if heat at 100 DKK/MWh heat is available the whole summer
A4	Absorption potential_Absorption chiller 1 MW_Summer.xlsx	Results processing of potential of absorption chiller if heat at 100 DKK/MWh heat is available the whole summer
A5	All consumers connected - 20 % less cooling demand.xlsx	Results processing if all consumers have a 20 % smaller cooling de-mand.
A6	All consumers connected - MARR 6 percentage.xlsx	Results processing if delivering cool-ing to both primary and secondary target group where the MARR of the cooling company is 6 %
A7	All consumers connected - MARR 8 percentage.xlsx	Results processing if delivering cool-ing to both primary and secondary target group where the MARR of the cooling company is 10 %
A8	All consumers connected - MARR 10 percentage.xlsx	Results processing if delivering cool-ing to both primary and secondary target group where the MARR of the cooling company is 10 %
A9	All consumers connected - MARR IRR.xlsx	Results processing: IRR for DC company when delivering cooling to both primary and secondary target group

A10	All consumers connected - Pipe price 5000.xlsx	Result processing when pipe and digging price is 5000 DKK/m channel and DC is delivered to both the primary and secondary target group
A11	All consumers connected - Pipe price 10000.xlsx	Result processing when pipe and digging price is 10000 DKK/m channel and DC is delivered to both the primary and secondary target group
A12	All consumers connected - Without capital injection.xlsx	Results processing if delivering DC to both primary and secondary target group and the DC consumers not pay a capital injection equal to their own investment if they should by new cooling production facilities
A13	All consumers connected.xlsx	Results processing if delivering DC to both primary and secondary target group
A14	Bilka-Ikea-Nyt OUH - Larger ATES capacity.xlsx	Results processing if delivering DC to Bilka, IKEA and Nyt OUH, where the ATES cooling capacity is increased from 1950 kW to 4648 kW.
A15	Bilka-Ikea-Nyt OUH - Larger cooling demand and without excess heat tax.xlsx	Results processing if delivering DC to Bilka, IKEA and Nyt OUH, where the cooling demand is increase with 20 % for Nyt OUH and Bilka and the excess heat tax is removed
A16	Bilka-Ikea-Nyt OUH - Larger cooling demand.xlsx	Results processing if delivering DC to Bilka, IKEA and Nyt OUH, where the cooling demand is increased with 20 % for Bilka and Nyt OUH.
A17	Bilka-Ikea-Nyt OUH - Larger cooling demand-without excess heat tax-and SP HP reduced.xlsx	Results processing if delivering DC to Bilka, IKEA and Nyt OUH, where the excess heat tax is removed and the spot price cost to the heat pump in relation to ATES is reduced with 58 %
A18	Bilka-Ikea-Nyt OUH Without Excess heat tax.xlsx	Results processing if delivering DC to Bilka, IKEA and Nyt OUH, without the excess heat tax
A19	Bilka-Ikea-Nyt OUH.xlsx	Results processing if delivering DC to Bilka, IKEA and Nyt OUH.
A20	Change in Excess heat tax.epp	energyPRO-file if delivering DC to both primary and secondary target group, where the excess heat tax change to be for the COP above 3 for the heat pump in relation to ATES

A21	Change in Excess heat tax_all consumers connected.xlsx	Results processing if delivering DC to both primary and secondary target group, where the excess heat tax change to be for the COP above 3 for the heat pump in relation to ATES
A22	Only primary target group - MARR IRR.xlsx	Results processing: IRR for DC company when delivering cooling to primary target group
A23	Only primary target group - Without capital injection.xlsx	Results processing if delivering DC to primary target group and the DC consumers not pay a capital injection equal to their own investment if they should by new cooling production facilities
A24	Only primary target group.xlsx	Results processing if delivering DC to the primary target group
A25	Referece_20 % less cooling demand.epp	energyPRO-file: 20% reduction in all consumers cooling demand for the reference situation (without DC)
A26	Referece_Bilka120-IKEA-Nyt OUH120_Larger cooling demand.epp	energyPRO-file: 20 % reduction in Bilka and Nyt OUH cooling demand – simulation of the reference situation in relation to determine the business case for delivering DC to bilka, IKEA and Nyt OUH
A27	Referece_Without DC.epp	energyPRO-file: Simulation of existing solution without DC for both the primary and secondary target group (**energyPRO-model 1**)
A28	Referece_Without DC_Only primary target group.epp	energyPRO-file: Simulation of existing solution without DC for the primary target group only
A29	Model 2 (with DC).epp	energyPRO-file: Simulation of DC solution with both primary and secondary target group (**energyPRO-model 2**)
A30	With DC_20 % less cooling demand.epp	energyPRO-file: Simulation of DC solution where all consumers cooling demand is reduced by 20 %
A31	With DC_Bilka-IKEA-Nyt OUH - Larger ATES capacity.epp	energyPRO-file if delivering DC to Bilka, IKEA and Nyt OUH, where the ATES cooling capacity is increased from 1950 kW to 4648 kW.
A32	DC model with correct modelling of ATES - heat pump and low temperature heat storage included.epp	Further development of **energyPRO-model 2, where ATES is modelled with heat pump and low temperature storage in energyPRO**. This make the simulation more accurate, but the model takes a lot of time to run, when the DC

		cold storage is set to some reasonable value such as 4,000 m^3
A33	With DC_Bilka-IKEA-Nyt OUH.epp	energyPRO-file if delivering DC to Bilka, IKEA and Nyt OUH.
A34	With DC_Bilka-IKEA-Nyt OUH-larger demand.epp	energyPRO-file if delivering DC to Bilka, IKEA and Nyt OUH, where the cooling demand is increased with 20 % for Bilka and Nyt OUH.
A35	With DC_absorption and adsorption chiller turn off.epp	EnergyPRO-file when delivering DC to both primary and secondary target group, where absorption and adsorption chiller is turn off
A36	With DC_Only primary target group.epp	EnergyPRO-file when delivering DC only to the primary group. Based on energyPRO-model 2 (A29 / Model 2 (with DC).epp)
A37	DC priority codes.epp	energyPRO-file based on energyPRO-model 2, where all the production units is in operation.
A38	Absorption potential_Absorption chiller 5 MW.xlsx	Data processing of energyPRO-model A39.
A39	Absorption potential_Absorption chiller 5 MW_Summer.epp	EnergyPRO-model of potential of 5 MW absorption chiller if heat at 100 DKK/MWh heat is available the whole summer
A40	Only electrical chiller.xlsx	Data processing, when the DC solution is based on a 10 MW electrical chiller and DC is delivered to both the primary and secondary target group
A41	Only electrical chiller.epp	EnergyPRO-model where DC is delivered to both the primary and secondary target group. The only production unit is a 10 MW electrical chiller.
A42	Bilka-Ikea-Nyt OUH_pipe price 5175 DKK per meter.xlsx	Data processing for delivering DC to Bilka, IKEA and Nyt OUH if the digging and pipe price is 5180 DKK/meter channel.
Folder: Offers		
B1	Absorption chiller_1MW_Thermax offer.docx	Offer on 1 MW absorption chiller from Thermax with hot water inlet temperature of 78 ℃ , chiller water inlet temperature of 18 ℃ and chiller inlet outlet temperature of 9 ℃

B2	Absorption chiller_2MW_Thermax offer.docx	Offer on 2 MW absorption chiller from Thermax with hot water inlet temperature of 78 ℃ , chiller water inlet temperature of 18 ℃ and chiller inlet outlet temperature of 9 ℃
B3	Absorption chiller_5MW_Thermax offer.docx	Offer on 5 MW absorption chiller from Thermax with hot water inlet temperature of 78 ℃ , chiller water inlet temperature of 18 ℃ and chiller inlet outlet temperature of 9 ℃
B4	Adsorption chiller-1MW-Bry-air.pdf	Offer on 1 MW adsorption chiller from Bry-air with hot water inlet temperature of 78 ℃ , chiller water inlet temperature of 18 ℃ and chiller inlet outlet temperature of 9 ℃
B5	Electrical chiller_brochure calculation-2MW modules-Johnson Control.pdf	Offer on electrical chiller from Johnson Control – brochure on electrical chiller
B6	Electrical chiller_COP calculation-2MW modules-Johnson Control.pdf	Offer on electrical chiller from Johnson Control – calculation of COP-cooling value
Folder: Main folder		
C1	Calculation of when block 8 and the wast incineration plant only produce.xlsx	Excel-file with Fjernvarme Fyn heat demand in 2016 including losses in the network. Used to calculate the hours with free capacity on the straw plant (block 8) and the waste incineration plant
C2	Primary and secondary_Pipe dimension.xlsx	Excel-sheet to choose pipe dimension when delivering DC to the primary and secondary target group
C3	Primary and secondary_Pump work.xlsx	Excel-sheet to calculate pump work when delivering DC to the primary and secondary target group
C4	Primary_Pipe dimension.xlsx	Excel-sheet to choose pipe dimension when delivering DC to the primary target group
C5	Primary_Pump work.xlsx	Excel-sheet to calculate pump work when delivering DC to the primary target group
C6	Nyt OUH cooling demand.xlsb	Estimation of Nyt OUH cooling demand separated in comfort cooling and process cooling
C7	Electricity price DK1 from Nord Pool Spot - formatted to EnergyPRO.xlsx	DK1 electricity price to use in all energyPRO files
C8	Bilka cooling data prepared to energyPRO.xlsx	Calculation of cooling demand based on electricity consumption (B9 and B10)

C9	Bilka raw comfort cooling data 2016 section north.xls	Bilka electricity consumption data received for comfort cooling in the north section of the store – received from Bilka
C10	Bilka raw comfort cooling data 2016 section south.xls	Bilka electricity consumption data received for comfort cooling in the south section of the store – received from Bilka
C11	IKEA comfort cooling 2016.xlsx	Comfort cooling data received from Peer Andersen at Fjernvarme Fyn
C12	ATES HP COP calculation of 9 degree Celcius.plt	CoolPack file, which calculate the COP value of the ATES heat pump with a condensing temperature of 78 ℃ and an evaporating temperature of 9 ℃
C13	ATES HP COP calculation of 16 degree Celcius.plt	CoolPack file, which calculate the COP value of the ATES heat pump with a condensing temperature of 78 ℃ and an evaporating temperature of 16 ℃
C14	Fjernvarme Fyn production units_version 2016.docx	Fjernvarme Fyn production units overview with heat and electricity capacity from Peer Andersen from Fjernvarme Fyn
C15	Fjernvarme Fyn heat marginal price.xlsx	Fjernvarme Fyn production units heat marginal price from Peer Andersen from Fjernvarme Fyn
C16	Fjernvarme Fyn heat demand 2016.xlsx	Fjernvarme Fyn heat demand in 2016 with losses
C17	Rosengårdcentret raw comfort cooling 2016.xlsx	Raw comfort cooling data in kWh electricity from Rosengårdcentret. The excel-sheet include calculation of GAU and GUF used in the energyPRO-model 1 and 2.
C18	Nyt OUH technical suggestion from Fjernvarme Fyn.pdf	Fjernvarme Fyn technical suggestion for the setup at Nyt OUH
C19	SDU cooling demand.xlsx	SDU cooling demand
C20	Datasheet Bilka electrical chillers.pdf	Datasheet for Bilka two electrical chillers

15.2 Description of the cooling customers

15.2.1 IKEA

IKEA receive comfort cooling from two electrical chillers installed with an individual cooling capacity of 750 kW. The electrical chillers are combined to one in energyPRO because they are assumed to have the same COP-cvalue. The COP-c value is set to 3.55, which is the average value used at Bilka. The production facilities for these two customers are assumed to be similar in their performance. The IKEA site in energyPRO is shown in Figure 15.1. The electrical chillers are owned by Fjernvarme Fyn and are intended as a temporary solution until a DC solution is installed in the area.

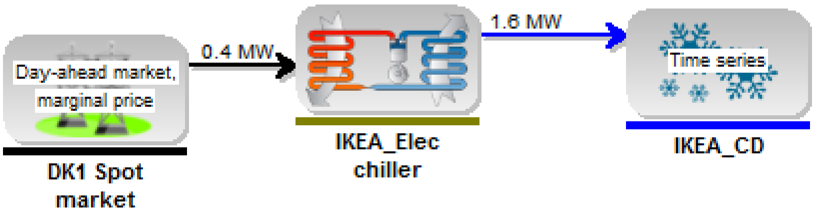


Figure 15.1 IKEA site in energyPRO. The two 750 kW electrical chillers are combined to one called IKEA_Elec chiller. The IKEA_Elec chiller by electricity from the DK1 spot market. The cooling demand (IKEA_CD) is based on hourly cooling demand data from Fjernvarme Fyn.

Fjernvarme Fyn has delivered IKEA´s hourly cooling demand, supply temperature and return temperature the year 2016, which is placed in Appendix 15.1 C11. The hourly cooling demand is inserted as a "time series" in energyPRO. The total yearly comfort cooling demand is equal to 433 MWh in 2016.

15.2.2 Bilka[135]

Bilka have three electrical chillers delivering comfort cooling:

- Two main electrical chiller which convers each their parts of the store apart from the "bistro" area. The datasheet is located in Appendix 0.
- One electrical chiller covers the "bistro area" with a capacity of 50 kW

The Bilka cooling demand site for in energyPRO is shown in Figure 15.2.

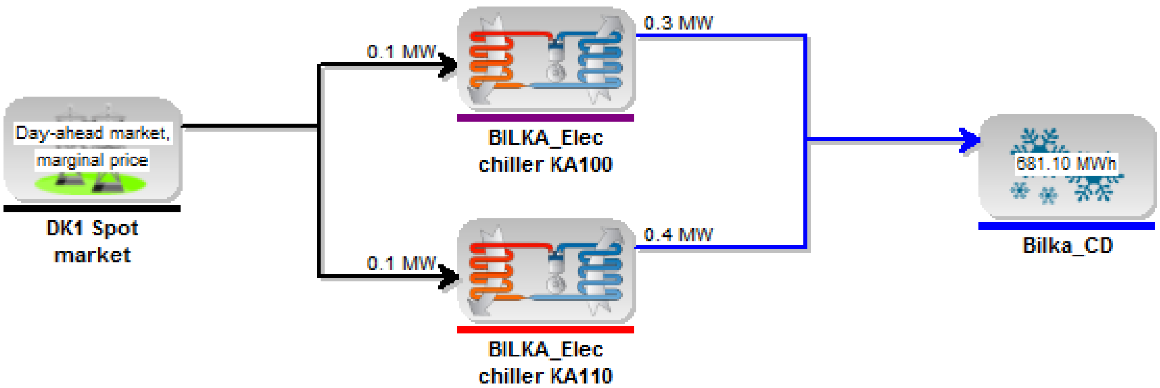


Figure 15.2 Bilka site in energyPRO. Bilka_CD is Bilka cooling demand. BILKA_Elec chiller KA100 and BILKA_Elec chiller KA110 is the two main electrical chillers. The two electrical chillers purchase electricity from the DK1 spot market.

The current cooling solution is based on a refrigerant sent around in the store to the individual cooling coils. The temperature range of the current solution varies from the planned DC temperature, which will add some costs when to switching to a DC solution. If any leakage event occurss on their cooling system, they are not allowed to fill their system with the same refrigerant. Thereby Bilka will need to make an investment in a new cooling system and in such situation, it makes sense to switch to DC, if it is cheaper than a new individual cooling solution cf. John Christensen, Section manager at technical department in Bilka.

[135] This section is based on an interview with John Christensen, Section manager at technical department in Bilka.

Bilka have supplied monthly electrical consumption data for the two main electrical chillers (see electrical consumption data in Appendix 15.1 C9 and 15.1 C10) and because the "bistro" area is small compared to the rest of the cooling area it is neglected in the calculation of the total cooling demand in Bilka (located in Appendix 15.1 C8). The monthly cooling demand is calculated as the electrical consumption multiplied by an average COP-c value of the two electrical chillers given in the datasheet as 3.52 and 3.56. The total comfort cooling demand is 681 MWh. Bilkas cooling production units are undersized cf. John Christensen and thereby they will consume more cooling if they were connected to a DC. This factor is not included in the energyPRO-model 2 but will be considered in the sensitivity analysis in section 12.2 and section 0 because the extra cooling demand is unknown.

Bilkas cooling strategy is to cool 2 ℃ below the outdoor temperature to give the customers a sense of comfortable cooling, when entering Bilka. Cf. Palle Mathiasen from Udvikling Fyn it is a good assumption that the production costs for cooling demand at $\Delta T = 2℃$ is independent of the outdoor temperature. It is defined in energyPRO that cooling needs to be applied at an outdoor temperature of above 18 ℃ (called reference temperature). This temperature may seem low, but the indoor temperature is higher than the outdoor temperature in the summer because of internal gains. 70 % of the cooling demand is degree day dependent based on the electrical consumption data. The electrical chillers are set to produce cooling from 04:00 to 22:00. This time window is adjusted until the cooling demand match the cooling production capacity. The defined cooling demand in energyPRO is shown in Figure 15.3.

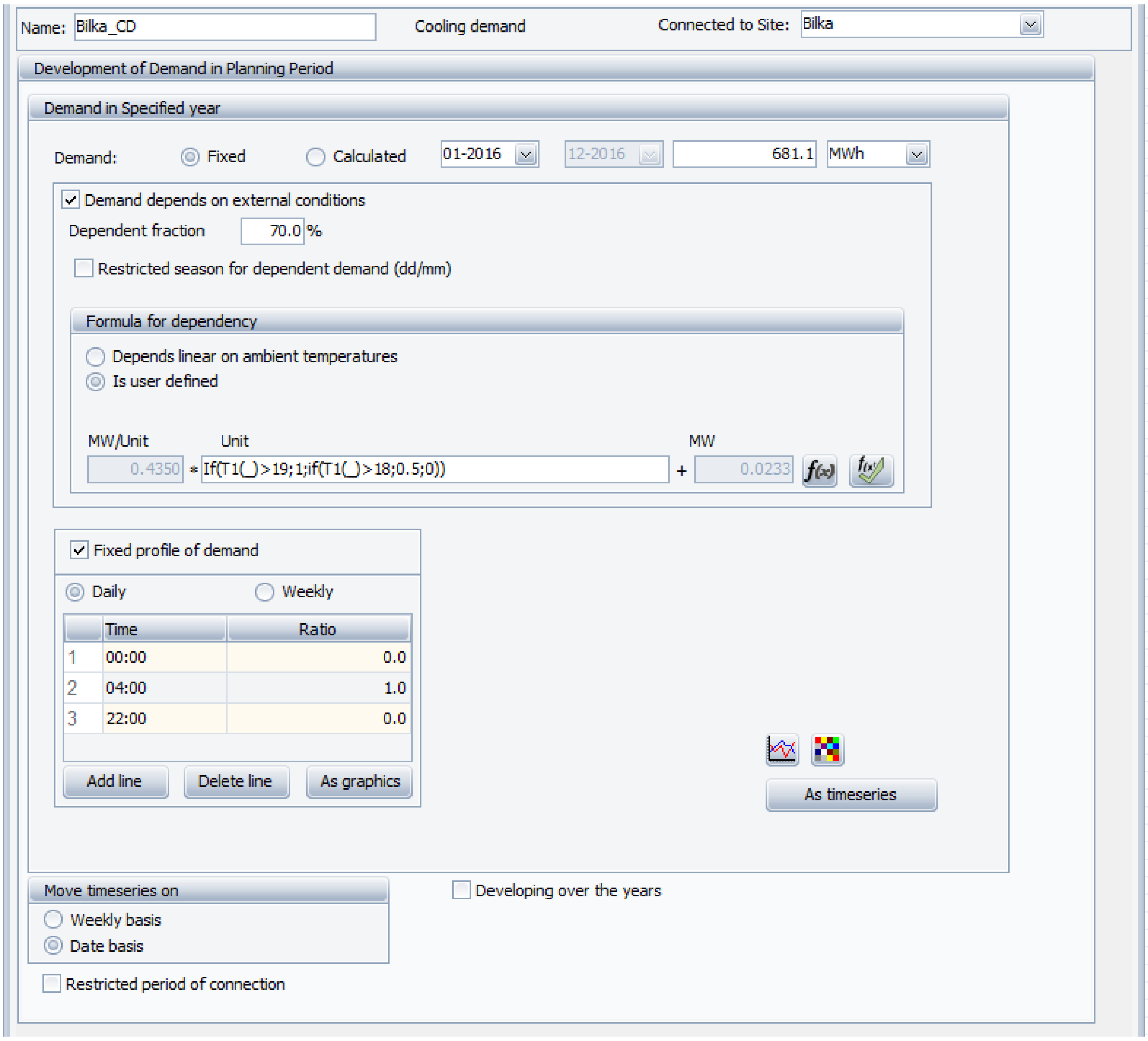


Figure 15.3 Bilka cooling demand in energyPRO. The total cooling demand is calculated to be 681 MWh where 70 % is degree day dependent. The "formula for dependency" calculates the hourly cooling demand based on the outdoor temperature [T1(_)]. Cf. the formula cooling is applied, when the outdoor temperature is above 18 ℃. When the outdore temperature is between 18 ℃ and 19 ℃ the cooling

demand is assumed half of the energy needed to reduce the indoor temperature of 2 ℃. It is defined that Bilka only has a cooling demand from 04:00 to 22:00.

15.2.3 Rosengårdcentret

Rosengårdcentret has delivered monthly electrical consumption data for the central comfort cooling system which is located in Appendix 15.1 C17. Some of the stores in Rosengårdcentret have their own comfort and/or process cooling, but this demand is not included in this project because it will be too time-consuming to gather this data. Instead, the effect of an extra cooling demand will be investigated in the sensitivity analysis.

The COP-c value for Rosengårdcentret central cooling solution has been received. Palle Mathiasen from Udvikling Fyn has advised that the COP-cvalue received from Rosengårdcentret seems too high and a more realistic COP-c value is 3 cf. Appendix 15.20. To avoid biased results, a COP-c value of 3.55 is used for Rosengårdcentret which is similar to the value used for the Bilka and IKEA. Rosengårdcentrets total comfort cooling demand is calculated to 2294 MWh. 92.3 % is degree day dependent based on the electrical consumption data placed in Appendix 15.1 C17. The cooling strategy is to cool down to a temperature of 20-22 ℃ cf. Appendix 15.20. Rosengårdcentret site in energyPRO is shown in Figure 15.4. The cooling demand profile defined in energyPRO is shown in Figure 15.5.

Figure 15.4 Rosengårdcentret site in energyPRO. Rosengårdscentret_Elec chiller is the electrical chiller placed at Rosengårdcentret. The electrical chiller purchase electricity from the "DK1 Spot market". "Rosengårdscentret_CD" is the cooling demand for Rosengårdcentret. The configuration of this cooling demand in energyPRO is shown in Figure 15.5.

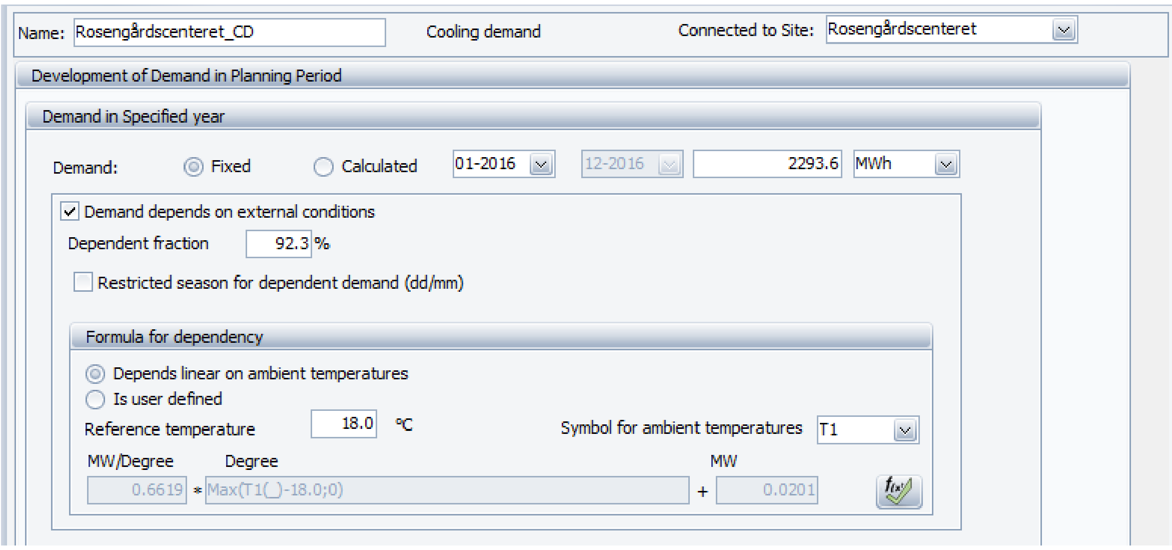


Figure 15.5 Rosengårdscentret cooling demand profile in energyPRO. 92.3 % is set to be degree dependent based on the electrical consumption. The three first and last months in the year are used to calculate the percentage degree-day dependent usage. Cooling is applied at an outdoor temperature [T1(_)] above 18 ℃.

15.2.4 Nyt OUH

The cooling demand used in energyPRO is based on data received from Janus Lading, a former employee at Medic OUH. This data includes hourly estimations of the cooling demand. The total cooling demand equals 8993 MWh and is a combination of both comfort and process cooling.

The taxes (electricity tax, described in more detailed in section 9.1) in relation to produced cooling depends highly on the cooling usage and which indicate, that the comfort cooling needs to be separated from the process cooling. It is assumed that the first and last three months of the year is process cooling only. The average hourly cooling of the selected period is calculated. When the hourly cooling demand in the summer months are above the average hourly process cooling demand, the extra cooling demands are assumed to be comfort cooling. The data received from Janus and the separation of the process and comfort cooling can be found in Appendix 15.1 C6. An hourly representation of the cooling demand for respectively comfort cooling and process cooling is shown in Figure 15.6 and Figure 15.7.

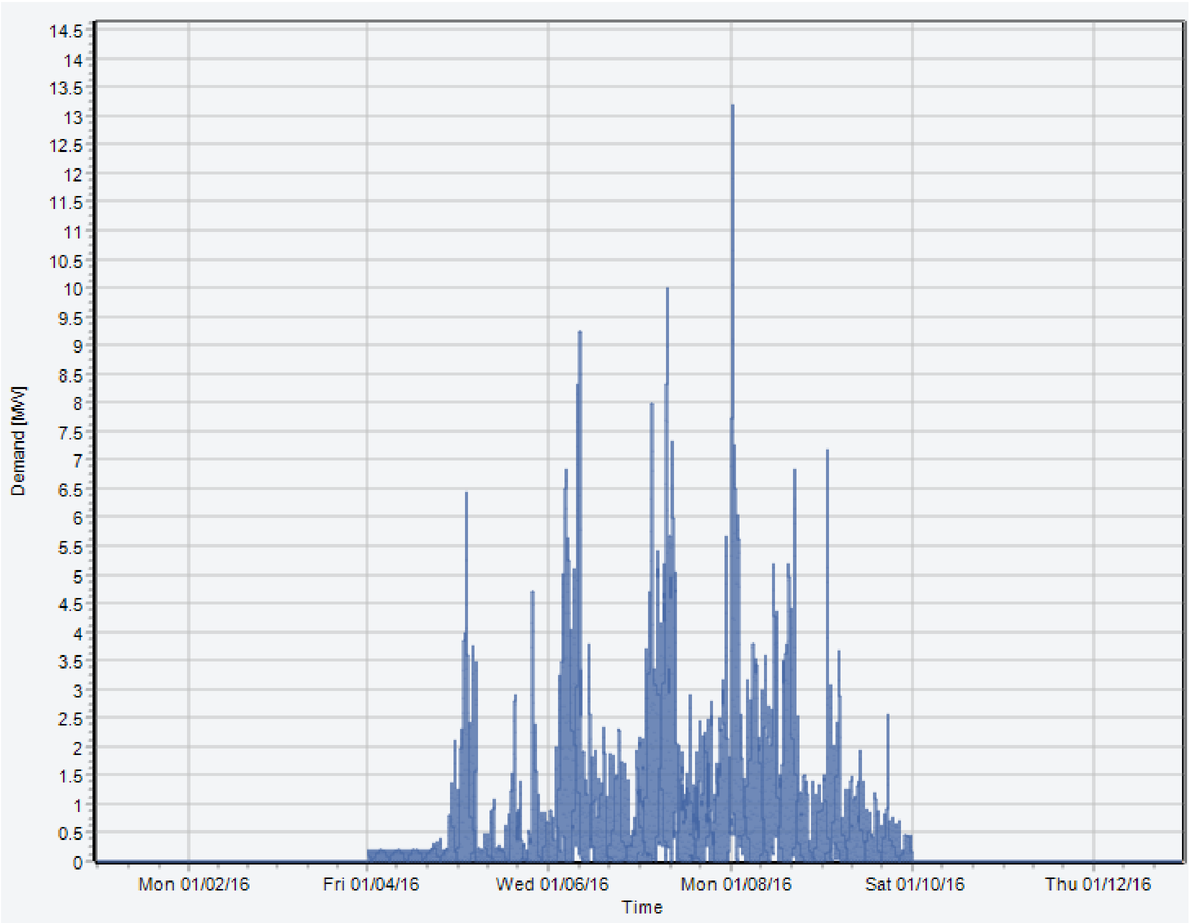


Figure 15.6 Estimated comfort cooling at the Nyt OUH site – Demand [MW] as function of time. The cooling demand is called "Nyt OUH_GAF" in energyPRO.

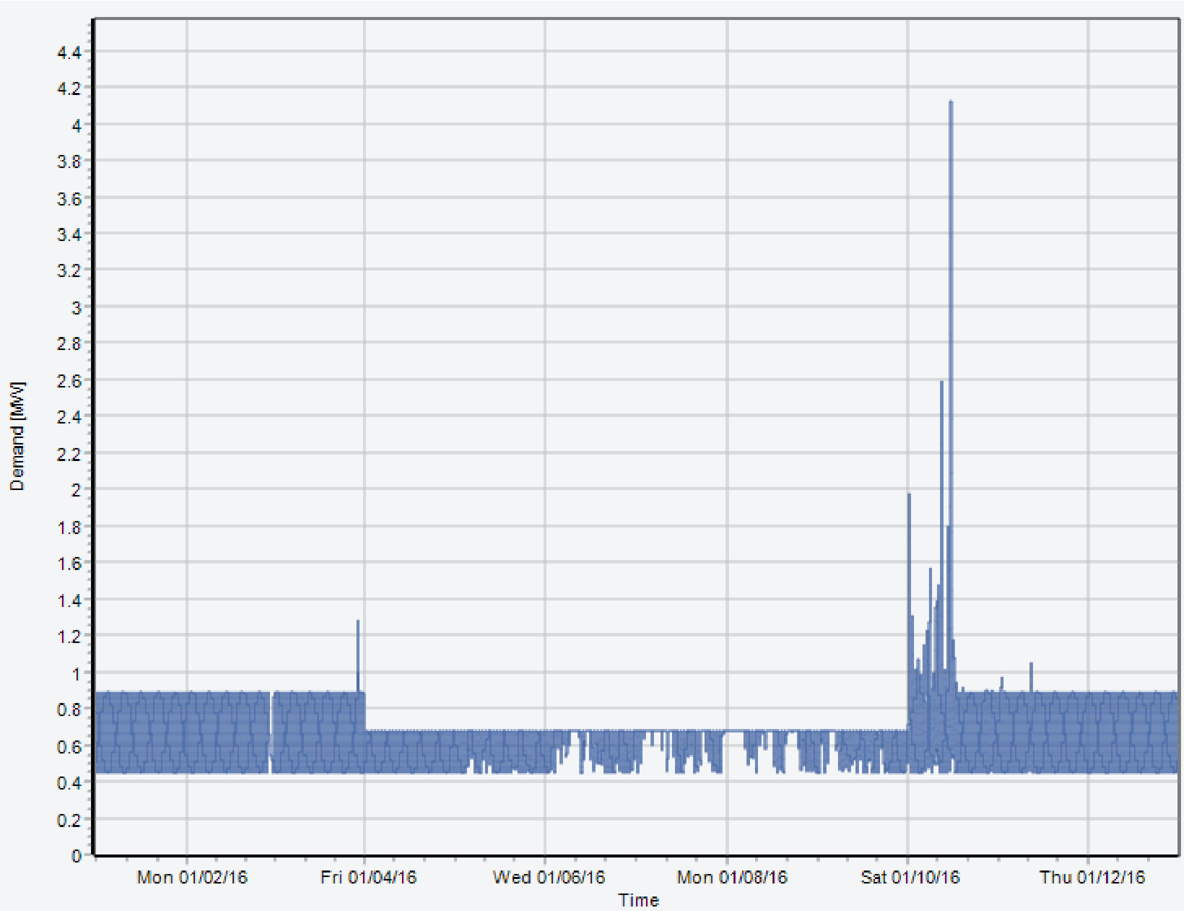


Figure 15.7 Estimated process cooling at the Nyt OUH site - Demand [MW] as function of time. The cooling demand is called "Nyt OUH_GUF" in energyPRO.

The production units to be implemented at the "Nyt OUH" site in energyPRO is based on Fjernvarme Fyn suggestion to a cooling solution (see Appendix 15.1 C18). The suggested solution from Fjernvarme Fyn is:

- Electrical chiller with a capacity of 7.1 MW cooling
  Dry cooler with a capacity of 7.1 MW cooling.
- Cold storage of 1300 m^3 with a temperature at the top of the cold storage equal 18 ℃ and at the bottom 12 ℃.

The final setup of the Nyt OUH site in energyPRO is shown below.

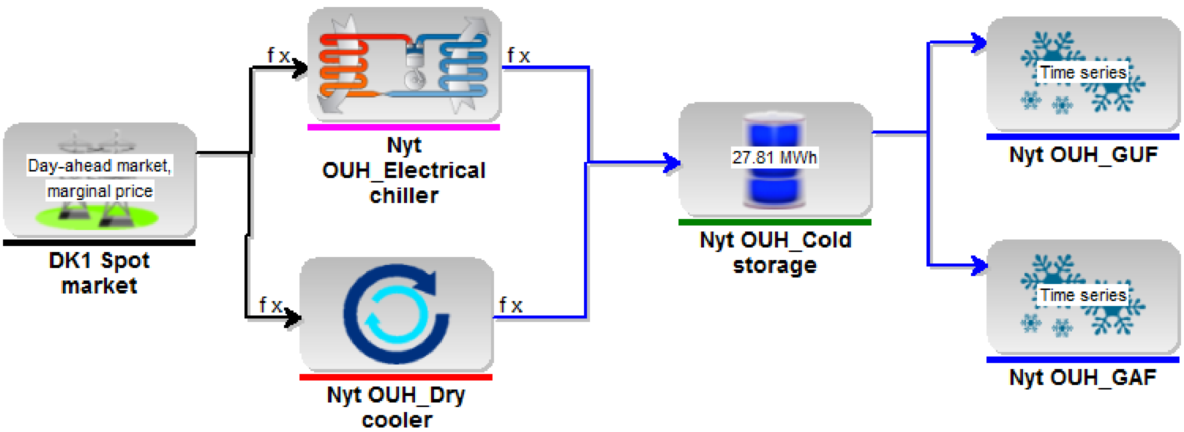


Figure 15.8 Nyt OUH site in energyPRO. The cooling production units are based on suggestions from Fjernvarme Fyn. The cooling demand is based on the hourly estimations from Janus Lading, a former employee at Medic OUH. The cooling demand is separated in process cooling ("Nyt OUH_GUF") and comfort cooling ("Nyt OUH_GAF"). The cold storage ("Nyt OUH_Cold storage") is set a bit higher than Fjernvarme Fyn suggestion because the assumed cooling peaks are higher in Janus Ladings calculation than Fjernvarme Fyns calculations. The Nyt OUH_Dry cooler will operate below 10 ℃ only. The electrical chiller is configured to operate above 10 ℃.

The electrical chiller is split op in two modes:

1) The electrical chiller is based on the vapor compression refrigeration cycle, where the heat from the condenser is chilled away through DH or by the dry cooler. This is assumed to be the case, when the temperature is above 10 ℃ and is represented by "Nyt OUH_Electrical chiller".
2) The dry cooler is used partly or completely to chill the heat away and is represented by "Nyt OUH_Dry cooler". The dry cooler can only deliver cooling below 10 ℃ cf. the offer from Fjernvarme Fyn.

The COP-c value of the electrical chiller is assumed to equal 4.97 which is the same COP-c value given in the offer for the electrical chiller for the DC solution, when mode 1 is used (see Appendix 15.12 / 15.1 B6 for the offer). It will be biased to set the COP-c value for Nyt OUH to a lower value than the electrical chiller in a DC solution because Nyt OUH has a larger cooling demand than the cooling demand for all the other customers together (as shown in Table 6.1).

The COP-c value of the dry cooler depends a lot on the outdoor temperature and best practice is to make a temperature dependent function for the electricity consumption, but this functionality is currently out of order in energyPRO. An average COP-c value have been used instead. The dry cooler in the offer from Johnson Control have a COP-c value of 30 when the outdoor temperature is below or equal to 2 ℃. The COP-c value above 10 ℃ is given as 4.97 in the offer. An average COP-c value of 17.485 has been used. The configuration of the dry cooler is shown in the figure below (Figure 15.9).

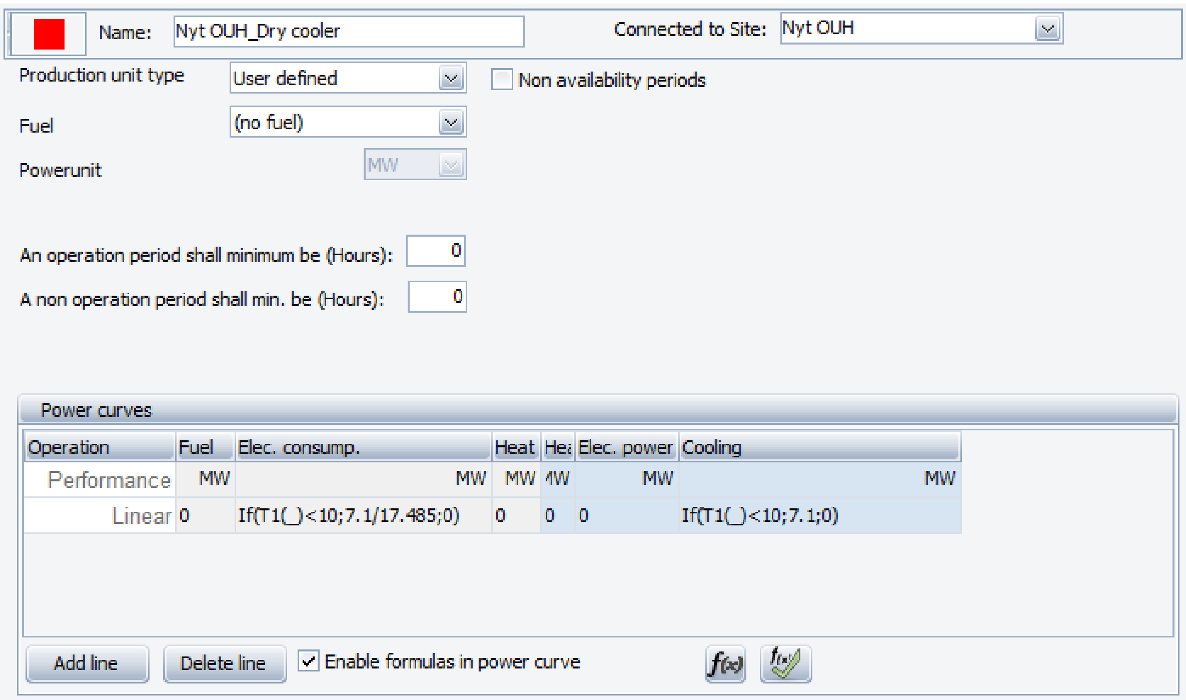


Figure 15.9 Configuration of the dry cooler at the Nyt OUH site in energyPRO. The dry cooler produces cooling at full capacity when the outdoor temperature [T1(_)] is below 10 ℃. The electricity consumption is calculated based on an average COP-c value equal to 17.485.

The electrical chiller is set to produce cooling above 10 ℃ as shown in Figure 15.10.

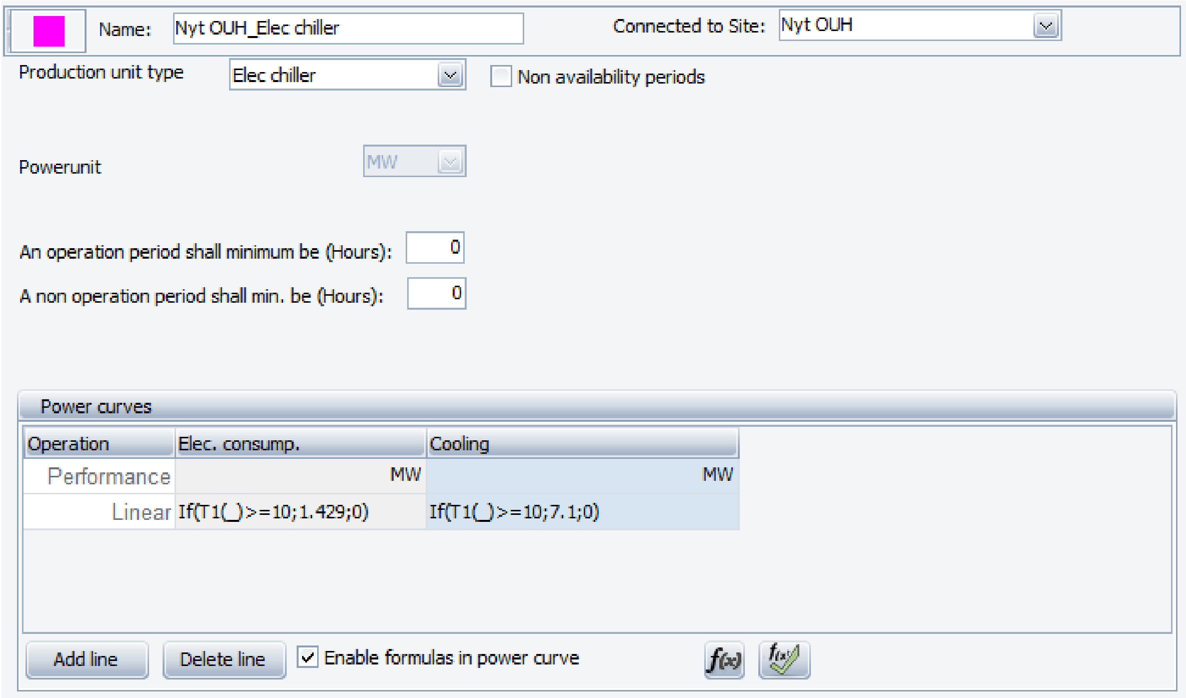


Figure 15.10 Configuration of the electrical chiller at the Nyt OUH site in energyPRO. The electrical chiller produces cooling at full capacity when the outdoor temperature [T1(_)] is above or equal to 10 ℃.

The volume of the cold storage ("Nyt OUH_cold storage" in Figure 15.11) is set to 4000 m^3 instead of 1300 m^3 as suggested by Fjernvarme Fyn. The reason is that Fjernvarme Fyn estimates a peak cooling demand of 9.2 MW, where Janus Lading estimates a higher peak cooling demand equal to 13.9 MW. A cold storage of 1300 m^3 cannot cover this peak. The ambient temperature is close to the temperature of cold storage which results in a negligible heat loss. In the model, the heat loss is set to zero. The configuration of the cold storage is shown in the figure below.

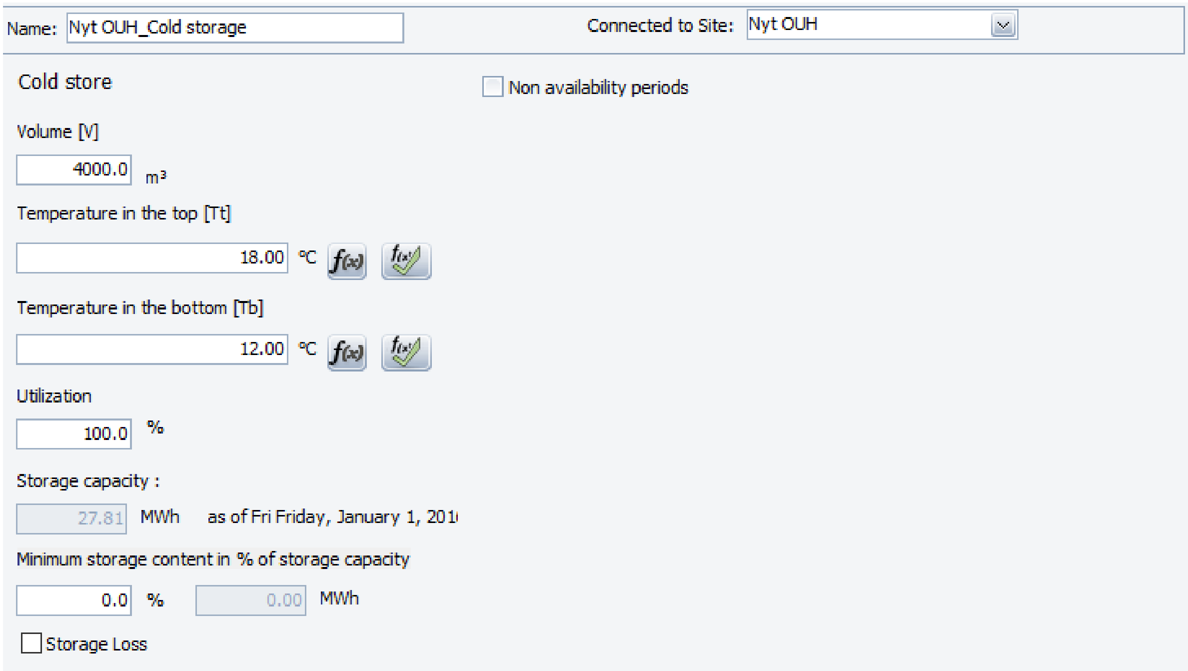


Figure 15.11 Configuration of cold storage at the Nyt OUH site in energyPRO. The volume of the cold storage at Nyt OUH is set to 4000 m^3. The temperature of the storage is set to 12 in the button and 18 in the top as suggested by Fjernvarme Fyn. Because the temperature of the storage is around the ambient temperature the loss is neglected.

15.2.5 University of Southern Denmark (SDU)[136]

SDU use cooling for three applications as shown in Table 15.1, which also include the type of cooling and the source of cooling.

Cooling type	Usage	Cooling delivered by
Process cooling	Laboratories at the engineer-ing faculty	2 electrical chillers and 1 free cooling unit
Process cooling	Servers	3 electrical chillers and 1 free cooling unit
Process cooling	Supercomputer	1 electrical chiller and 1 free cooling unit

Table 15.1 The tree pools of cooling demand at SDU.

To simplify the energyPRO-model the three individual cooling demands in Table 15.1 is combined to one cooling demand, the electrical chillers are combined to one electrical chiller and the free coolers are combined to one free cooler.

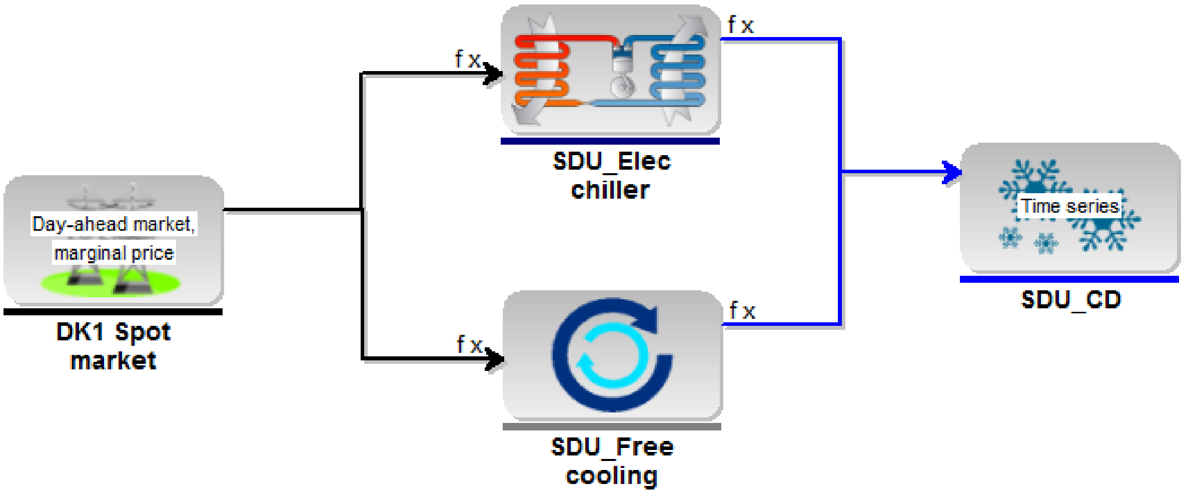


Figure 15.12 SDU site in energyPRO. "SDU_Elec chiller" represent the 6 electrical chillers. "SDU_Free cooling" represent the 3 free coolers. "SDU_CD" is SDU cooling demand based on received hourly data from technical service at SDU. The electrical chiller and free cooler purchase electricity at the "DK1 Spot market".

The combined electrical chillers and free coolers have a cooling capacity of around 750 kW and 250 kW, respectively. The free cooler and electrical chiller do not produce at the same time. The strategy implemented in energyPRO is that the electrical chiller produces when the outdoor temperature is above or equal to 10 ℃ and the free cooler produce when the outdoor temperature is below 10 ℃. The COP-c value for the electrical chiller is assumed to equal 3.55 as the same COP-c value used at Bilka.

The free cooler COP-c value is based on an average between 3.55 and 30, where the lower COP-c value, for high ambient temperature conditions, are given by Johnson Control. Figure 15.13 and Figure 15.14 shows the configuration of the electrical chiller and free cooler in energyPRO, respectively.

[136] All relevant data and information about SDU cooling solution is received from technical service at SDU through Nicolaj Tidemand Haagensen and Anders Bloch, which are two SDU students their work on a project with a combined heat pump between SDU and Nyt OUH

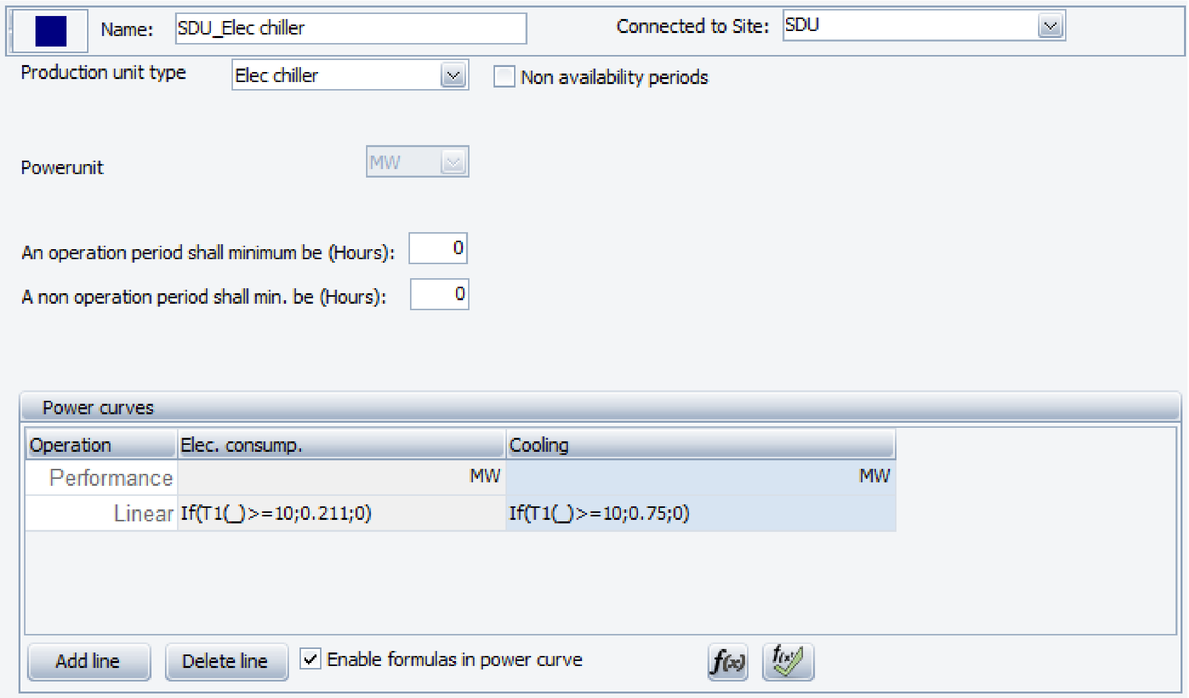


Figure 15.13 Configuration of the electrical chiller at the SDU site. The electrical chiller has a production capacity of 750 kW cooling when the outdoor temperature [T1(_)] is above or equal to 10 ℃.

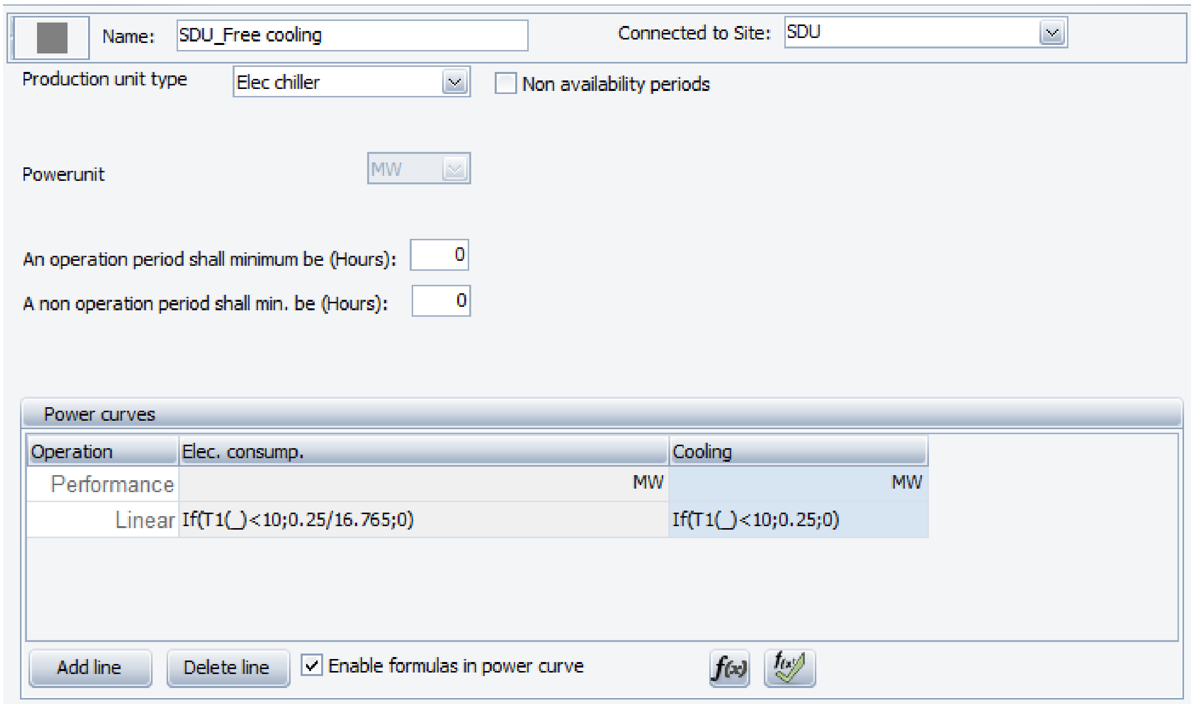


Figure 15.14 Configuration of the free cooler at SDU. The free cooler has a production capacity of 250 kW cooling, when the temperature is below 10 ℃.

Hourly cooling demand data is received from technical service.[137] This data is separated in server cooling and electricity used for cooling. The data can be found in Appendix 15.1 C19. The electricity consumption to produce cooling need to be converted to a cooling demand. Multiply the COP-c value with the electricity consumption and add it with the server cooling give the cooling demand. The total process cooling demand equals 1259 MWh.

[137] The data is received from two students at SDU - Nicolaj Tidemand Haagensen and Anders Bloch

It should be noted that the SDU cooling profile differs from the profiles, where comfort cooling is used such as at Rosengårdcentret. The process cooling demand is used more or less independent of the outdoor temperature. This is illustrated in the figure below:

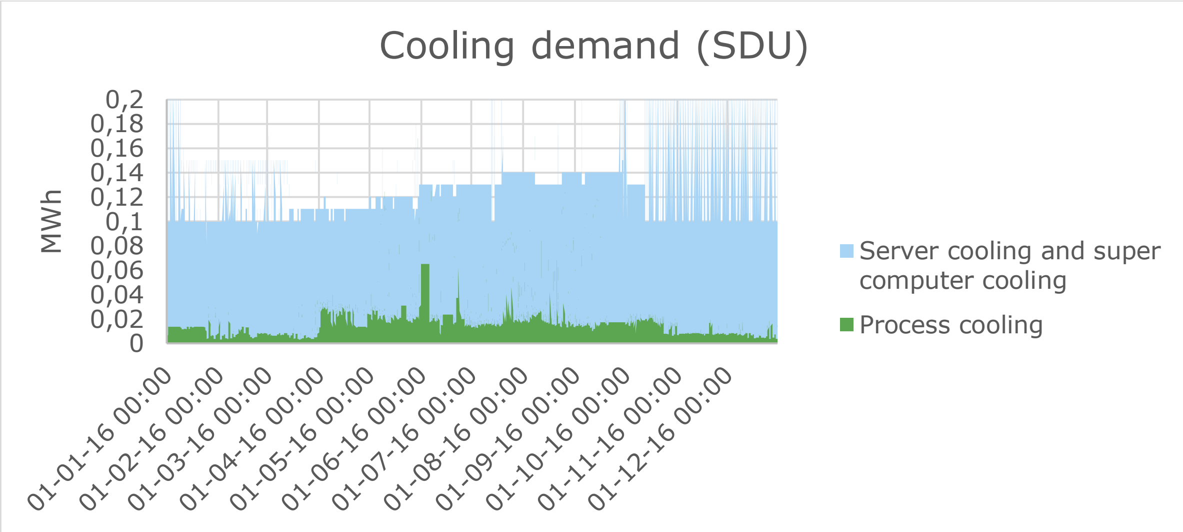


Figure 15.15 Cooling demand at SDU based on the two types of applications: server cooling and process cooling.

15.3 Offer from Bry-Air on F-330 Adsorption chiller: Mail conversation

Attached same.

On 3/10/2017 8:07 PM, Martin Grunnow Vinstrup wrote:
Great ☺

Can I receive the data sheet for this working condition?

From: Vijay [mailto:vraina@pahwa.com]
Sent: Friday, March 10, 2017 3:11 PM
To: Martin Grunnow Vinstrup <mvins14@student.sdu.dk>
Cc: Klaus Christian Jespersen <kljes14@student.sdu.dk>
Subject: Re: ADC-Website: Bry-Air: Feedback from Website

Yes it is possible.

We can provide you IN/OUT-----18/9 Deg C chilled water profile in our chiller.

Regards

Vijay

On 3/10/2017 7:33 PM, Martin Grunnow Vinstrup wrote:
I'm sorry – the mail I sent before were completely wrong.

Is it possible that I can get the data for a **chilled water inlet temperature of 18 ℃** and **outlet of 9 ℃**. With the hot water Inlet temperature keep at 78 ℃.

From: Vijay [mailto:vraina@pahwa.com]
Sent: Friday, March 10, 2017 2:47 PM
To: Martin Grunnow Vinstrup <mvins14@student.sdu.dk>
Cc: Klaus Christian Jespersen <kljes14@student.sdu.dk>
Subject: Re: ADC-Website: Bry-Air: Feedback from Website

No, I have given you complete offer with technical data sheet of same as a chiller.

Chilled Water Inlet is 14 and outlet is 9 Deg C.

Our machine is chiller and not a heating machine.

We are providing chilled water and not a hot water.

Regards

Vijay

On 3/10/2017 6:42 PM, Martin Grunnow Vinstrup wrote:
Hallo Vijay

Thanks. Is it possible that I can get the data for a chilled water temperature inlet of 9 ℃ and outlet of 14 ℃? With the Hot Water Inlet temperature keep at 78 ℃.

From: Vijay [mailto:vraina@pahwa.com]
Sent: Tuesday, March 7, 2017 2:50 PM
To: Martin Grunnow Vinstrup <mvins14@student.sdu.dk>
Cc: Ashok Prusty <aprusty@pahwa.com>
Subject: Fwd: ADC-Website: Bry-Air: Feedback from Website

Dear Martin,
Greetings from Bry Air,
Based on your below mail, please find attached our techno commercial details for your further study and recommendations in Fjernvarme Fyn for DC projects.
Also please note that there is negligible maintenance required for our Adsorption chillers as negligible moving parts in this chiller.
If you want you can take fixed maintenance cost as USD 8000 Per Annum.
Operation cost is only 1.3 KW power consumption for 335 TR CHILLER.
Hope now above is clear and shall wait for your valuable feedback.
Best Regards

Vijay Raina
Asst. National Sales Manager- Adsorption Chillers.
hot water inlet temperature (K, â„ƒ or â„‰). The desired chiller output temperature is 9 â„ƒ.
If you do not can provide a formula – what is then the COP-value / cooling output at a hot water inlet of 78 â„ƒ and an output chiller temperature of 9 â„ƒ.
- What is the excess heat at the working point: hot water inlet of 78 â„ƒ and an output chiller temperature of 9 â„ƒ?
- Investment cost
- Yearly O&M fixed cost
- O&M variable cost
- Other relevant cost?
Bry-Air (Asia) Pvt. Ltd.,
419-420, Phase-III,Udyog Vihar Gurgaon 122016, India
Email : vraina@pahwa.com, Website : www.bryair.com,
Phone : 91-124-4184444 Extn. 501 Fax : 91-124-4184400,
Mobile No: +91-9821026510

-------- Forwarded Message --------
Subject:ADC-Website: Bry-Air: Feedback from Website
Date: Tue, 7 Mar 2017 09:33:30 +0530
From: Naresh Verma <webmaster@pahwa.com>

To:vraina@pahwa.com
CC:aprusty@pahwa.com, mspaul@pahwa.com, dharmendra@pahwa.com

From: mvins14@student.sdu.dk [mailto:mvins14@student.sdu.dk]
Sent: 06 March 2017 23:53
To: webmaster@pahwa.com
Subject: Bry-Air: Feedback from Website

Name	:	Martin Vinstrup
Company	:	SDU
Email	:	mvins14@student.sdu.dk
City	:	Odense V
Country	:	Denmark
Phone	:	Country Code / City Code / Phone / Extn
Aplication Industry	:	Energy
Comments/Queries	:	Hallo Bry-air

We contacted you last week for economic data and technical data about you absorption chiller. We just want to remind you on this email because it is critical for the project, which will establish the groundwork for our collaboration company Fjernvarme Fyn to determine whether Fjernvarme Fyn should invest in a DC network and an absorption chiller.

The mail with the question sent earlier:
We are two students from the Energy Technology education at The University of Southern Denmark. We are currently working on analyzing the economically potential of converting heat to cooling by using the adsorption technology.

We hope that you can help us

with some technical and economically details about the adsorption chiller F-330 with a rated capacity of 335 RT. We need the following information:
- Refrigeration Capacity / cooling output (%, kW or TR) as function / table of the

--

Regards,

Vijay Raina Asst. National Sales Manager- Adsorption Chillers. Bry-Air (Asia) Pvt. Ltd., 419-420, Phase-III,Udyog Vihar Gurgaon 122016, India
Email : vraina@pahwa.com, Website : www.bryair.com, Phone : 91-124-4184444 Extn. 501 Fax : 91-124-4184400

Det sammenkædede billede kan ikke vises. Filen er muligvis blevet flyttet, omdøbt eller slettet. Kontrollér, at linket peger på den korrekte fil og placering.

Celebrating 50 years... thanks to you!

A global solution provider for Humidity/Moisture Control/Removal, Drying, Gas Phase Filtration & Complete Environmental Control Systems, with subsidiaries in China, Malaysia, Brazil and Switzerland and associate plant in USA.

15.4 Offer from Bry-Air on F-330 Adsorption chiller: PDF attached with offer

BRY-AIR (ASIA) PVT. LTD.

ISO 9001:2008 & 14001:2004 CERTIFIED

Regd. Office: 20, Rajpur Road, Delhi 110054, India • Phone: +91-11-23906666

Corp. Office: 21C, Sector 18, Gurgaon 122015, Haryana, India • Phone: +91 124 4091 111

Plant-I: 419-420, Udyog Vihar III, Gurgaon, Haryana • Phone. +91 124 4184 444 • Fax: +91 124 4184 400.CIN:U74210DL1981PTC012456

Date: 10.03.2017
Ref: ADC/DEN/ E NO.100001 and Q NO. EEU000058/2017-18

The University of Southern Denmark
Odense V
Denmark.N

Kind Attn: Martin Vinstrup

Subject: **Your requirement for Hot Water Driven based Adsorption Chiller.**

Dear Sir,

We thank you for your interest & the enquiry for the adsorption chiller.

We take pleasure in submitting our techno commercial proposal for Adsorption Chiller based on Hot Water Heat Source to generate chilled water.

The Adsorption Chiller, is manufactured by Bry-Air under technical licensee from Power Partners, Inc USA.

Bry-Air, an **ISO-9001 & ISO-14001 company**, has been at the forefront of desiccant dehumidification globally. It utilizes the world's best research and development facilities and manufacturing practices, to ensure not only swift supply of consistently high quality products, but also to provide continuous inputs to further improve the existing line of activities and develop new 'state of the art' technologies. The company maintains own offices at Malaysia, China, Philippines, Indonesia, Vietnam, Bangladesh, Nigeria, Brazil, Australia, UAE and USA, and has dedicated marketing agents in 40 other countries

We hope you will find the above in line with your requirements.

In case of any clarifications, please feel free to get in touch with us.

Thanking you and assuring you of our best services at all times.

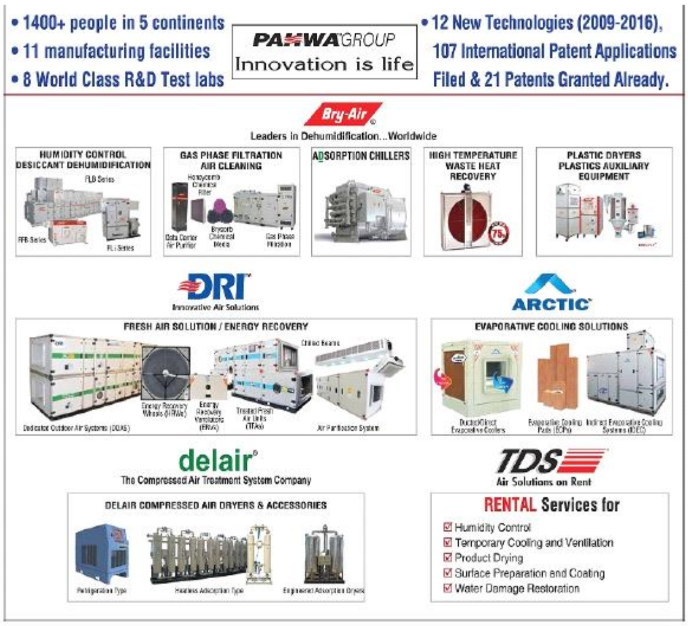
for **Bry-Air (Asia) Pvt. Ltd.**

Raina

Vijay Raina

Customer Name : SDU Page 1
Date : 10.03.2017
Proposal No. : **ADC/DEN/E NO. 100001 and Q NO.EEU000058/2017-18**

PRODUCT RANGE OF PAHWA GROUP

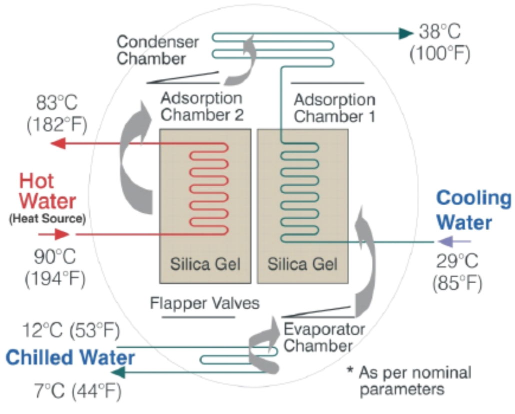


INDEX

Section -1

Desiccant based Vapour Adsorption Cooling Principle

How our adsorption chiller works



Operating Principle

The principle of adsorption works with the interaction of gases and solids. With adsorption chilling, the molecular interaction between the solid and the gas allow the gas to be adsorbed into the solid. The adsorption chamber of the chiller is filled with solid material, silica gel, eliminating the need for moving parts and eliminating the noise associated with those moving parts. The silica gel creates an extremely low humidity condition that causes the water refrigerant to evaporate at a low temperature.

As the water evaporates in the evaporator, it cools the chilled water. The adsorption chiller has four chambers; an evaporator, a condenser and two adsorption chambers. All four chambers are operated at nearly a full vacuum.

BRY AIR Adsorption chiller uses a simple refrigeration process

The chiller cycles the adsorption chambers 1 and 2 between the processes of adsorbing and desorbing. In the figure above, the water vapor flashes off the surface of the tubes in the evaporator, creating the chilling effect captured in the output of chilled water. The water vapor enters Chamber 1 through the open ports in the bottom of the chamber and is adsorbed into the silica gel in Chamber 1. Cool water is circulated in this chamber to remove the heat deposited in Chamber 1 by the adsorption process.

Hot water enters Chamber 2 to regenerate, or desorb, the silica gel while Chamber 1 is in the adsorption process. The water vapor is driven from the silica gel by the hot water. The refrigerant water vapor rises to the condenser portion of the chiller where it is then condensed to a liquid state. The condenser water is recycled in a closed-loop to the bottom of the machine where it is immediately available for re-use.

As the machine cycles, the pressure in Chamber 1 is slightly lower than in the evaporator chamber. A portion of the water refrigerant evaporates and moves to Chamber 1. Simultaneously, the pressure in Chamber 2 elevates slightly as the water

vapor is driven from the silica gel. The water vapor is then pushed to the condenser chamber where it is condensed back to the liquid state and returns to the evaporator chamber.

When the silica gel in Chamber 1 is saturated with water and the silica gel in Chamber 2 is dry, the machine's process reverses. The first step is the opening of a valve between the two chambers, allowing the pressure to equalize. Then, cool water is sent through Chamber 2 to transfer any residual heat to Chamber 1, which begins the heating process. The reversal is completed and the adsorption in Chamber 2 commences while Chamber 1 is dried by the desorption heating.

The adsorption chiller is capable of operating within a wide range of temperatures. The machine self-regulates and balances the performance of the system by the control programs, shifting to the program best suited for the system conditions. For optimal performance of chillers, the hot water should be 90°C, the cool water about 24°C to 35°C and the output cold water 7°C to 12 °C.

Section- 2

Adsorption versus conventional mechanical chillers – Why an BRY AIR adsorption chiller is a better choice

Adsorption chillers eliminate noisy compressors, high-pressure refrigerant systems, high amperage electrical connections, refrigerant monitoring and alarm systems, and high maintenance costs. Adsorption chillers, specifically BRY AIR chillers, will provide a 99% reduction in the chiller's electrical usage.

Adsorption versus mechanical chiller comparison

Attribute	Adsorption Chiller	Mechanical Chiller
Sound Pressure Level	Very low <50 db (A)	Loud > 80db (A)
Operating Cost	Negligible	High
Maintenance	Replace vacuum pump oil as needed (recommended every 5 years) Annual cleaning of condenser tubes	Seasonal maintenance required per year or greater Annual oil analysis Replace oil every 5 years Periodic tear down and rebuild required Annual cleaning of condenser tubes
Chemistry	Normal tap water and silica gel	HFC and HCFC refrigerant with synthetic oils
Energy Requirements	Hot water- 60°C to 93 °C	Electricity – 440 or 4,160 volts
Cooling water requirements	34 °C to 10°C. Lower temperatures increase capacity of the system	29.4°C to 18°C minimum temperature -- unstable at low temperatures.
Life of equipment	25 to 30 years	Needs replacement every 10-15 years.

Section- 3

Physical facts & assumptions.

1	**Adsorption Chiller Model**		**F-330**
2	Nominal Capacity	TR	335
2 a	Actual Capacity as per site condition	TR	**330**
3	**Chilled Water Circuit**		
i	Chilled Water Temperature Profile- Inlet/Outlet.	Deg C	**18/9**
ii	Chilled Water Flow Rate.	M3/hr	**111.5**
4	**Condenser Water Circuit**		
i	Condenser Water Temperature Profile- Inlet/Outlet.	Deg C	29.4/34.6
ii	Condenser Water Flow Rate.	M3/hr	550
5	**Hot Water Circuit**		
i	Hot Water Temperature Profile- Inlet/Outlet.	Deg C	**78/71.9**
ii	Hot Water Flow Rate.	M3/hr	**304.3**

Section- 4

Technical data sheet for Adsorption Chiller

Sr. No.	Description	Unit	Chiller Model F-330
A.	**Chilled Water Circuit**		
1	Rated Capacity	TR	**335**
1 a	Actual capacity at site condition	TR	**330**
2	Quantity	No's	1
3	Chilled Water Inlet Temperature	°C	18
4	Chilled Water Outlet Temperature	°C	9
5	Chilled Water Flow Rate	M3/hr.	111.5
6	Connection Size	MM	200
B.	**Condenser Water Circuit**		
1	Cooling Water Inlet Temperature	°C	29.4
2	Cooling Water Outlet Temperature	°C	34.6
3	Cooling Water Flow Rate	M3/hr.	550
4	Connection Size	MM	250
C.	**Heat Source Hot Water Circuit**		
1	Hot Water Inlet Temperature	°C	78
2	Hot Water Outlet Temperature	°C	71.9
3	Hot Water Flow Rate	M3/hr.	304.3
4.	Connection Size	MM	200
D.	**Electrical Circuit**		
1	Voltage	Volt-Ph.	440- 3
2	Frequency	Hz	50/60
3	Continuous Operating kW Consumption	Kw	1.3
E.	**Air Supply**		
1	Air Pressure	Kg/cm2	4.89
2	Air Consumption	CFM	0.34
F.	**Dimensions (Approximate)**		
1	Width	Mtr.	3.7
2	Length	Mtr.	5.3
3	Height	Mtr.	3.5
G.	**Weight (Approximate)**		
1	Empty	Tons	21
2	Operating	Tons	24
H.	**Refrigerant Type**		

Section -5

SCOPE OF WORK

1. Scope of supply of hot water fired Adsorption Chiller

Sr. No.	Description	Qty.
1	Single Shell Comprising of evaporator, Absorber Chambers 1 & 2 and Condenser & Silica Gel.	1
2	Refrigerant (Water) pump.	1 lot
3	Vacuum pump.	1 lot
4	Microprocessor based control panel.	1
5	Locally mounted instruments & safeties.	1 Lot
6	Inter connecting piping and wiring.	1 Lot
7	Operation maintenance manual.	1

2. Controls & Safeties:

A. The chiller includes a factory-installed and factory-wired microprocessor control system with modular component construction. The controls are of the PID type and are continuously monitor the operation of the chiller and perform self-diagnostic checks to maintain control limits.

B. The control system is open source with an Ethernet protocol for integration.

C. The display indicates power on, run status, safety circuit, and alarm status.

D. An Ethernet port is provided to communicate with the PLC controller to view status, set point, and make any changes in the field.

E. The following inputs are monitored (Please refer to PID attached for scope clarity):

a. Remote hot water tank level
b. Condenser water temperature entering the condenser
c. Compressed air pressure level
d. Vacuum pump proof of vacuum at beginning of vacuum cycle
e. Inverter operation
f. Evaporator refrigerant temperature (wet bulb)
g. Refrigerant low level
h. Refrigerant high level
i. Refrigerant pump
j. Chilled water entering temperature
k. Chilled water leaving temperature
l. Cycle time
m. Chilled water flow

The following safeties are monitored. An abnormal condition of the following faults shall shut down the operation of the chiller and create an alarm:

- Hot water tank level abnormal (high or low).
- Refrigerant water level abnormal.
- Condenser water temperature abnormal.
- Air pressure level abnormal.
- Inverter operation abnormal.
- Evaporator temperature abnormal.
- Refrigerant pump abnormal.
- Float level abnormal.
- Vacuum pump abnormal.
- Vacuum level abnormal.

3. BATTERY LIMITS :

Chilled water	Inlet / outlet flange of the evaporator header box.
Cooling water	Inlet flange of the adsorber water box.
	Outlet flange of the condenser water box.
Hot water	Inlet / outlet nozzle of the adsorber box.
Instrument air tapping	At the inlet of the pneumatic valves on our chiller.
Power	Terminal connection on the control panel. 440 V,+/- 10%, 60 Hz +/- 3%
Earthing	At the earthling port on the control panel.

4. EXCLUSIONS:

1	Transportation from BRY AIR factory, Unloading at site including transit insurance.
2	Civil foundation.
3	Complete chilled water circuit including the pumps, isolation valves, strainers, NRVs, piping will all necessary fittings like flanges, bends etc. along with insulation and necessary instruments beyond terminal point.
4	Complete cooling water circuit including the pumps, isolation valves, strainers, NRVs, piping will all necessary fittings like flanges, bends, etc. and necessary instruments beyond our terminal point.
5	Cooling tower.
6	Complete hot water circuit including the booster pumps, isolation valves, strainers, NRVs, piping will all necessary fittings like flanges, bends etc. along with insulation and necessary instruments beyond our terminal point.
7	Instrument quality air for chiller at pressure of 4.89 kg/cm2 (g)
8	Communication from our control panel to plant.
10	Separate earth pit for the chiller control panel earthing.
11	Water treatment plant, if any required.
12	Any other item not specifically mentioned in scope of supply.

Performance Testing:

Bry-Air Adsorption chillers are performance tested at site in real life situation.

The following inputs to be provided by the purchaser for site performance tests during commissioning.

A) Steady load for rated capacity.

B) Inlet parameters as per rated conditions.

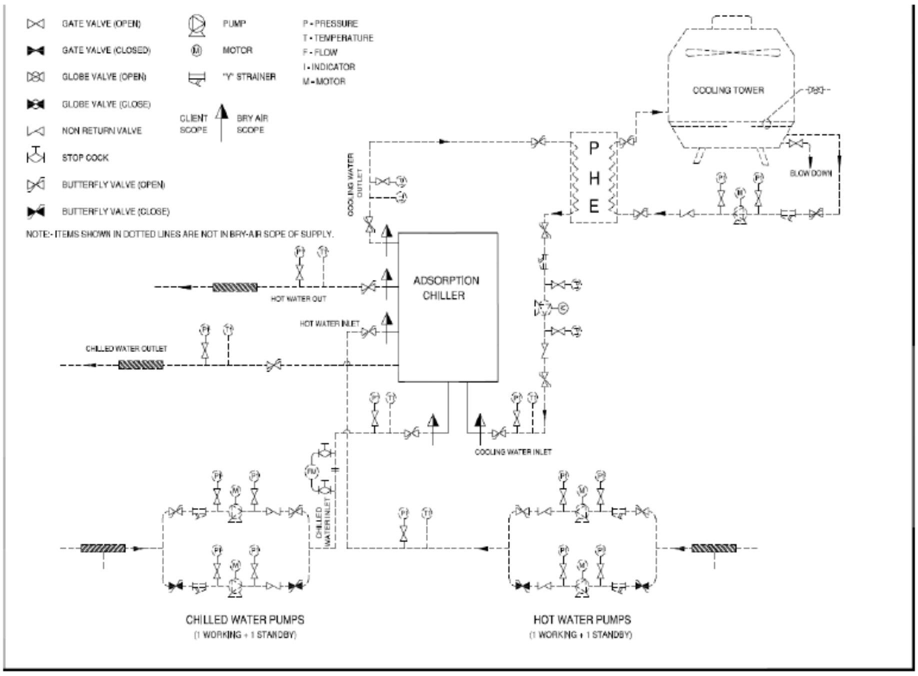
1. Chilled water inlet temperature not below rated conditions.
2. Cooling water inlet temperature not above rated temperature
3. Chilled / Cooling circulation water flow rates as per technical data sheet.
4. Heat source (i.e. HW) at rated flow rate and condition

All measurements are subjected to Instrument Tolerance of about ± 3 %

Performance trials will be carried out within 15 days of commissioning of the chiller, at the available load. In case the load or rated utilities are not available, the unit will be deemed as handed over after the performance trials are taken on the available parameters.

The duration of performance test at site shall be for 24 hours.

Typical P&I D for Adsorption Chiller



Section - 6
PRICE SCHEDULE

Sr. No.	Description	Unit Price (USD)	Quantity	Total Price in (USD)
1(a)	Price for MODEL **F-330** Chilling Capacity, Factory Charge of Refrigerant (Water), Pneumatically Actuated Valves with Factory Start-Up as per Technical Data Sheet and Scope of Supply enclosed as per our above offer. **Ex our works at Gurgaon.**	400,000	1	400,00
1(b)	Supervision of Erection & Commissioning (3 days) Lump sum.	3,000	1	3,000

All the above prices are exclusive of any taxes and duties, and are ex-works, Gurgaon. The to & fro travelling, boarding & lodging charges for our supervising engineers will be extra at actual.After 3 days , Supervision of Erection & Commissioning cost charges will be applicable as 1000 USD per day basis.

Other commercial terms:

Packing charges	Packing for dispatch, whenever necessary will be in accordance with our standard practice and packing charges @ 3% of the total value of the order.
Excise Duty	Not Applicable
C.S.T	Not Applicable
Octroi	Not Applicable
Freight	By Purchaser.
Insurance	By Purchaser. We shall convey the dispatch particulars prior to actual dispatch to enable the purchaser to arrange insurance.
Dispatch of goods	Within 5 months from the receipt date of technically & commercially clear order along with the specified/agreed advance.
Payment Terms	40% as advance along with purchase order. 60% against Performa Invoice prior to dispatch.
Offer validity	60 days from the date of offer and subject to confirmation thereafter.
Inspection	If necessary, the goods will be offered for visual inspection & functional test only at our works. The date of inspection will be intimated by us about 15 days in advance and confirmed by the purchaser accordingly. If inspection is not carried out on the date so advised, we shall be free to dispatch consignment as per terms of delivery.
Standard terms & conditions of sale	As enclosed.

Order Confirmation

The order for BRY AIR Adsorption Chiller will require to be made out directly in favor of **M/s. Bry-Air (Asia) Pvt. Ltd.**, 20, Rajpur Road, Delhi – 110054. Cheques/drafts for advance and other payments are to be made out in favor of Bry-Air (Asia) Pvt. Ltd.

Kindly send the Purchase Order (Original), Road Permit & Advance Cheque on the following address: **Bry-Air (Asia) Pvt. Ltd.**, 419-420, Udyog Vihar, Phase-III, Gurgaon-122016, Haryana, India.

Section-7

General terms and conditions of sales

1. **Guaranty**: We guaranty for a period of one year from the date of shipment from our plant, all merchandise sold by us. The terms of this guaranty are:

   (a) The merchandise must have been installed and maintained in accordance with our instructions and literature. If, for some reason, our literature is not included with any shipment, let us know at once.

   (b) The guaranty applies ONLY to parts which were detective when shipped from our plant. If a part is found to be defective when shipped whether this defect shows up immediately or, during the year, though proper use of the merchandise, we will either repair or furnish replacement part or issue a credit memorandum, at our option.

   (c) Our guaranty does not cover the supply of consumable items like oil for lubrication, desiccant, seals, refrigerant, V belts etc. and also does not cover routine maintenance of the plant such as starting and stopping of the plant, its cleaning and the deceleration of the plant due to atmospheric conditions.

   (d) In the case of parts or components not manufactured by us, the purchaser shall have the benefit, in so far as it may be transferred to the purchaser, of any rights which we may have against the supplier of such parts or components in respect thereof, is limited to making the benefit of such rights available to the purchaser to the extent aforesaid.

   (e) The effects of corrosion, erosion, excessive heat, dirt, dust or foreign materials, and normal wear are **specifically** excluded from Bry-Air's warranty.

2. **Disclaimer of Warranties**: Except for the guarantee set out above, BRY-AIR (ASIA) PVT.LTD MAKES NO WARRANTY OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, OR ANY OTHER WARRANTY, EXPRESS OR IMPLIED, AS TO THE MERCHANDISE SOLD CUSTOMER. Customer acknowledges and represents to Bry-Air (Asia) Pvt.Ltd. that no employee, agent or representative of Bry-Air (Asia) Pvt. Ltd. has made any warranty or representation regarding the merchandise, except as set out in paragraph **1**, above.

   The following is excluded from warranty hereunder (1) equipment which has been installed improperly, or which has not been operated and maintained in accordance with Seller's ratings and instructions and in accordance with good industry practices; (2) equipment which has been damaged in transit or by misuse, neglect, or accident; (3) equipment which has been repaired or modified without authorization from Seller; (4) the effects of normal wear and tear, and the effects of corrosion or erosion due to the presence of substances in the environment in which the equipment is operated and / or in gases passing through the equipment;

3. **Limitation of Remedy & Liability**: Sole obligation under its guaranty is to repair or furnish the replacement part or credit memorandum. Bry-Air is NOT obligated to pay the cost of shipping the defective part to and from our plant.

   In no event will be liable to customer for consequential damages sustained by customer, whether such damages are caused by the nondelivery of merchandise, the delivery of defective or unordered merchandise delay in performance, or any other cause.

   The term "Consequential Damages" shall include, but not be limited to, loss of anticipated profits, loss of use, loss of revenue and cost of capital.
   Seller shall not be liable for, and Customer assumes liability for all personal injury and property damage connected with the handling, transportation, possession, use, further manufacture, or resale of the Equipment. No costs or charges incurred by Customer will be paid by Seller unless authorized in writing in advance by Seller.

4. IF DELIVERY IS NOT TAKEN OR DESPATCH INSTRUCTIONS NOT PROVIDED BY CUSTOMER WITHIN 15 DAYS OF INTIMATION OF READINESS TO SHIP/DESPATCH, THE PRICE OF MERCHANDISE WILL BE INCREASED AT THE RATE OF 2% PER MONTH FOR EACH MONTH.

5. **Freight and risk of Loss** : Unless otherwise stated, (a) all merchandise is sold ex-works Bry-Air (Asia) Pvt.Ltd, plant, and (b) Customer has title to the merchandise, and the risk of its loss or damages is on the Customer, from and after the time the merchandise leaves our plant, (c) Delivery/Despatch may be made in one lot or in several lots at our option and when made, in several lots, bills will be made out by us representing approximately the price of each lot and the amount of any such bills will not be disputed as long as the total of all bills does not exceed contract dues.

6. **Technical Advice**: Upon request we will furnish technical advice to Customers regarding the use of our merchandise, but only on the understanding that we assume no obligation or liability for such advice or the results obtained therefrom and that such advice is given and accepted at Customer's risk.

7. **Taxes & Duties**: Unless otherwise stated, the price does not include any taxes and duties. The Customer agrees to reimburse us for any taxes required to be paid by us, upon the sale, transportation, or purchase of the merchandise sold hereunder.

8. We hereby reserve the right to make without notice such minor modification in specifications, designs or materials as it may be deemed necessary or desirable by experience.

9. The Purchaser shall not without our prior consent assign or any way dispose off any of its rights or obligations hereunder to any other persons, firm or company.

10. In the event of any dispute arising in relation to or in connection with the contract, the same shall be referred to Arbitration in Delhi and shall be settled in accordance with the Indian Arbitration Act of 1940 or any statutory modification or re-enactment thereof.

11. CUSTOMER DATA/SPECIFICATIONS: To the extent that Seller has relied upon any specifications, information, representation of operating conditions or any other data supplied in writing by Customer to Seller in the selection or design of the Equipment or otherwise in connection with this Contract or the preparation of Seller's quotation and in the event that the actual operating conditions or other conditions differ from those supplied by Customer and relied upon by Seller, ANY WARRANTIES OR OTHER TERMS AND CONDITIONS CONTAINED HEREIN WHICH ARE AFFECTED BY SUCH CONDITIONS SHALL BE NULL AND VOID.

12. **Modification**: Any claim by Customer that the parties have modified the above terms shall be ineffective to create additional or different obligations on BRY-AIR (ASIA) PVT. LTD. unless such modification is in writing and signed by authorised representative of BRY-AIR (ASIA) PVT. LTD.

Hopefully, the above statements are clear and complete. However, if you have any question please contact your local BRY-AIR (ASIA) PVT. LTD. representative or BRY-AIR (ASIA) PVT. LTD. directly for further information.

At the time of placement of order by customer on BAA, the customer indicates his assent to the above terms as the sole & exclusive terms of the agreement between BAA and customer, as to the sale and purchases of the merchandise detailed in the quotation annexed either by signing below or retaining this guarantee, terms & condition sheet for 10 days without objecting thereto.

Yours faithfully,
For **Bry-Air (Asia) Pvt. Ltd.**

Section 8
Partial List of customers

1. U.S. Embassy, Monrovia, Liberia. U.S. Dept. of State, OBO (Overseas Building Operations) - Capacity 150TR @ 11°C chilled water application.
2. Sustainable Technologies Center SFCC. 30TR @ 7°C chilled water-Solar application-LEED Gold.
3. Architect Atlanta, GA. 40TR @ 7°C chilled water, Tri-generation with 2 – 65kW Capstone micro-turbines, LEED Platinum.
4. Parris Island Marine Corps Recruit Depot. 80TR @ 7°C chilled water, Solar application, driven water 71°C hot water.
5. U.S. Embassy, Dakar Senegal. U.S. Dept. of State, OBO (Overseas Building Operations), Two – 80TR @ 36°C inlet cooling water, CHP application.
6. Ed W. Clark High School Las Vegas, NV. HVAC Modernization Project105TR.
7. **Frito Lay, Beloit, WI, Manufacturing plant.** Waste Heat Recovery Application, 150TR.Hot Water Source: Waste heat from frying process recovering waste heat from the exhaust gases.
8. Duty Free Shops (Subsidiary of Louis Vuitton), Garapan, Saipan 90TR Tri-generation application.
9. Construction industry counselâ zero carbon building, Hong Kong, PRC 20 TR Tri-generation application.
10. Network Appliance Data Center, Sunnyvale, California Hot Water Source: Waste heat from internal combustion cogeneration engines coupled with a heat exchanger providing hot water to the ADC- 120 TR X 3 No's.
11. Adnan Menderes Universitesi, TURKEY 75 TR Modernization project.
12. I I T Delhi 3 TR Capacity, Modernization project
13. MNIT , Jaipur 3 TR Capacity, Modernization project
14. INTEL CORPORTAION, Bangalore 3 TR x 4 No's Solar Based Air Conditioning project.

15.5 Offer on 1 MW absorption chiller – mail conversation

From: Stuart Johnston [mailto:stuart@thermax-europe.com]

Sent: Friday, March 10, 2017 3:49 PM

To: Martin Grunnow Vinstrup <mvins14@student.sdu.dk>

Cc: Klaus Christian Jespersen <kljes14@student.sdu.dk>

Subject: Re: FW: Thermax Absorption Chillers

Hello Martin,

Sorry for the delay, been a bit of a busy week!

Attached some selections for 1MW, 2MW and 5MW of chilled water.

Cost of these units are as follows

1MW - 125,000 Euros

2MW - 220,000 Euros

5MW - 520,000 Euros

These prices include delivery to site, commissioning visits and cold insulation of the machines.

Maintenance costs for the unit are normally around 5,000 Euros per year in terms of labour, we suggest an engineer goes to site 3 times a year to check the operation of the machine and take a sample of the internal solution. The main maintenance point on the unit is the Lithium Bromide corrosion inhibitor which needs to be topped up every year, normally costing around 2,500 euros for 10 years or so.

Expected lifetime of our unit is around 20 years assuming service is carried out at regular intervals.

I've attached a tech manual of the 5G hot water series for your own info

If you have any further questions then let me know, i'll try and get back to you a bit faster than this time :)

Kind regards,

Stuart Johnston
Technical Support Engineer

+44 1908 378914 Work

+44 1908 379487 Fax

Thermax Europe Limited
2 Studio Court
Bletchley, Milton Keynes
MK2 2DG
England

15.6 Offer on 1 MW absorption chiller – technical datasheet sheet

	Description	Unit	
	Capacity (± 3 %) :	**kW**	1000.0
A	**Chilled Water Circuit :**		
1.	Chilled water flow	m³/hr	95.4
2.	Chilled water inlet temperature	°C	18.0
3.	Chilled water outlet temperature	°C	9.0
4.	Evaporator passes	No.	2+2
5.	Chilled water circuit pressure loss	kPa	76.3
6.	Chilled water Connection diameter	DN	150
7.	Glycol type		NA
8.	Chilled water glycol %	%	0.0
9.	Maximum working pressure	kPa(g)	785
B	**Cooling Water Circuit:**		
1.	Heat rejected	kW	2233.4
2.	Cooling water flow	m³/hr	400.0
3.	Cooling water inlet temperature	°C	27.0
4.	Cooling water outlet temperature	°C	31.8
5.	Absorber / Condenser passes	No.	2,2/1,1
6.	Cooling water circuit pressure loss	kPa	99.2
7.	Cooling water connection diameter	DN	200
8.	Glycol type		NA
9.	Cooling water glycol %	%	0.0
10.	Maximum working pressure	kPa(g)	785

C	**Hot Water Circuit :**		
1.	Heat input ($\pm$ 3 %)	kW	1233.4
2.	Hot water flow ($\pm$ 3 %)	m^3/hr	110.0
3.	Hot water inlet temperature	°C	78.0
4.	Hot water outlet temperature	°C	68.1
5.	Generator passes	No.	1+1
6.	Hot water circuit pressure loss	kPa	7.2
7.	Hot water connection diameter	DN	200
8.	Glycol Type		NA
9.	Hot water glycol %	%	0.0
10.	Maximum working pressure	kPa(g)	785
D	**Electrical Data :**		
1.	Power supply		415 V ± 10%, 50 Hz ± 5%, 3 Phase+N
2.	Power consumption	kVA	6.9
3.	Absorbent pump rating	kW (A)	1.5 (5.0)
4.	Refrigerant pump rating	kW (A)	0.3 (1.4)
5.	Vacuum pump rating	kW (A)	0.75 (1.8)
E	**Physical Data :**		
1.	Length	mm	4670
2.	Width	mm	2040
3.	Height	mm	3060
4.	Operating weight	kg	15400
5.	Flooded weight	kg	23000
6.	Dry weight	kg	11100
7.	Shipping Weight	kg	12900
8.	Tube cleaning space	mm	4300
F	**Tube Metallurgy :**		
1.	Evaporator tube material		Copper
2.	Absorber tube material		Copper
3.	Condenser tube material		Copper
4.	Generator tube material		SS 430Ti
G	**Fouling Factor:**		
1.	Chilled water fouling factor	m^2 K/kW	-
2.	Cooling water fouling factor	m^2 K/kW	-
3.	Hot water fouling factor	m^2 K/kW	-

PS: 1. This selection is valid for insulated chiller only.

2. For non-insulated chiller, the capacity & heat source consumption will vary.

3. Plant room temperature should be from +5°C to +45°C (41°F to 113°F).

4. Please contact Thermax representative/office for customised specifications

15.7 Data from Peer Andersen, Fjernvarme Fyn – Mail conversation 1

Hej Peer

Mange tak! Glemte at få spurt, men er det sådan, at du/i har en gæt på meterpris for anlæg af fjernkøling?

From: Peer Andersen [mailto:pa@fjernvarmefyn.dk]
Sent: Tuesday, February 21, 2017 5:28 PM
To: Martin Grunnow Vinstrup <mvins14@student.sdu.dk>
Subject: SV: Statusopdatering og liste over nødvendige data

Hej Martin

IKEA:
Vedlagt IKEA´s køleforbrug i 2016 på timebasis. Det er komfortkøl det hele.

Køleanlægget blev sat i drift omkring årsskiftet 2009/2010, dvs. første sæson var i 2010. Der er installeret 2 ens 750 kW anlæg, idet IKEA ønskede 1,5 MW køleeffekt. De kører dog stort set aldrig samtidigt, så de er lavt belastede. Den tekniske levetid er mindst 15 år. De samlede omkostninger for projektet inkl. køleledninger blev 5,6 mio. kr.

Kraftvarmeanlæg på Fynsværket:
Der er vedlagt diverse oplysninger om kraftvarmeenhederne i vores system. Der er eksempler på brændselspriser, men I skal selvfølgelig selv vælge blandt de offentligt tilgængelige kilder til brændselspriser.
Opstartstiden på kraftvarmeanlæggene fra kold er ca. 10 timer.
Fjernvarmenettet:
Vedlagt det samlede varmebehov i 2016 ab værk.

Bilka, Rosengårdscenteret, SDU og IKEA leverer ikke varme ind på nettet. Vi ved ikke, om der bliver etableret varmegenvinding fra køling på Nyt OUH. Foreløbige undersøgelser viser, at det muligvis kan hænge sammen økonomisk, hvis der er et kølebehov om vinteren. Prisen på varmen skal være lavere end prisen på varmen fra de eksisterende kraftvarmeanlæg.

Wallenténs formel til beregning af varmetab fra twinrør er ikke relevant for kølerør, da man ikke vil anvende twinrør som kølerør. Typisk bruges præisolerede enkeltrør, serie 1 eller uisolerede PE rør.

Facebook
Vi kan desværre ikke sige noget nærmere om Facebook på nuværende tidspunkt.

Øvrigt:
Afgifter: Som kraftvarmeproducent kan vi dividere vores varmeproduktion med en afgiftsmæssig varmevirkningsgrad på 1,2, også for spids- og reservelast kedler. Procesvarmekunder kan få godtgjort energiafgiften.
Med venlig hilsen

Peer Andersen
Fjernvarme Fyn A/S

Telefon: 65 47 30 12
Mobil: 30 62 79 71

15.8 Data from Peer Andersen, Fjernvarme Fyn – Mail conversation 2

Hej Martin

Enhedspris for DN 400 rør i vej, inklusiv materialer, svejsning, gravearbejde og retablering af asfalt er ca. 7.200 kr./m kanal.

Prisen på kølelager kunne måske sættes til 2.000 kr./m3 op til 1.000 m3 og 1.500 kr./m3 over 1.000 m3.

Der vil skulle betales el-afgift (405 kr./MWh) for varmepumpens el-forbrug ved produktion af fjernvarme i et ATES anlæg. Afgiften opkræves over varmeprisen. Der er også afgift på den varme, som Fjernvarme Fyn sælger.

Med venlig hilsen

Peer Andersen
Fjernvarme Fyn A/S

Telefon: 65 47 30 12
Mobil: 30 62 79 71

Fra: Martin Grunnow Vinstrup [mailto:mvins14@student.sdu.dk]
Sendt: 19. april 2017 11:10
Til: Peer Andersen <pa@fjernvarmefyn.dk>
Emne: Opfølgning på forrige møde og mails

Hej Peer

Vi har været i gang med at undersøge, hvilket rør, som bør anvendes ifm. fjernkøling. Vores bud vil være et DN 400 serie 1 rør fra Logstor.

Jeg vil desuden gerne følge op på forrige sendte spørgsmål:

- Har du et bud på hvad et kølelager koster? Vi har endnu ikke fundet den optimale dimensionering, så hvis du kan sige noget om hvordan et kølelagers omkostninger variere med rumfanget, så vil det være super! ☺
- Bud på rørpris og graveomkostninger.

Desuden vil jeg spørger om du kan svare på:

- Hvis Fjernvarme Fyn fjernkøling sælger varme fra ATES anlægget til Fjernvame Fyn er der så afgift på denne varme, som Fjernvarme Fyn køber?
- Hvis Fjernvarme Fyn fjernkøling køber varme af Fjernvarme Fyn er der så afgifter på den varme, som fjernkølingsselvskabet køber?

Kind regards,

Martin Grunnow Vinstrup
Student BSc Energy technology, 6th semester

Tlf. +45 2962 9848
Email mvins14@student.sdu.dk

15.9 Mail correspondence with Energi Fyn: Electricity distribution tariff for DC customers

Hej

Virksomheder i Odense som er af den størrelse som du nævner er typisk B-lav med egen station. Tariffen er lidt speciel og er et arvestykke fra det tidligere Odense Energi. Da OE og Energi Fyn fusionerede ønskede man ikke at ændre tilslutningsforhold/ejerskab for de store kunder så derfor er den bibeholdt. I det øvrige Fyn er virksomheder at samme type typisk B-høj.

Med venlig hilsen

Hans Pahus Holst
Teknisk, økonomisk controller

Det sammenkædede billede kan ikke vises. Filen er muligvis blevet flyttet, omdøbt eller slettet. Kontrollér, at linket peger på den korrekte fil og placering.

Telefon: +45 63 17 19 00
Direkte: +45 63 17 25 52
Mobil: +45 23 63 18 43
Energi Fyn, Sanderumvej 16
5250 Odense SV - www.energifyn.dk

Fra: Hans Pahus Holst
Sendt: 21. marts 2017 15:43
Til: 'mvins14@student.sdu.dk' <mvins14@student.sdu.dk>
Cc: 'kljes14@student.sdu.dk' <kljes14@student.sdu.dk>
Emne: tariffer for store kunder i Odense SØ

Hej Hans

Det er også fair nok. Er det muligt, at du kan generalisere for sådan virksomheder, hvilken tarifkategori/tilslutningskategori de typiske vil tilhøre?

From: Hans Pahus Holst [mailto:hph@energifyn.dk]
Sent: Tuesday, March 21, 2017 3:43 PM
To: Martin Grunnow Vinstrup <mvins14@student.sdu.dk>
Cc: Klaus Christian Jespersen <kljes14@student.sdu.dk>
Subject: tariffer for store kunder i Odense SØ

Hej

Som I sikkert ved er der vandtætte skillevægge mellem monopoldelen i elforsyningen og de kommercielle elhandlere - vi kan ikke se hinandens informationer om elkunder.   Netselskabet er desuden underlagt regler om håndtering af henholdsvis forretningsmæssige følsomme og forretningsmæssige fordelagtige oplysninger - det er beskrevet i en bekendtgørelse om Intern Overvågning. Det betyder at jeg ikke kan og ikke må oplyse specifikke virksomheders tilslutningsforhold.

Jeg kan dog oplyse tarifferne som er gældende i dag hos Energi Fyn Net og så må I enten lave nogle antagelser om nettilslutningsniveau eller rette henvendelse til de virksomheder I ønsker at medtage I jeres undersøgelser.

Tarifferne fremgår af Energi Fyn Nets hjemmeside: https://www.energifyn-net.dk/priser/nettariffer

I skal lige være opmærksom på at disse tariffer kun er betaling til Energi Fyn Net. Den enkelte kundel skal foruden markedsel fra en valgt elleverandør også betale PSO, system- og nettariffer til EnergiNet.dk og evt. elafgift til staten.

Med venlig hilsen

Hans Pahus Holst
Teknisk, økonomisk controller

Det sammenkædede billede kan ikke vises. Filen er muligvis blevet flyttet, omdøbt eller slettet. Kontrollér, at linket peger på den korrekte fil og placering.

Telefon: +45 63 17 19 00
Direkte: +45 63 17 25 52
Mobil: +45 23 63 18 43
Energi Fyn, Sanderumvej 16
5250 Odense SV - www.energifyn.dk

Hej Energi Fyn Net,

Vi er to studerende, som er i gang med et bachelor projekt, som undersøger potentialet i at levere fjernkøling til Rosengårdcentret, Bilka, IKEA, SDU og Nyt OUH.

Vi har i den forbindelse behov for, at kende net tariffen for de nævnte virksomheder. Vi håber derfor, at i kan hjælpe med net tariffen eller evt. tarifkategorien for de nævnte virksomheder?

Kind regards,

Martin Grunnow Vinstrup
Student BSc Energy technology, 6th semester

Tlf. +45 2962 9848
Email mvins14@student.sdu.dk

Det sammenkædede billede kan ikke vises. Filen er muligvis blevet flyttet, omdøbt eller slettet. Kontrollér, at linket peger på den korrekte fil og placering.

15.10 Offer electrical chiller, Johnson Control – mail conversation 1

Hej Martin & Klaus,

Som aftalt med Svend og refererende til e-mail fra 29/3 2017 & telefonsamtale 5/4 2017 hermed vores bedste skøn/svar.

Ønsket køleeffekt vil komme til at ligge mellem 2 og 10 MW.
Vi har opbygget vort prisskøn i 2 MW moduler, som en basispris på DKK 15 mio. samt tillæg pr. 2 MW på DKK 6 mio.
Dvs. 1 stk. 2 MW anlæg vil koste DKK 21 mio.
1 stk. 10 MW anlæg vil koste DKK 45 mio.

Pris indeholder:
- n x 2 MW PAC233SR chiller (én chiller er på ca. 2 MW køl)
- n x 3 stk. GFD tørkølere (der skal 3 tørkølere til pr. chiller)
- kølevands installationer inde i kølecentral
- glykolrør installationer mellem chillere og tørkølere
- frikølkreds mellem vand- & glykolsystem
- el-tavler, styringer, og elinstallationer for ovenstående inkl. ISAC Scada system

Ikke indeholdt bl.a.:
- Kølecentral bygning
- Kølevandsledninger uden for kølecentral bygning.
- Tranformatorstationer og forsyninger til eltavler for køleanlæg.

Faste D&V omkostninger pr. år:
Skøn DKK 100.000,-

Variable driftomkostninger:
El ca. DKK 200,- / MWh køl (i design sommer periode med udeluft temp. +30°C) (ved lavere udetemp. vil el forbrug falde).

Variable vedligeholdelsesomkostninger:
Service ca. DKK 8,- / MWh køl.

Investeringsomkostninger:
Se ovenstående

Levetid på anlæg:
Ca. 30 år

Datablad på anlæg:
Se vedhæftede over chiller & tørkølere

Ovenstående omkostninger er at betragte som grove overslag, da meget jo afhænger af anlæggets belastningsprofil set over året.
I perioder med ren frikøling vil omkostningsniveau være helt anderledes.

Har i yderligere spørgsmål, er i selvfølgelig velkomne til at kontakte os.

Med venlig hilsen
Claus Thomsen
Sales Support
Køleteknik
Systems & Service
Tel: +45 87 36 31 09
Fax: +45 87 36 31 01
E-mail: Claus.Thomsen@jci.com
Internet: www.johnsoncontrols.dk

Johnson Controls
Building Efficiency
Sortevej 30
8543 Hornslet
Denmark

15.11 Offer electrical chiller, Johnson Control – mail conversation 2

Hej Martin,

For 2 MW system kan regne med basis på 8 mio, og hvis der ikke skal etableres buffer/kuldelager tank kan du regne med 6 mio.
Dvs. 2 MW system 14 eller 12 mio

mvh/claus

Fra: Martin Grunnow Vinstrup [mailto:mvins14@student.sdu.dk]
Sendt: 3. maj 2017 07:36
Til: Claus Pilegaard Thomsen <Claus.Thomsen@jci.com>
Emne: RE: Tilbud på eldrevne chillere for fjernkølingsprojekt

Godmorgen ☺

Havde gennemskuet systematikken var bare i tvivl om basisprisen også galte ved 2 MW.

Nu skriver du at det ikke bliver mere end de 15 mio i basis pris. Ved godt at du ikke kender alle detaljer om projektet. Hvis du skulle give et realistiske ikke-bindende bud på basis prisen ved 2 MW vil det stadigvæk være 15 mio?

From: Claus Pilegaard Thomsen [mailto:Claus.Thomsen@jci.com]
Sent: Wednesday, May 3, 2017 06:25
To: Martin Grunnow Vinstrup <mvins14@student.sdu.dk>
Cc: Klaus Christian Jespersen <kljes14@student.sdu.dk>; Svend Juul Madsen <Svend.Madsen@jci.com>
Subject: SV: Tilbud på eldrevne chillere for fjernkølingsprojekt

God morgen Martin,

Det fremgår faktisk også af nedenstående.
2 MW koster 15 + (1 x 6) = 21 mio
4 MW koster 15 + (2 x 6) = 27 mio
osv

Der er selvfølgelig tale om grove overslag og alt efter system krav og bestykning vil især basis på de 15 mio kunne variere, men det bliver ikke mere end de 15.

mvh/claus

15.12 Offer electrical chiller, Johnson Control – datasheet electrical chiller

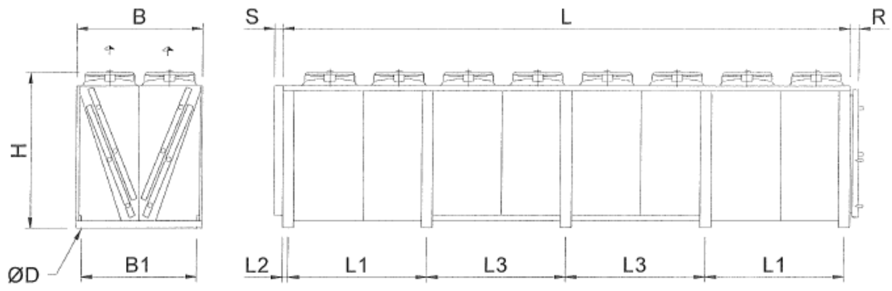
Date:	2017-04-06
Enquiry dated:	
Project:	
Quotation-no.:	
Item:	
Reference:	

Drycooler	GFD 090.3D/2x8-MS1C/2P.E		
Capacity:	771.4 kW	Medium:	Propylene glycol 30 Vol. %(1)
Surface reserve:	0.0 %	Inlet:	40.0 °C
Air flow:	362640 m³/h	Outlet:	35.0 °C
Air velocity:	2.1 m/s		
Air inlet:	30.0 °C	Pressure drop:	0.44 bar
Altitude:	0 m	Volume flow:	138.76 m³/h
Air outlet:	36.6 °C		
Heat transf. coeff.:	35.63 W/(m²·K)	Mass flow:	141675 kg/h
Fans (EC): (VT03065U.1) 16 Piece(s) 3~400V 50-60Hz		Noise pressure level:	56 dB(A)(2)
Data per motor (nominal data):		at a distance of:	10.0 m
Speed:	785 min-1	Noise power level:	89 dB(A)
Capacity (el.):	1.30 kW	ErP:	Compliant(3)
Current:	1.89 A(4)		
Total el. power consumption: 21.63 kW		Energy efficiency class:	D (2014)
Casing:	Galv. Steel, RAL 7035	Tubes:	Copper(5)
Surface:	5690.5 m²	Fins:	Aluminum(5)
Tube volume:	716.5 l	Connections per unit:	
Fin spacing:	2.40 mm	Inlet:	4 x 88.9 * 2.00 mm
Dry weight:	5816 kg(6)	Outlet:	4 x 88.9 * 2.00 mm
Max. operating pressure: 16.0 bar		PED classification:	Art. 4, par. 3(7)
		Passes:	2
Dimensions:(6)			
Length:	10464 mm	Outlet header:	2 x 88.9 * 2.00 mm
Width:	2400 mm	Inlet header:	2 x 88.9 * 2.00 mm
Height:	2850 mm(6)	Circuits:	2N
No. of legs:	10	Distributions:	2 * 144

GPC.EU Customer, 2015.72-124/2017-02-06, PL 1/2015 . Unnamed . Page 1 of 3 . MTO . GFD 090.3D/2x8-MS1C/2P.E/M4//129/190/191/241

GFD 090.3D/2x8-MS1C/2P.E

Project:
Quotation-no.:
Item:
Reference:



File: EMF\GVD_CD2x8_UNI.emf

L	=	10224 mm	B	=	2400 mm	H	=	2850 mm
R	=	220 mm	L1	=	2505 mm	L2	=	77 mm
B1	=	2300 mm	S	=	20 mm	ØD	=	17 mm

Attention: Drawing and dimensions not valid for all accessory options!

Accessories	Piece(s)
EC fuse box system[8]	1
1 x (5209278) Power Distribution Block 3ph+N 32A	
8 x (5209043) Circuit Breaker 3ph, 6A	
1 x (5209039) Circuit Breaker 1ph+N, 6A	
1 x (5209008) GPD Güntner Power Distribution Housing (Plastic) 600x300x132 [mm]	
Temp. sensor with stainless steel pocket	1
Mounting and wiring	1
EC fans with motor management GMM EC/16	1
Repair switch (single-speed), fans wired to front in pairs	8

Important remarks / explanatory notes:

(1) Fluid group 2 according to pressure equipment directive 2014/68/EU

(2) According to the enveloping surface method defined in EN 13487; Eurovent tolerance = +2 dB(A). Applies only for AC fans, AC fans with sine control and EC fans. Noise caused by other control methods, water spraying systems or sound reflexions occurring at the installation site are not taken into account and may result in an increased sound pressure level.

(3) This unit is equipped with fans that meet the efficiency requirements of Directive 2009/125/EC (ErP Directive).

(4) The current consumption can differ in dependance of the air temperature and of the variations of system voltage according to the VDE guidance.

(5) The unit may not be suitable for very corrosive atmospheres (close to shores, in smoke rooms, etc.). For further information see program menu "?", "Material recommendations brochure", or ask your sales partner.

(6) Dimensions and weights are not valid for all possible options! They may differ for units with accessories or special units (S-...).

(7) Piping (DN = 84.9 mm, TSmax = 100 °C, liquid). Final classification according to pressure equipment directive 2014/68/EU during order processing.

(8) (GMEC16-0189CB2-PNNCNNN-N-001) Width x Height x Depth: 600 mm x 300 mm x 132 mm, weight: 9 kg, Protect. system IP 54, mounted and wired on inlet side, Operating temperature range: -20.0 °C - 34.8 °C, Power supply: 400 VAC / 3-Ph+N+PE, Full load amperage (FLA): 30.2 A, Maximum overload protection (MOP): 40.0 A(gL/gG)

Please pay attention ...

15.13 Interpretation of §2 and 4 in law about DC

Kære Martin og Klaus

Her kommer et svar til at jer på jeres spørgsmål om forståelsen af lov om fjernkøling:

Ad "Har kommunen nogen mulighed for at hjælpe økonomiske med etableringen af fjernkølingsselvskabet? Hvis kommunen ikke har mulighed for at bidrage med kapital ved du evt. hvorfra et kommunale fjernkølingsselvskaber så typiske vil få sin kapital fra?"

Lov om fjernkølings § 4 siger ganske rigtigt, at kommuner ikke må yde tilskud til eller stille lånegarantier for fjernkølingsanlæg, der er omfattet af loven. Kommuners udøvelse af fjernkølingsvirksomhed sker på kommercielle vilkår i et selvstændigt selskab med begrænset ansvar, hvori der ikke må udøves andre aktiviteter end fjernkøling, jf. § 3, stk. 1. Det betyder også at adskillelsen mellem fjernvarme- og fjernkølingsvirksomheden blandt andet indebærer, at aftaler om levering af ydelser fra fjernvarmevirksomheden til fjernkølingsvirksomheden skal ske på kommercielle vilkår. Fjernkølingsvirksomheden finansieres af ansvarlig indskudskapital og ved fremmedkapital. Kommunen har ikke låneadgang til den ansvarlige indskudskapital, men det forudsættes, at fjernkølingsvirksomheden vil kunne optage lån uden konsekvenser for den kommunale lånerамme (der gælder særlige regler når kommuner skal optage lån). Virksomhedens låntagning er således ikke reguleret af de kommunale låneregler. Fjernkølingsvirksomheden kan herefter optage lån til etablering mv. på lige vilkår med andre kommercielle virksomheder. De må altså afsøge det almindelige lånemarked for at opnå bedst mulige finansieringsvilkår.

Såfremt virksomheden indgår i en koncernstruktur *kan* der være mulighed for at de enkelte selskaber indenfor forsyningskoncernen yder lån til hinanden. Den situation reguleres bl.a. af de enkelte forsyningslove og de kommunalretlige regler. Fjernkølingsaktiviteter, som udøves i en koncernstruktur omfattet af elforsyningslovens §§ 37 og 37 a eller varmeforsyningslovens §§ 23 l og 23 m, vil blive omfattet af reglerne om modregning i kommuners bloktilskud – typisk i forbindelse med bl.a. udlodning af udbytte. Se nærmere herom i Betænkningen til det oprindelige lovforslag (kan findes via http://www.ft.dk/samling/20072/lovforslag/L127/som_fremsat.htm#dok).

I øvrigt; vær opmærksom på at *kommunal* fjernkølingsvirksomhed dækker over at kommuner helt eller delvist kan eje *andele* i et fjernkølingsselskab, som er omfattet af loven. Det betyder, at kommuner kan indgå partnerskaber med private om etablering af fjernkøling, hvilket kan bidrage til, at kommunens økonomiske engagement og deraf følgende risiko for tab minimeres. Det bidrager endvidere til at sikre, at kommuner investerer efter et markedsøkonomisk investorprincip. Lovens forudsætning er fortsat, at det kommunale engagement fordrer udnyttelse af overskudsvarme (synergihensynet).

Ad "Ift. §2 i lov om fjernkøling ved du hvor grænsen går ift. hvornår der er synergieffekt med fjernvarmenettet og hvornår der ikke er synergieffekt med nettet? Er der synergieffekt, hvis man har installeret absorptionskøling (konvertering af varme fra CHP til køling), men ikke nødvendigvis bruger maskinen. Er der dannet retspraksis indenfor området ift. hvor synergieffekt grænsen går?"

Som nævnt har forudsætter det kommunale engagement synergieffekter med fjernvarme. Det medfører, således at kun kommuner, der ejer et fjernvarmeværk, må således deltage i kølingsprojekter. Kravet om, at køling skal ske med henblik på at udnytte synergieffekter med fjernvarme, medfører dog ikke nødvendigvis, at en kommune ikke har hjemmel til at eje, etablere og drive *rene* kølingsanlæg, men kræves, at *det samlede kølingssystem er med til at udnytte synergier med fjernvarme*. Det vil sige, at den kommunale fjernkølingsvirksomhed vil kunne anvende forskellige teknikker til produktionen af køling, som f.eks. absorptions- eller kompressionsvarmepumper kombineret med et kølingslager og frikøling, hvis *systemet som helhed* udnytter synergieffekter med fjernvarme. Loven fastsætter ikke en egentlig grænse hvornår der er tale om synergieffekter. Hvornår der er tale om synergieffekter vil dermed afhænge af en konkret vurdering af, hvad der ligger i ordet "synergieffekt", jf. § 2. Vurderingen kan efterfølgende prøves af energiklagenævnet og evt. domstolene.

Formålet med lov om fjernkøling er også at fremme energieffektiv køling. Forslaget til den første lov om (kommunal) fjernkøling nævner, at "i det omfang fjernkøling giver mulighed for at nyttiggøre energi, som ellers ville gå tabt, kan der være brændselsbesparelser. Fjernkøling giver således ikke anledning til et brændselsforbrug, når der er varme til rådighed fra kollektive varmeforsyningsanlæg, som ikke ville blive nyttiggjort uden absorptionskøleanlægget. Ligeledes vil der ikke være tale om et brændselsforbrug, når fjernkølingen (i perioder) baseres på lokale ressourcer eks. fra havet, havne m.m., når temperaturen i vandet er tilpas lav (dvs. i vinterperioden). Dette betegnes ofte som frikøling og forbedrer energiregnskabet. Udover absorptionskøling og udnyttelse af frikøling fra eksempelvis havvand, kan en del af kølebehovet i et fjernkølingssystem blive produceret af en stor kompressorenhed, der kan have højere virkningsgrad end mindre enheder hos de enkelte kunder. Den højere virkningsgrad giver da anledning til en elbesparelse, såfremt den øgede effektivitet er højere end tabet ved distributionen. I absorptionsanlæg bruges der i almindelighed elbaserede kompressorer til at varetage spidsbelastningsbehov." Synergieffekterne kan derfor umiddelbart godt henføres til alene at vedrøre en del af året.

Dokumenter vedr. det forslag til lov om (kommunal) fjernkøling kan I se her http://www.ft.dk/samling/20072/lovforslag/L127/som_fremsat.htm#dok . I kan med fordel læse bemærkningerne til lovforslaget som helhed samt bemærkninger til de enkelte bestemmelser.

Ændringen af lov om fjernkøling (bl.a. udgik ordet *kommunal* i titlen) i 2014 var et resultat af EU's energieffektiviseringsdirektiv. I kan se dokumenter vedr. lovforslaget her http://www.ft.dk/samling/20131/lovforslag/L121/index.htm#dok . (Bemærk at lovforslaget også vedrører ændring af andre love end lov om fjernkøling).

I 2015 blev fjernkølingsloven også ændret sammen med en række andre love. Forarbejderne til denne lovændring kan I se her: http://www.ft.dk/samling/20151/lovforslag/L12/index.htm

Energiklagenævnet er myndighed for behandling af klager over energistyrelsens og kommuners afgørelser truffet efter fjernkølingsloven. Energiklagenævnet har umiddelbart ikke på nuværende tidspunkt truffet afgørelse efter fjernkølingsloven. I kan se nævnets praksis her www.ekn.dk

Venlig hilsen

Lisa Christensen
Videnskabelig assistent
Juridisk Institut

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Syddansk Universitet
Campusvej 55
5230 Odense M
www.sdu.dk

Det sammenkædede billede kan ikke vises. Filen er muligvis blevet flyttet, omdøbt eller slettet. Kontrollér, at linket peger på den korrekte fil og placering.

Fra: Martin Grunnow Vinstrup
Sendt: 10. marts 2017 12:38
Til: Bent Ole Gram Mortensen
Cc: Klaus Christian Jespersen
Emne: Fortolkning af §2 og §4 i lov om fjernkøling

Hej Bent

Vi er to studerende fra Energiteknologi, som er i gang med at undersøge potentialet i at anlægge fjernkøling til Rosengårdscentret, Bilka, IKEA og evt. SDU og Nyt OUH.

Fjernvarme Fyn vil være oplagt til at varetage driften af fjernkøling i et selvstændigt selskab.

Jeg håber, at du kan hjælpe med at fortolke §4 i lov om fjernkøling: " Kommuner må ikke yde tilskud til eller stille lånegaranti for fjernkølingsanlæg omfattet af denne lov eller § 2, stk. 1, nr. 3, i lov om varmeforsyning.". Har kommunen nogen mulighed for at hjælpe økonomiske med etableringen af fjernkølingsselvskabet? Hvis kommunen ikke har mulighed for at bidrage med kapital ved du evt. hvorfra et kommunale fjernkølingsselvskaber så typiske vil få sin kapital fra?

Ift. §2 i lov om fjernkøling ved du hvor grænsen går ift. hvornår der er synergieffekt med fjernvarmenettet og hvornår der ikke er synergieffekt med nettet? Er der synergieffekt, hvis man har installeret absorptionskøling (konvertering af varme fra CHP til køling), men ikke nødvendigvis bruger maskinen. Er der dannet retspraksis indenfor området ift. hvor synergieffekt grænsen går?

Kind regards,

Martin Grunnow Vinstrup
Student BSc Energy technology, 6th semester

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Det sammenkædede billede kan ikke vises. Filen er muligvis blevet flyttet, omdøbt eller slettet. Kontrollér, at linket peger på den korrekte fil og placering.

15.14 PwC answer about taxation on ATES

Hej Martin

Tak for dine spørgsmål.

Det lyder som et interessant projekt, hvor vi selvfølgelig gerne kommer med lidt input.

For god ordens skyld skal jeg understrege, at mine svar alene er af generel og vejledende karakter i forhold til jeres opgaver. Svarene hverken kan eller skal således tages som konkret rådgivning i forhold til det pågældende projekt.

Ud fra et afgiftsmæssigt synspunkt er der tale om nogle spændende problemstillinger, som også kan have stor betydning for projektets økonomi. Vi vil selvfølgelig gerne komme med mere konkrete input til selve projektet, hvis I/Fjernvarme Fyn ønsker det.

Se mine bemærkninger med rødt under de enkelte spørgsmål nedenfor. Du er velkommen til at ringe/skrive, hvis du ønsker at drøfte svarene yderligere.

Med venlig hilsen / Best regards

Sebastian Houe
PwC | Senior Manager, PhD
Indirect Taxes
D: +45 8932 5531 | M: +45 2441 0930
Email: sho@pwc.dk | www.pwc.dk
Nobelparken, Jens Chr. Skous Vej 1, DK-8000 Aarhus C

From: Martin Grunnow Vinstrup <mvins14@student.sdu.dk>
To: "jof@pwc.dk" <jew@pwc.dk>
Cc: Klaus Christian Jespersen <kljes14@student.sdu.dk>
Date: 24-04-2017 10:58
Subject: Afgifter på ATES produktion?

Hej,

Vi er i gang med at undersøge fjernkølings potentialet for udvalgte kunder i Odense i samarbejde med Fjernvarme Fyn. Tanken er, at der skal oprettes et fjernkølingsselvskab, som producere og levere køling til fjernkølekunder, som både består af kunder med komfortkøling og proceskøling behov.

En af teknologier, som producere køling i fjernkølingsselvskabet et ATES (Aquifer Thermal Energy Storage). ATES fungere ved, at der pumpes koldt vand op for et grundvands reservoir i sommerperioden. Denne køling leveres så til fjernkølings-kunderne, hvorved temperaturen af vandet stiger. Det varmevand lagres i reservoiret, hvorefter det om vinteren pumpes op. Varmen opgraderes via en varmepumpe og sælges til et fjernvarme selskab.

Vores spørgsmål:

- □ □ □ □ **Hvilken afgifter gælder der for anvendelsen af ATES til varme og køleproduktion?**

○ Tænker, at der skal pålægges elafgift til pumpe effekten. I givet tilfælde, hvilket godtgørelse skal anvendes – pro-ceskøling eller afhænger godtgørelsen af hvilken kunden, som kølingen leveres til dvs. om kølingen leveres til proceskun-der eller komfortkøle kunder.

Der skal betales elafgift af strømforbruget til de pumper, som anvendes i systemet - både de pumper, som henter grundvandet, og de pumper, som sender vandet/kulden ud i fjernkølingssystemet. Der vil dog være tale om såkaldt procesforbrug, hvor hele elafgiften godtgøres undtagen 0,4 øre/kWh. I 2017 udgør elafgiften 91,0 øre/kWh. Heraf vil man således kunne få godtgjort 90,6 øre/kWh af elfor-bruget i pumperne. Det er uden betydning, om kølingen anvendes til proces eller komfort ude ved kunden.

Der vil ikke være afgifter på det kolde vand, da der alene er tale om grundvand, som ikke er nedkølet ved hjælp af kompressor eller lign.

Der vil fortsat skulle betales PSO-tarif mv. af strømforbruget til pumper, hvorfor disse udgifter selv-følgelig skal medregnes i projektet.

○ Hvilke afgifter pålægges varmeproduktionen herunder varmepumpen. Gælder der overskudsvarmeafgift og elaf-gift? Igen, hvilken godtgørelse gælder der?

Når det kolde vand er varmet op ude ved forbrugerne - og herefter føres tilbage i reservoiret - vil det som udgangspunkt ikke have afgiftsmæssige konsekvenser. Hvis vandet direkte varmes op ved hjælp af særlige installationer, hvor der genvindes varme fra en proces, kan reglerne om overskudsvarme-afgift måske komme i spil (50,7 kr./GJ eller 33 % af vederlaget). Det vil dog kræve en konkret vurde-ring af den pågældende situation.

Når vandet varmes yderligere op ved hjælp af en varmepumpe, skal der betales elafgift af elforbruget i varmepumpen. Her kan man få godtgjort 50,5 øre/kWh i 2017, da der ikke er tale om procesfor-brug, men derimod forbrug, som anvendes direkte til opvarmning. Nettoafgiften vil således udgøre 91,0 - 50,5 = 40,5 øre/kWh input i varmepumpen. Afgiftsbelastningen på selve varmen afhænger så-ledes af COP-værdi mv. Afgiften kan eventuelt godtgøres yderligere ved varmeaftager, hvis denne an-vender varmen til procesformål (fx et gartneri).

Der gælder endvidere en anden ordning benævnt "elpatronordningen". Her udgør afgiften på den producerede varme max 215 kr./MWh output varme i varmepumpen. Ved anvendelse af denne ord-ning fritages man endvidere for PSO-tarif af elforbruget i varmepumpen. Har varmepumpen en COP-værdi over 3 vil ordningen dog typisk ikke være relevant/økonomisk rentabel.

Kind regards,

Martin Grunnow Vinstrup
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15.15 EIA duty cost estimation by Ramboll

Hej Martin, det er ganske vanskeligt at sige, da det vil afhænge af en række faktorer, herunder størrelsen af et anlæg og sårbarhed af området, hvor boringerne skal placeres i samt myndighedernes øvrige betragtninger om miljøforhold i et muligt projektområde, herunder biologiske og arkæologiske forhold. Alle forhold jf. VVM-reglerne skal belyses, og jeg antager, at en grundvandsmodellering kan være nødvendig for at give indikation af påvirkninger i primær magasin og terrænnært grundvand/overfladevand. Umiddelbart skønner jeg, at en VVM vil kunne gennemføres for mellem 500.000 kr. til 1 mio. kr., idet der som sagt er en stor usikkerhed på grundlaget for et sådan overslag.

Yours sincerely
Sesse Bang

Chief Consultant,
M.Sc. Biology/Geography
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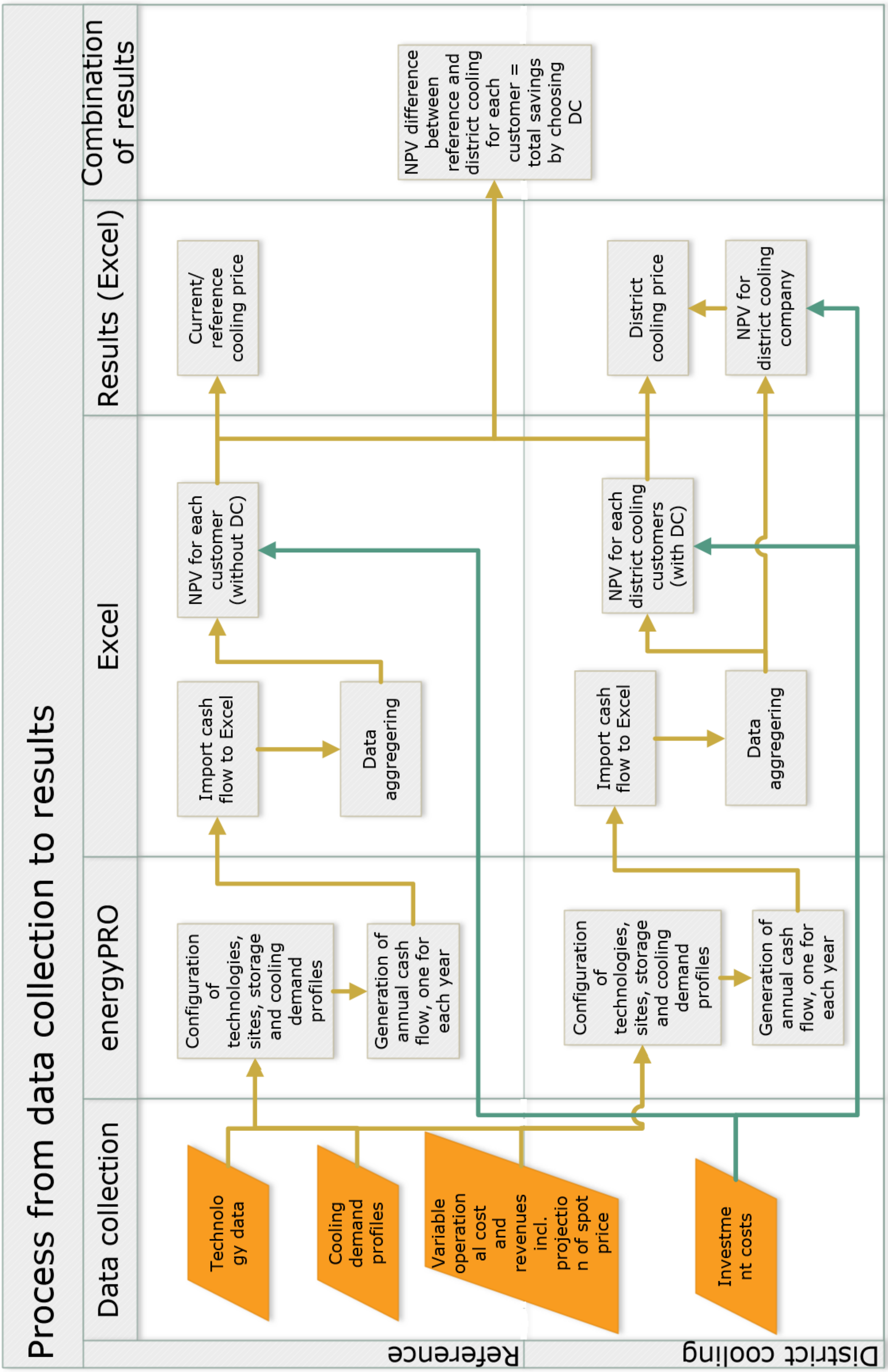
15.16 Diagram: From data collection to results



15.17 Datasheet electrical chiller at Bilka

KLIMA- OG KØLETEKNIK **birton a/s**

Hovedkontor/administration
Markvangen 4, DK-8260 Viby J
Telefon: 86 14 62 11. Telefax: 86 14 29 21

Salg/Service Sjælland:
Telefon: 43 42 70 03
Telefax: 43 42 64 51

26.06.96.

TEKNISK BESKRIVELSE

KØLEANLÆG

Køleanlæg	:	**Anlæg KA-100.**	**Anlæg KA-110.**
Linde type	:	VPP 320-4061	VPP 320-4081
Mål: længde x bredde x højde	:	210 x 79 x 180 cm.	210 x 79 x 140 cm.
Vægt	:	1450 kg.	1480 kg.
Kompressorer antal / type	:	3 x Bitzer 6H-35.2Y	3 x Bitzer 6G-40.2Y
Antal kapacitetstrin	:	9 trin.	9 trin.
Recieverindhold	:	185 liter.	185 liter.
Kølemiddel type	:	HFC R-404A	HFC R-404A
Kølekapacitet *)	:	**310,0 kw. *)**	**355,5 Kw. *)**
Optagen effekt herved	:	86,7 kw.	100,8 Kw.
Afgiven kondensatoreffekt	:	396,7 kw.	456,3 Kw.
Kompressorvirkningsgrad	:	3,57 (COP)	3,52 (COP)
***) Kapaciteten er opgivet ved:**	:	**+5 / +42°c.**	**+5 / +42°c.**
Luftkølede kondensatorer:		2 stk.	2 stk.
T.T Coil type	:	2 stk. BTB-145-700H	2 stk. BTB-154-700H
Længde / bredde / højde	:	2 x 461 x 150 x 148 cm.	2 x 569 x 150 x 148 cm.
Vægt	:	2 x 633 kg.	2 x 731 kg.
Kondensatoroverflade	:	2 x 853 m2.	2 x 850 m2.
Antal ventilatorer	:	2 x 4 stk. 950 mm.	2 x 5 stk. 950 mm.
Lydniveau (10 meters afstand)	:	2 x 58 dB(A)	2 x 59 dB(A)
Kapacitet / temp.differens	:	396,7 Kw. dt=12,2°c.	456,3 Kw. dt=12,6°c.
Eldata ventilatormotorer:			
Spænding	:	3 x 380 volt.	2 x 3 x 380 volt.
Effektforbrug	:	2 x 4 x 1300 w.	2 x 5 x 1300 w.
Strømbelastning	:	2 x 4 x 4,2 amp.	2 x 5 x 4,2 amp.
Kølemaskinens samlede eldata (incl. luftkølet kondensator):			
Hovedspænding	:	3 x 380 volt +N +J.	3 x 380 volt +N +J
Nominelt effektforbrug.	:	97,1 Kw.	113,8 Kw.
Nominelt strømforbrug.	:	180,6 amp.	209,4 amp.
Max. strømforbrug.	:	116,6 amp.	276,0 amp.
Max. startstrøm pr. kompressor.	:	262,0 amp.	323,0 amp.
Underkøling:			
Fabrikat og type	:	Swep V45x38.	Swep V45x44.

15.18 Additional information about ATES

15.18.1 Examples of ROI

Table 15.2 show a list of projects conducted by ENOPSOL and provided an indicator of the ROI and the size of the ATES system.

Project	Size	Return on Investment (ROI)
Grundfos – Bjerringbro	1.5 MW cooling 1.8 MW heating	Less than 5 years
Widex A/S	2.3 MW cooling 1 MW heating	Less than 4 years
Rambøll HQ	1 MW cooling 500 kW heating	Less than 4 years
SDU in Kolding	450 kW cooling 500 kW heating	Less than 4 years
CPH airport	5 MW cooling	Less than 6 years
Village Heating, ELFORSK project	2 MW heating	Less than 10 years
Jærgerprise CHP	1 MW heating	Less than 10 year
Ejby DH	2 MW heating	Less than 10 years

Table 15.2 List of ATES project conducted by ENOPSOL. Show the return on investment and size of the individual projects. Modified table from (ENOPSOL, 2017).

15.18.2 Application process for ATES

It is only allowed to establish and use ATES, when the municipality have accepted the project cf. §5 in AHG.

To accept a ATES project the applicant need to document at least the bullets below cf. AHG §§ 6-7:

- The extraction and injection need to be to and from the same aquifer.
- Conduction of a ground water model which provides information about:
  - Aquifer geology and extent
  - Aquifer hydrological conditions
  - Aquifer chemistry and microbiology
  - Hydrothermal characteristics
- Aquifer temperature may not rise more than 0.5 ℃
- In areas with special drinking water interests (OSD areas) after a 10-year period after shutdown of an ATES-system the aquifer need to be applicable for use as water supply

15.18.3 ATES development of the temperature in the hot and cold well

Graph showing the respective development of the temperature in the hot and cold well.

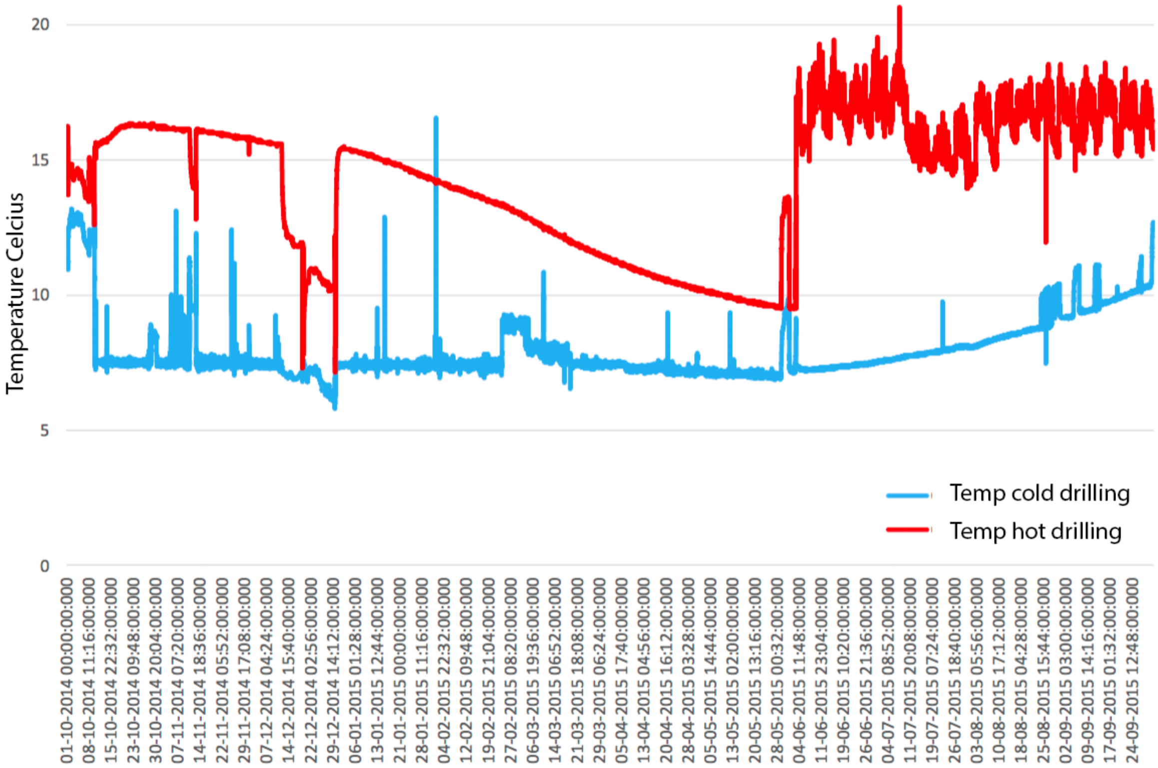


Figure 15.16The graph shows the temperature of hot and cold water as function of time, from the same dipole. The graph starts in the winter season, where hot water is processes for DH. The temperature of the hot water drilling declines from approx. 16 to 9 ℃ in an almost linear fashion, until the pump is re-versed. In the summer season, heat is stored at approx. 18 ℃, while cold water from the blue drilling is delivered to the customers. Notice how the temperature increases. Figure from Lars Hjortshøj Jacobsen, Ingeniør Huse.

15.19 Addition information about heat driven chillers

There are different types of absorption chillers, but they all work based on the same principles.[138]

- Single effect hot water driven systems
- Double effect hot water driven systems
- Direct fired single-effect, driven by a gas combustion source
- Double effect exhaust gas driven

Double effect hot water driven systems are more effective than single effect systems. The higher COP-a value is achieved by using a second tray in the absorber, thereby increasing the concentration in the absorber.

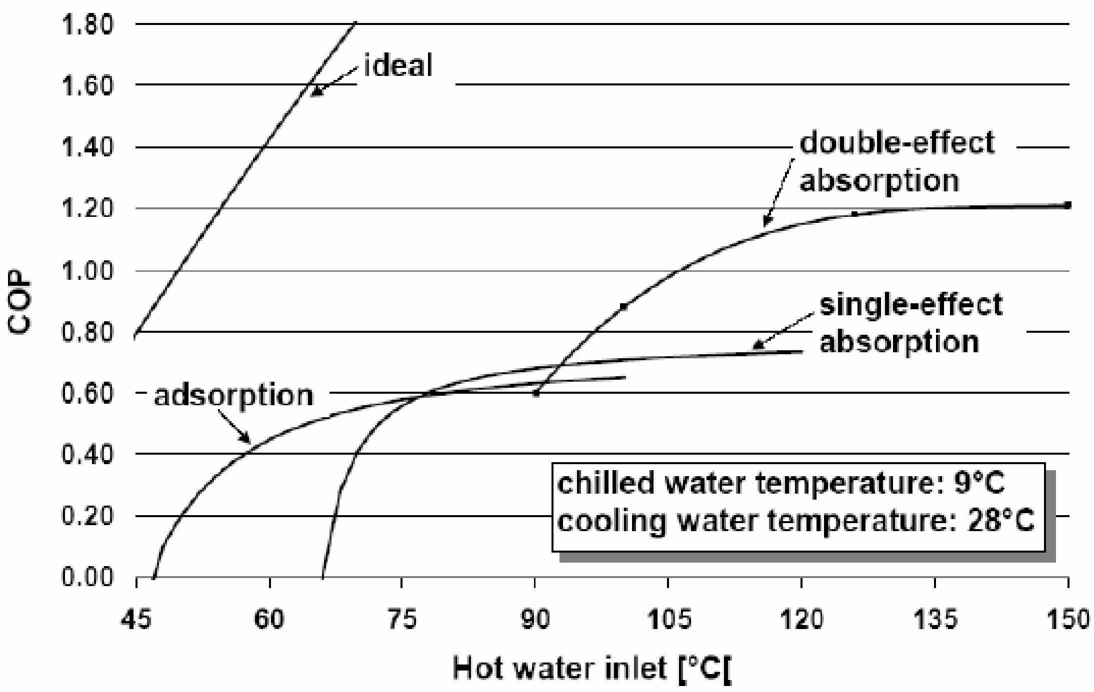


Figure 15.17 Comparison of performance for adsorption and absorption chillers. Adsorption chillers work at lower temperatures but the COP-a is low.

[138] (Goldman Energy, 2017)

15.20 Mail correspondence with Palle Mathiasen about Rosengårdcentret

Hej Palle,

Vedlagt de spørgsmål vi ønsker at undersøge i forbindelse med vores projekt om fjernkøling.

Vi er skriver et bachelor projekt omkring det økonomiske potentiale i at anlægge fjernkøling til Rosengårdscenteret, Bilka og IKEA samt evt. SDU og Nyt OUH. Projektet undersøger mulighederne i at kombinere flere konverteringsteknologier og dermed opnå en besparelse for brugerne af løsningen. Projektet skrives i samarbejde med Fjernvarme Fyn.
Vi arbejder med følgende teknologier: ATES (grundvand), absorption ved lav temperatur, adsorption og el kompressor.

Kølebehov og konverteringstekonologier modelleres herefter i et optimeringsværktøj, som kan beregne den optimale økonomiske løsning under de givne forudsætninger.

For at opnå en retvisende model, har vi behov for at kende følgende værdier.

- Køle areal i kvm?
  Svar fra Palle/Ivan: (kun vis du lige har data, ellers kan de måle op på Krakkort)Det må findes på kort

Ivan kan ikke huske m², men det er stueetagen inklusive butikker. Så gå på nettet og mål op – måske 100000m²? Til info er der lovet en køling på 60W/m²

22/3 På hjemmesiden står der 100000kvm. Betyder det, at Rosengaardcentret betjener all forretninger med køl?

- Køler Rosengaardcentret til en fast temperatur eller afhænger det af ude temperaturen?
  Svar fra Ivan: Køler til 5 grader

Der køles med en fast temperatur (gennemsnit af 8 målinger på gangarealer)

22/3 Vi ønsker at vide hvilken komfort temperatur der køles til i butikkerne. Er det en fast temperatur på 19 grader? F.eks. har Bilka et dynamisk setpunkt på 2 grader under udetemperatur over 19 grader. Hvilken kølestrategi anvender Rosengaardcentret for komforttemperatur?

Har lovet en indblæsning på 21°C til butikkerne men setpunkt er typisk 20-22°C

- Køle behov i så høj detalje grad som muligt. Kan eksempelvis være elforbruget fra kølekompressoren.
  Svar fra Ivan: I elforbruget er også forbrug til alt hjælpemaskineri, så forbruget er ikke kun køl.

Se vedhæfte fil og skriv for oven

22/3 Er det muligt at anslå et samlet forbrug, samt hvilken andel der forbruges af kølekompressorer. Det vil være en hjælp, hvis det er muligt at oplyse forbrug måned for måned.

Se vedhæfte fil og skriv for oven

- Hvad er COP-værdien for jeres køleanlæg?
  Anlæggets COP er opgivet til 5.1 (indregnet motorvirkningsgraden) ved 100% belastning.

Jeg vil tro at en COP-værdi på 5,1 er helt urealistisk (salgstal i testbænk er det nok muligt) da forbrug til øvrige komponenter ikke er medregnet. Regn med en på 3,0

Tak, ingen uddybninger er nødvendig

- Hvad er rest levetiden på jeres køleanlæg?
  Ivan: Anlægget er indkørt i 2003

en restlevetid på 15-20 år ikke være urealistisk

Hvad er den forventede levetid på kølekompressoren

Da det er skruekompressorer og kun 14 år gamle da vil en restlevetid på 15-20 år ikke være urealistisk – husk det NH3 anlæg (amoniak9

mvh Klaus og Martin

On 22 Mar 2017, at 10:26, Palle Mathiasen <pamat@udviklingfyn.dk> wrote:

SE LIGE DET MED GRØN SKRIFT

Venlig hilsen

Palle Mathiasen
Maskinmester | Energi og Byggeri
M: +45 51 48 06 70 | E: pamat@udviklingfyn.dk
MiljøForum Fyn | Forskerparken 10 | DK-5230 Odense M

<image001.png>Følg MiljøForum Fyn på LinkedIN

Tilmeld dig MiljøForum Fyns nyhedsbrev.

<image002.png> <image007.png> <image004.jpg>

Hej Palle.

Fredag efter kl.10 vil passe fint.

Se svar med grøn

Med venlig hilsen / Kind regards,

Ivan L. Pedersen (Mr)
Deputy Technical Manager

Rosengårdcentret Odense
Ørbækvej 75
5220 Odense SØ

Phone: +45 6315 2568
Mobile: +45 2182 6712
E-Mail: ivan.pedersen@ece.com

Fra: Palle Mathiasen [mailto:pamat@udviklingfyn.dk]
Sendt: 22. marts 2017 08:08
Til: Pedersen, Ivan
Emne: SV: Fjernkøling med mere

Hej Ivan.
Jeg mangler lige en tilbagemelding på denne mail. Har du/I tid til et møde i dag eller skal vi finde en anden dag? Kan du så ikke komme med et forslag til det – måske på fredag?

Venlig hilsen

Palle Mathiasen
Maskinmester | Energi og Byggeri
M: +45 51 48 06 70 | E: pamat@udviklingfyn.dk
MiljøForum Fyn | Forskerparken 10 | DK-5230 Odense M

<image001.png>Følg MiljøForum Fyn på LinkedIN

Tilmeld dig MiljøForum Fyns nyhedsbrev.

<image002.png> <image003.png> <image004.jpg>

Fra: Palle Mathiasen
Sendt: 13. marts 2017 17:24
Til: 'Pedersen, Ivan' <Ivan.Pedersen@ece.com>
Emne: Fjernkøling med mere

Hej Ivan.
Tak for sidst, det var hyggeligt lige at drikke en kop kaffe sammen med dig og lige hører lidt om din erfaring med vores fælles skæbne – har givet stof til eftertanke.

Ivan, kunne vi mødes med jer og se kølemaskinestuen: **onsdag d. 22 mellem kl. 0900-1400, du bestemmer tiden**

Kunne følgende data sendes til mig inden mødet:

- Køle areal i kvm? (kun vis du lige har data, ellers kan de måle op på Krakkort)Det må findes på kort
- Køler i til en fast temperatur eller afhænger det af ude temperaturen? Køler til 5 grader
- Køle behov i så høj detalje grad som muligt. Kan eksempelvis være elforbruget fra kølekompressoren. I elforbruget er også forbrug til alt hjælpemaskineri, så forbruget er ikke kun køl.
- Hvad er COP-værdien for jeres køleanlæg?Anlæggets COP er opgivet til 5.1 (indregnet motorvirkningsgraden) ved 100% belastning.
- Hvad er rest levetiden på jeres køleanlæg? Anlægget er indkørt i 2003

Jeg har sagt til de studerende at de skal tænke fremtiden ind sådant et anlæg, men det tager jeg lige med dem og deres vejleder. Det er et absolut must, for at det giver mening

Venlig hilsen

Palle Mathiasen
Maskinmester | Energi og Byggeri
M: +45 51 48 06 70 | E: pamat@udviklingfyn.dk
MiljøForum Fyn | Forskerparken 10 | DK-5230 Odense M

<image001.png>Følg MiljøForum Fyn på LinkedIN

Tilmeld dig MiljøForum Fyns nyhedsbrev.

<image002.png> <image003.png> <image004.jpg>

15.21 Mail from Gert Laursen, Odense municipality about ATES legislation

From: Gert Michael Laursen [mailto:gel@odense.dk]
Sent: Wednesday, February 15, 2017 11:23 AM
To: Martin Grunnow Vinstrup <mvins14@student.sdu.dk>; Klaus Christian Jespersen <kljes14@student.sdu.dk>
Cc: Gert Michael Laursen <gel@odense.dk>
Subject: SV: Kort over grundvandspotentiale og områder, hvor ATES må installeres

Kære Martin og Klaus
Det er et rigtig spændende og yderst relevant emne I har kastet Jer over, og jeg glæder mig til at se hvad I finder ud af.
De planmæssige rammer for brug af grundvand til varme-/køle-formål er givet i kommuneplanen. Hvis I kigger under pkt 13.2 Vandindvinding, vil I finde teksten:

Indvinding af vand til varmeudvinding og køleformål:

13.2.j
Indvinding af vand til varmeudvinding og køleformål bør ikke være vandressourceforbrugende og må normalt ikke påvirke vandføringen i vandløb samt vandudskiftning og vandstand i vådområder i øvrigt i sommerperioden.

Grundvand skal derfor efter varmeafgivelsen/varmeoptagelsen normalt ledes tilbage til det jordlag, hvorfra det indvindes. Indvinding til varmeudvinding og køleformål må ikke virke begrænsende for eksisterende eller fremtidige indvindinger til andre formål.

13.2.k
Grundvandskøleanlæg må normalt ikke etableres inden for område med særlig drikkevandsinteresse samt indvindingsoplande til vandværker beliggende uden for område med særlige drikkevandsinteresser. Anlæg skal endvidere placeres, så der ikke sker en temperaturpåvirkning af indvindingsanlæg.

Som udgangspunkt skal ATES-anlæg altså placeres udenfor områder med særlige drikkevandsinteresser (OSD) og må heller ikke placeres i indvindingsoplandene til de vandværker der ligger udenfor OSD.
Som I kan se står der "bør", "normalt" eller "normalt ikke" flere steder i kommuneplan-teksten, og det betyder jo, at retningslinjerne (måske) kan udfordres.

I praksis mener jeg der findes masser af planmæssigt egnede steder at placere ATES-anlæg, men så er der jo også lige de geologiske forhold der skal tages hensyn til…
Jeg er bekendt med at der tidligere har været overvejelser omkring ATES i forbindelse med gartneriet Hjortebjerg (Nordfyns Kommune), SDU, VIVA (den gamle slagterigrund) og det sidste projekt I selv nævner fjernkøling af "IKEA-Rosengaardcentret-SDU-SUND-Nyt OUH". Der er både geologiske, hydrogeologiske og økonomiske årsager til at det indtil videre kun er blevet til overvejelser….

Hvad angår grundvandspotentialer for Odense-området vil jeg foreslå, at I retter henvendelse til Johan Linderberg, Vandcenter Syd. Han vil kunne hjælpe Jer med magasin-specifikke potentialekort.

Har lige et par deadlines der skal overholdes, så jeg kan ikke uddybe yderligere for nuværende, men la os snakkes ved engang i næste uge…

Sendt fra en pc, og med de bedste hilsener
Gert Michael Laursen
Slotsgeolog - Miljøvagt - Klimamedarbejder

Tlf: 40219789
Mail: gel@odense.dk

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By- og Kulturforvaltningen
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5100 Odense C
www.odense.dk

15.22 Calculation of pump work

The pump work is calculated based on the following losses:

Pressure loss	Value	Remarks
Pipe friction	• 4 Pa/m for primary and secondary target group • 11 Pa/m for primary target group only	The pipe friction is calculated by using the Excel sheet in Appendix 15.1 C3 and C5. The pipe friction is based on the average cooling transferred through the pipe calculated by using energyPRO-model 1 and 2 and the pipe chosen in section 7.3.
Pressure difference at consumer	0.3 bar	It has not been possible to find the typical pressure difference at the consumer and therefor is the typical value for DH used[139], asbecause they have similar characteristics.
Pipe and individual frictions on the plant	0.7 bar	It has not been possible to find the typical pipe and individual friction on the plant.

The pump work is calculated as:[140]

$$W_{pump} = \frac{\Delta p * q_v}{\eta_{pump}} [W] \quad (15.1)$$

Where Δp is the pressure loss [Pa], q_v is the maximum water flow $\left[\frac{m^3}{\mathrm{h}}\right]$ calculated by using the Excel sheet Appendix 15.1 C3 and C5 and η_{pump} is the efficiency of the pump, which is set equal to 90 %. The calculation of the pump cost is implemented in the Excel sheet used in combination with energyPRO.

[139] (Andersen, et al., 2015, p. 283)

[140] (Andersen, et al., 2015, p. 288)

15.23 List of contact persons

Name and company	Contribution	E-mail	Phone
Anders Block, SDU student	Pass on data about SDU and Nyt OUH cooling demand and data about the production units at SDU and Nyt OUH (suggested production units)	Anblo11@student.sdu.dk	
Christian Frandsen, EMD international	Input in relation to energyPRO	cf@emd.dk	96 35 44 47
Claus Pilegaard Thomsen, Johnson Control	Product offer on electrical chiller	Claus.thomsen@jci.com	87 36 31 09 / 87 36 31 01
Gert Laursen, Odense municipality	Input about ATES legislation	gel@odense.dk	40 21 97 89
Jens Ole Pihl-Andersen, HOFOR DC	See HORFOR DC absorption chiller an sea water cooling	jepi@hofor.dk	27 95 42 46
Johan Linderberg, Vandcenter Syd	Introduction to GEUS database and general understanding of geological behind ATES	jl@vandcenter.dk	63 13 23 27 / 40 80 84 72
John Christensen, Bilka	Data about Bilka cooling production technologies and strategies	John.christensen@dsg.dk	30 58 91 77
John Tang, Dansk Fjernvarme	Help about taxes in relation to DC technologies	jt@danskfjernvarme.dk	24 42 88 84
Lars Hjortshøj Jacobsen, Ingeniør Huse	Help to estimate ATES potential, help estimating economically figures for ATES and general understanding of ATES	lars@ingenioerhuse.dk	30 32 51 25
Leif Holm Tambjerg, EMD international	Input in relation to energyPRO	lht@emd.dk	96 35 44 57
Lisa Christensen, Science assistant at Legal institute at SDU	help to interpretation of the law about district cooling	lch@sam.sdu.dk	
Nicolaj Tidemand Haagensen, SDU student	Pass on data about SDU and Nyt OUH cooling demand and data about the production units at SDU	Nihaa12@student.sdu.dk	

	and Nyt OUH (suggested production units)		
Niels Henning Nielsen, Skat	Help about taxes in relation to DC technologies		72 38 56 78
Palle Mathiasen, Udvikling Fyn	Help with various smaller questions and providing contact to Rosengårdcentret	pamat@udviklingfyn.dk	51 48 06 70
Peer Andersen, Fjernvarme Fyn	Data about the district heating network in Odense City, realistic sales and purchase price for heat from/to Fjernvarme Fyn, IKEA cooling demand and general inputs to the project	pa@fjernvarmefyn.dk	65 47 30 12 / 30 62 79 71
Sebastian Houe, PwC	Help about taxes in relation to DC technologies	sho@pwc.dk	89 32 44 31 / 24 41 09 30
Stig Niemi Sørensen, ENOPSOL	General inputs about ATES	sn@enopsol.dk	38 40 03 31 / 22 75 74 14
Stuart Johnston, Thermax Europe	Product offer on absorption chiller	stuart@thermax-europe.com	+ 44 19 08 37 89 14 / + 44 19 08 37 94 87
Vijay Raina, Bry-Air	Product offer on adsorption chiller	vraina@pahwa.com	+91 12 41 84 44 4