Energy mapping and analysis of the COOL DH demo sites

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Thesis for the degree of Master of Science in Engineering
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Abstract

The EU project, COOL DH, a pioneering project for 4th generation district heating is cooperating with participants from Denmark and Sweden to support the construction of two new energy efficient district heating systems in Lund and Høje Taastrup. These systems are to be monitored and evaluated as a part of COOL DH project to provide information for the future development of similar projects and as promotion for decision-makers.

The purpose of this thesis is to investigate the current and future state of the district heating grids in Brunnshög and Høje Taastrup and to provide analysis on challenges regarding monitoring and evaluation goals for the COOL DH project. This is done by investigating the heat production and customer heat demand for the two district heating grids by mapping the construction projects in the demo areas and performing simulations of the future performance of the Brunnshög DH grid with NetSim and Logstor Calculator.

From the results of the mapping, Brunnshög is shown to produce enough waste heat from the two science facilities MAX IV and ESS to supply the entire Brunnshög grid with heat, at least until the end of the COOL DH project in September 2021. The construction projects in Brunnshög has suffered delays and several of the projects end close to, or after the end of COOL DH, resulting in a reduction in data available for evaluation.

Simulations with NetSim and Logstor Calculator provide data on the velocity and heat losses in the LTDH grid respectively and from this data an estimation of the thermal efficiency of the Brunnshög grid is calculated as 63 %.

Using the results from the these findings, an analysis of the challenges achieving monitoring and evaluation goals for the COOL DH project is made. This analysis shows that the low heat density in the Brunnshög grid, early in the districts development, can lead to problems with evaluating achieved energy savings, CO_2-reductions and operational costs. The same analysis for Høje Taastrup show that it faces less challenges with its evaluation goals, as it is replacing an already existing system and will therefore not have problems with its thermal efficiency.

Keywords: Brunnshög, Høje Taastrup, COOL DH, district heating, LTDH, 4th generation district heating, MAX IV, ESS, CITY2 mall, NetSim.

Sammanfattning

I EU-projektet COOL DH, ett banbrytande projekt för fjärde generationens fjärrvärme, samarbetar deltagare från Danmark och Sverige för att stödja byggandet av två energieffektiva fjärrvärmesystem i Lund och Høje Taastrup. Dessa system ska övervakas och utvärderas som en del av COOL DH-projektet för att ge information för utveckling av framtida projekt och för att förenkla för beslutsfattare.

Syftet med denna rapport är att undersöka nuvarande och framtida läget för fjärrvärmenäten i Brunnshög i Lund och Høje Taastrup och att analysera utmaningarna med att övervaka och utvärderingsmålen i COOL DH-projektet. Detta görs genom att undersöka värmeproduktionen och kundens värmebehov för de två fjärrvärmenäten genom att kartlägga byggprojekten i demoområdena och utföra simuleringar av Brunnshögs fjärrvärmenäts framtida prestanda med NetSim och Logstor Calculator.

Kartläggningen visar att vetenskapsanläggningarna MAX IV och ESS kommer producera tillräckligt med spillvärme för att försörja hela lågtempererade fjärrvärmenätet i Brunnshög i slutet på september 2021, när COOL DH-projektet slutar. Byggprojekten i Brunnshög har drabbades av förseningar och flera av projekten slutar nära, eller efter slutet av COOLDH, vilket resulterade i en minskning av tillgängliga data för utvärdering.

Simuleringar med NetSim och Logstor Calculator ger data om hastigheten och värmeförlusterna i det lågtempererade fjärrvärmenätet och från dessa data beräknas en uppskattning av verkningsgraden i Brunnshögsnätet till 63 %.

Från resultaten av simuleringarna görs en analys av vilka utmaningar som kan uppkomma för att uppnå övervaknings- och utvärderingsmålen i COOL DH. Analysen visar att den låga linjetätheten i Brunnshögsnätet, tidigt i stadsdelens utveckling, kan leda till problem med att utvärdera uppnådda energibesparingar, CO2-minskningar och driftskostnader. Samma analys för Høje Taastrup visar att de står inför mindre utmaningar med sina utvärderingsmål, eftersom de ersätter ett redan existerande system och därför inte kommer att ha problem med låg linjetäthet.

Nyckelord: Brunnshög, Høje Taastrup, COOL DH, fjärrvärme, LTDH, 4th generation district heating, MAX IV, ESS, CITY2 mall, NetSim.

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At first we would like to thank our supervisors Per-Olof Johansson Kallioniemi and Kerstin Sernhed for helping us along the way and for welcoming us in to the group.

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Abbreviations and Definitions

COOL DH - **C**ool ways of using low grade Heat Sources from C**oo**ling and Surplus Heat for heating of Energy Efficient Buildings with new **L**ow Temperature **D**istrict **H**eating (LTDH) Solutions.

COP - Coefficient of Performance

DHW - Domestic Hot Water

ESS - European Spallation Source.

KPI - Key Performance Indicator

LTDH - Low Temperature District Heating

LTH - Lunds Tekniska Hg̈skola.

RES - Renewable Energy Source

WP - Work Package

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1 Introduction

At the onset of the 4th generation of district heating, Horizon 2020, the biggest EU research and innovation program, has funded COOL DH, a pioneering project for district heating solutions using a lower supply temperature than conventional district heating. COOL DH is a collaboration between the municipalities in Lund and Høje Taastrup, their respective district heating suppliers Kraftringen and Høje Taastrup Fjernvarme, Lund University, Europower and heat and the companies Cetetherm, COWI and Logstor. The two test sites for the project are Brunnshög in Lund, Sweden and Høje Taastrup in Copenhagen, Denmark.

In Lund, Brunnshög is being built as a whole new district and all the buildings that are going to use the district heating system will be modern, energy efficient buildings designed and built for a lower supply temperature than in conventional district heating systems. Two large, new research facilities, MAX IV and ESS, are being developed here which have a large cooling demand and will provide waste heat for the LTDH grid.

Høje Taastrup is a suburb to Copenhagen and is one of the most engaged municipalities in Denmark in working towards greater sustainability for cities. Here, an already existing residential area called Østerby is going to receive a new district heating system designed for a lower supply temperature. Later on it will be expanded to heat other residential areas.

In both cases the heat for the district heating network will come from excess heat from large cooling machines. These heat pumps that produce the cooling will be able to co-produce heat. In the case of Høje Taastrup, the heat pump is used to cool a shopping center, CITY2, close to Østerby and CITY2 has a large solar panel installation on its roof available to power it. Future plans exist to incorporate additional sources of waste heat in the LTDH grid such as, for example, a hotel in central Høje Taastrup as well as a food and flower market. In Lund the heat comes from the cooling of the two big science facilities, MAX IV and ESS. In both areas the new LTDH systems will make recovery of lower grade waste heat possible, which will open up for the possibility of prosumers and small scale producers to deliver heat to the LTDH grid.

Among the variety of different participants involved in the COOL DH project Lund University is of greatest relevance for this thesis. Their part in COOL DH involves monitoring and evaluation with regards to environmental and social impacts, gains in energy efficiency and costs implications. To be able to evaluate the systems fairly, a comprehensive understanding of the two systems and their circumstances is required. This report will include an energy mapping of the two systems to quantify what can be measured in the different systems within the time frame of COOL DH and try to evaluate and identify challenges with these tasks. Both areas will still be under development by the end of COOL DH and thus the analyses performed may perhaps not portray the systems fairly. This is especially true in the case of Brunnshög. To investigate this an analysis of what the future of Brunnshög will bring in terms of buildings and how the pipe network will perform will be carried out.

1.1 Aim

The objective of the thesis is to map the rate of expansion of two different LTDH systems. That includes mapping the expansion of the LTDH grid and the construction and connection of different production units and customers by investigating a multitude of different sources from involved participants. The study of heat demand and production will be limited to facilities and systems that produce energy for, or are fed energy from the low temperature district heating system.

Furthermore the future situation for the district heating system in Brunnshög will be analyzed with regards to different scenarios where both the performance of the grid and the variation of heat demand over time will be studied. The study aims to make estimations about the future heat demand for the LTDH grid in Brunnshög and the future heat production from the research facilities MAX IV and ESS.

The thesis will also include an analysis of possible challenges that may arise when monitoring and evaluating data from the two demonstration sites Brunnshög and Høje Taastrup.

To achieve the purpose of this study the following steps will be taken:

- Mapping of heat production facilities in regards to energy volume, temperatures, periods of revisions and mapping of customers in regards to energy demand. This will be achieved trough interviews and gathering of information from involved participants.
- Mapping of the planning for the introduction of different production units and customers, mapping of the plans of grid expansion and the connections of new customers to the grid.
- Estimations of how the balance in heat demand and production will match in different seasons and over time.
- Simulations to provide estimations of how the low temperature district heating grid in Brunnshög will perform by 2021, at the end of COOL DH, in regards to linear temperature drop, heat loss and efficiency and how future additional heat demand will affect these parameters.
- Investigation into what main challenges exists for reaching the COOL DH monitoring and evaluation goals in Brunnshög and Høje Taastrup within the time frame of the COOL DH project.

2 Description of the Demo Projects

This chapter aims to provide information on the areas, systems and projects relevant for the energy mapping and district heating system analysis in its current and future state. It firstly provides information regarding the state of the district heating systems in Brunnshög and Høje Taastrup. This also includes descriptions of MAX and ESS as well as section on district heating production in Brunnshög and Høje Taastrup. Lastly it gives some background for the COOL DH project and its monitoring and evaluation goals, relevant for this thesis.

2.1 Brunnshög

In the northeastern part of Lund a brand new city district is under development called Brunnshög. The municipality of Lund has ambitious plans for Brunnshög to be an international and innovative hub for research as well as creating a place for sustainable living for its future inhabitants (Dalman et al., 2016). The energy output from the two major research facilities, MAX IV and ESS, are meant to supply waste heat to buildings in Central and South Brunnshög, which locations can be seen in Figure 1.

Figure 1: Map over Brunnshög with the different districts (Dalman et al., 2016).

South Brunnshög (*Södra Brunnshög*) is the most southern part of the district of Brunnshög and is the first you will reach when traveling from Central Lund. It is also were the first residential houses are being built in the new district. Most of the housings will be apartment buildings with some townhouses in the middle. There will be approximately 700 dwellings in total in South Brunnshög (Lunds Kommun, 2018d). Most of the houses will be using district heating for space heating and domestic hot water (DHW). Initially all of South Brunnshög would receive conventional district heating but as the project progressed contractors in South Brunnshög asked Kraftringen for the possibility to have their building connected to the LTDH grid. Kraftringen concluded that the northern part of South Brunnshög would be able to connect to the LTDH grid (Gierow and Falkvall, 2018).

The next part of Brunnshög you will reach is Central Brunnshög (*Centrala Brunnshög*). This is the hub for the whole district and will have most of the stores including a grocery store and will house most of the people living in Brunnshög. It also connects to the north where you will find the science facilities of MAX IV, Science Village and ESS (Dalman et al., 2016). Kraftringens objective is that all of the buildings in Central Brunnshög will be heated by the LTDH (Gierow and Falkvall, 2018).

To the north of Central Brunnshög lies the research facilities ESS, MAX IV and Science Village Scandinavia. This is where most of the people working in Brunnshög will work. It will also be the main supplier of heat for the LTDH grid. ESS and MAX IV have a great cooling demand because of their energy intensive internal processes. The waste heat that they produce can be captured and used for district heating.

MAX IV and ESS will here have a special situation wherein they produce enough waste heat through their internal cooling processes to the point of not being considered a load to the district heating system (Parker et al., 2013). Instead they will be able to completely cover their own heat demand and be considered production facilities as their output of heat is always a net positive. This is expanded upon further in chapter 5.1.

The area known as Science Village will be constructed in the more northern part of Brunnshög just between MAX IV and ESS. This area will be developed by Science Village Scandinavia AB and has as an aim to develop the the district to foremost meet the needs of the two major research facilities. Through the establishment of these major facilities they are hoping to attract other companies looking to establish themselves and make use of the pulse of innovation the research facilities might bring to this part of Brunnshög. Science Village Scandinavia AB will construct a Science Center on their own eventually, but until then they are focused on selling land to interested parties, that by their presence, will contribute to the area and the research facilities (Ideberg, 2018).

The municipality of Lund has stated as a vision for Brunnshög that around "40 000 people should live and work in the district within the next 40 years" (Dalman et al., 2016). The municipality has acknowledged the fact they quite naturally won't be able to predict how many people that will inhabit the area in the future as the market governs the demand for new offices and homes but that the vision exists as basis for dimensioning of infrastructure needed to supply the district (Dalman, 2018).

The tramway is connecting all of Brunnshög with the rest of Lund and it runs from Lund

C, all the way up to ESS, passing the hospital, LTH and Ideon on it's way up to Brunnshög. By positioning parking garages further away than the stops for the tram it has been made easier to choose the more environmentally friendly alternative. The goal is that all the traffic to and from Brunnshög will be a third each by car, bike and public transport (Dalman et al., 2016).

The tramway stations will be connected to a ground-heating system that will provide comfort and protection for pedestrians and cyclists against icy conditions (Gierow and Falkvall, 2018). There will be four ground heating systems located in Brunnshög, built together with the tramway stations by Solbjer, Södra Brunnshög and Brunnshög torg, MAX IV, Science Village Scandinavia and Rydbergstorg.

2.1.1 LTDH Network

The main pipe of the low temperature district heating system follows the tramway tracks from ESS in the north down to MAX IV and Central Brunnshög. The District heating system will work with a 65 °C supply temperature year round. The return temperature is designed to be 35 °C. These temperatures are significantly lower than Lund's conventional district heating system which have a supply temperature of 80-110 °C. MAX IV and ESS will supply the district heating system with heat surplus heat from cooling machines. If the heat from MAX IV and ESS does not cover the heat demand in Brunnshög, heat from the conventional district heating system will be provided by a heat exchanger. If MAX IV and ESS produce more heat than is needed in Brunnshög it will instead be fed into the conventional district heating system (Gierow and Falkvall, 2018).

2.1.2 MAX IV

MAX IV is the world brightest synchrotron light facility. A synchrotron light facility works by accelerating electrons to near the speed of light and then by making the electron change direction they emit synchrotron light, light with much shorter wave length than visible light. Since the wave length are much shorter they can can show much more detail compared to visible light. Max IV comprise of three main parts, the LINAC, the 1.5 GeV storage ring and the 3GeV storage ring. The LINAC is the linear accelerator which accelerate the electron to their operating energies of the storage rings. The storage rings is where the electrons are made to change direction by leading them through opposing magnets. this change in direction is what make the electron emit the synchrotron light. The synchrotron light is led to the beamlines. The beamlines sit tangentially out from the storage rings and is where the science happen (MAX IV, 2017b).

In 2009 the financing for MAX IV was finalized and the planning of the building started. Peab and Whilborgs won the public tender and will be constructing and then letting the facility to Lund University. In 2010, FOJAB were commissioned to design the buildings of MAX IV and in 2011 the construction started. The building was completed in june 2015 and one year later it was inaugurated and started operating (ArchDaily, 2016).

2.1.3 ESS

European Spallation source (ESS) is a research facility based around the worlds lagrgest neutron source. the neutron source can be likened to a very large microscope and will be investigating every thing from materials, proteins and archaeology.

In 2014, the construction of ESS started. Five years later, in 2019, the first operation is planned to begin. This is also when the installation of the instruments will begin and when the first heat for the LTDH system is planned to be produced (COOL DH, 2018a). The instrument commission and the user programs will start in 2022 and 2023 respectively. According to Kraftringen this is when the first neutrons will start flowing. ESS is planned to be fully operational in 2025 (European Spallation source, 2018). This process is displayed with a timeline in Figure 2.

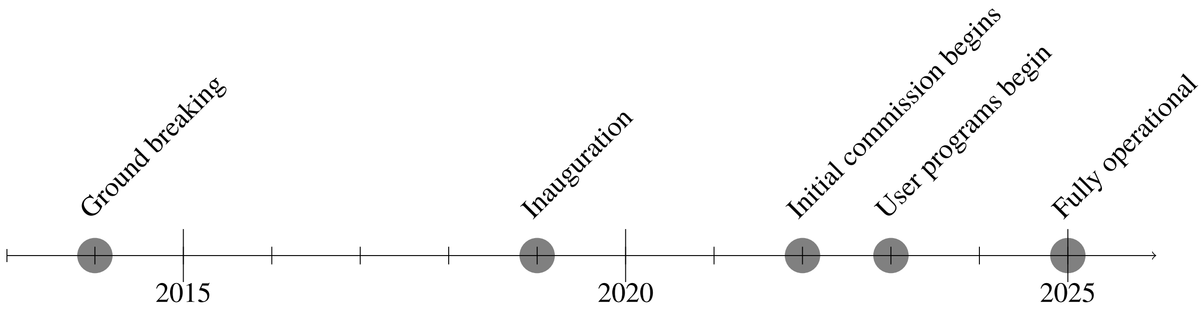

Figure 2: A timeline of important events in the development of ESS.

With the worlds largest neutron source the cooling need for ESS is huge, and will produce large amounts of waste heat. As stated previously, the waste heat will be fed to the district heating systems of Lund. It will primarily supply the LTDH system of Brunnshög and the excess, that isn't used in Brunnshög, will supply the conventional district heating system (Gierow and Falkvall, 2018). The cooling will be done at three different temperature levels shown in Table 1. The two lower levels of cooling (CWL and CWM) will be using heat pumps to reach the correct temperatures and the hottest (CWH) will be cooled by the return of the district heating network. All three temperature levels will supply the district heating network with a temperature of 75 - 90 °C (Parker et al., 2013).

Table 1: Cooling temperature levels proposed to be used in ESS (COOL DH, 2018a).

Cooling temperature level	**Supply temperature**	**Return temperature**
CWL	8 °C	15 - 22 °C
CWM	25 °C	26 - 40 °C
CWH	50 °C	55 - 70 °C

To achieve the delivery of all the waste heat from the return lines from ESS's internal cooling system, an innovative system of heat exhanger coupling is used. This enables the utilization of the low grade surplus heat from the CWL and the CWH.

2.1.4 Science Village

Science Village is located between MAX IV and ESS and is an area which will house business, research, university and educational facilities. The business and research buildings in Science Village may have a cooling need and will therefore produce waste heat. Kraftringen projected that in the future Science Village will produce about the same amount of heat as they consume (Gierow and Falkvall, 2018).

2.2 Høje Taastrup

Høje Taastrup is a suburb of Copenhagen with approximately 50 000 inhabitants and located 18 km outside of Copenhagen city center. The city is one of the most sustainable in Denmark and have lowered its CO_2 emissions by 3 % per year in the last ten years. In order to achieve this, Høje Taastrup has enrolled in sustainability projects including the EU-project ECO-life and the Going Green project financed by the Danish energy agency. Both projects aim to showcase solutions to make the city more energy efficient and to reduce the amount of emitted CO_2(COOL DH, 2018b).

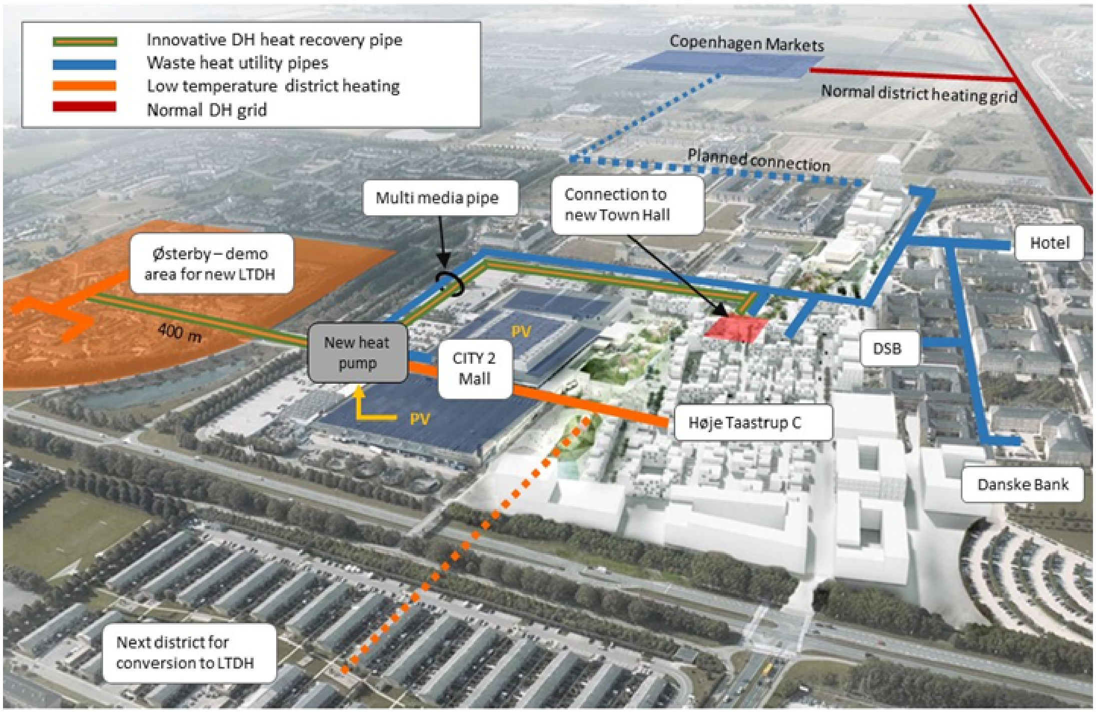

Figure 3: Map of Høje Taastrup. Overlayed with early plans for the expansion of the LTDH system COOL DH (2018b).

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The residential area Østerby, with 159 dwellings, will be the first to be connected to the LTDH which consists of apartment blocks and terraced houses built in 1985-1986. The residential area is shown as the orange area in Figure 3. The next area outlined to be converted is a residential area to the east of CITY2 with 350 houses and is the area in the bottom of Figure 3. In the future Høje Taastrup plans to expand the LTDH to new building planned in the center of Høje Taastrup (COOL DH, 2018b).

The heat for the LTDH grid is projected to come from the year around cooling need of the CITY2 mall, Copenhagen market and companies like Danske Bank and DSB. The CITY2 mall have installed more than 16 300 m^2 of photo voltaic solar panels on it's roof, the biggest roof mounted PV plant in northern Europe. The electricity generated will power heat pumps that supply cooling for the district cooling system and heating for the LTDH system. The cooling will at first be used for the indoor areas of the mall and hotels and to cool the servers of Danske Bank and DSB. In the future Copenhagen markets, the largest wholesale marketplace and distribution center for fruit/vegetables in the north of Europe, will join with a constant cooling need of 11 MW and ability to produce 8.7 MW of surplus heat to the LTDH system (COOL DH, 2018b).

Another project financed by the Danish Energy Agency is "Full-scale demonstration of low temperature district heating in existing buildings". The project includes three test sites. One of the test sites is Sønderby, right next to Østerby. The project included 75 single family houses built in 1997-1998 with floor heating. The old district heating system in Sønderby suffered from large losses in the system, up to 44 %, and therefore new, better insulated pipes were installed and the supply temperature was lowered from an average of 80 °C to an average of 55 °C. This lowered the losses in the system to around 13 % (Li et al., 2017).

2.3 Goals for Monitoring and Evaulation in the COOL DH project

The eight subjects below are the pointed out as the key subject for the project COOL DH (DH, 2018).

1. **Waste Heat recovery**
   LTDH networks enable efficient recovery of energy from surplus heat and cooling, for example from the science facility MAX IV in Lund and a shopping mall with solar powered heat pumps as well as several other buildings in Høje Taastrup.

2. **Prosumers**
   LTDH is well adapted to low-energy houses and enables local integration of customer's renewable heat sources. COOL DH investigates control technology for integration of several types of heat sources.

3. **Pipe design and materials**
   LTDH enables the use of non-conventional pipe materials and design, lowering the investment cost, allowing easier and safer transportation and installation and facilitating coordination with other infrastructure. COOL DH evaluates different types of plastic pipes and pipe components.

4. **Network layout and control**
   Due to lower temperature losses, LTDH enables more efficient heat distribution. To optimize the distribution and minimize heat losses, COOL DH evaluates network layout, connections and control of heat pumps and chillers in the LTDH system.

5. **Demand side installation**
   COOL DH verifies and compares different technical solutions of demand side installations that affect the heat load and return temperature in the LTDH system. For example, heat driven appliances as well as substation components are investigated.

6. **Avoiding risk of legionella**
   COOL DH investigates different techniques to reduce the risk of growth of Legionella bacteria in LTDH systems.

7. **LTDH applications: Ground heat**
   COOL DH investigates LTDH applications that can optimize the use of low-temperature heat while benefiting the public, for example through ground heat that removes snow.

8. **Business models/Legislation/Knowledge sharing**
   COOL DH investigates possible LTDH business models, legislative frameworks related to district heating and shares the knowledge at European level.

COOL DH is divided in to different work packages (WP) that address a multitude of different aspects of the work surrounding the two low-temperature district heating systems in Lund and Høje Taastrup. These WP:s all have separate objectives that will feed into each other and, in the end produce outputs in the form of new business models, training, replication preparation, dissemination and promotion (European Commission, 2018).

Lund University's main part in the project is to monitor and evaluate the two LTDH systems. The main objective includes monitoring the overall energy, CO_2 emissions and the social impact. Lund University will also monitor the energy performance of the involved plants, networks and buildings. The goals are divided into three subsections; the monitoring of energy flows, energy flow evaluation and determination of KPIs, and, finally, monitoring and optimization of heat delivery systems. The monitoring and optimization of heat delivery systems falls outside the scope of this thesis and will therefore not be investigated or explained further from here on out. A more extensive explanation of the monitoring of energy flows, energy flow evaluation and determination of KPIs follows below.

The goals regarding monitoring energy flow in Lund and Høje-Taastrup, are defined as determination of the following:

- Monthly metering values for energy generation and consumption
- Weather data
- Metering of energy flows and temperatures in RES-plants heat pumps and poly-generation plants
- Metering of energy consumption in demonstration buildings (total LTDH heating, DHW heating, electricity for heat pump / electrical topping, PV contribution, cooling if relevant)
- Where relevant more detailed sampling will be performed in periods to support different analysis

The second subsection of goals concerns energy flow evaluation and performance indicators. From the monitored data several pre-determined key performance indicators will be created. These are mainly concerned with the physical attributes and performance of the DH-nets as well as their economies and are shown in detail in Figure 4.

Energy density	Energy delivered an net	Max delivered	Max load duration	Flowtemp Winter	Flowtemp Summer	Return temp Winter	Return temp Summer
MWh/y per m	MWh/y	MW	hours /y	deg. C	deg. C	deg. C	deg. C

Heat loss	Water loss	Heat loss due to water loss	Length main pipes	Length distr.	Turn over for LTDH net	Cost of low-grade heat	Price for consumer
MWh/y per m	m³ /y per m	MWh/y per m	km	km	€/y excl VAT	€/MWh excl VAT	€/MWh excl VAT

Heat composition	CWL	CWM	CWH	Solar	Heat pump	Electric	Other
Percentage of total delivered	%	%	%	%	%	%	%

Figure 4: Key performance indicators to be created for the demonstration sites.

The heat pump installations will be monitored and evaluated to determine a range of different factors such as COP, energy efficiency and temperatures. Finally, two monitoring reports will be prepared, one for Brunnshög and one for Høje Taastrup. The reports will describe the following:

- Method of monitoring and evaluation
- Energy savings achieved
- CO_2 reductions
- Costs and economic feasibility
- Comfort and user satisfaction and other social impacts
- Recommendations for further use.

2.4 District Heating Production

In Europe the total amount of district heating systems tally up to about 6000 separate systems (Werner, 2017). The majority of the heat supplied to residential and service sector buildings of Europe is provided by natural gas and 2014 the composition was 41 % natural gas, 15% petroleum products, 13% heat, 14 % electricity, 13 % combustible renewables, 3% coal and coal products and 1 % solar, wind or others (Werner, 2017). This composition is shown in Figure 5.

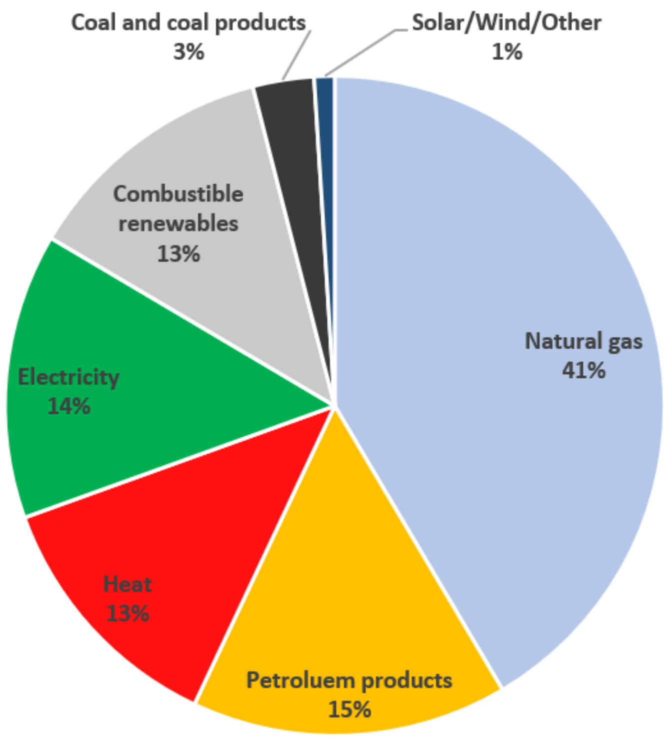

Figure 5: Heat use in residential and service sector buildings in the European Union in 2014 (Werner, 2017).

In Sweden district heating has been a part of the energy system since the 1950's and makes up the largest part of the heating supply-side for residential buildings and facilities covering 58 % of their total energy use. The fuel used in the Swedish district heating system comes mainly from biofuels at 63 % of the supplied energy. Other sources include waste heat, heat pumps, coal and oil, natural gas, recycled waste products, electric boilers and other fuels (Energimyndigheten, 2017). These fuels and their percentage of the total mix are show in Figure 6.

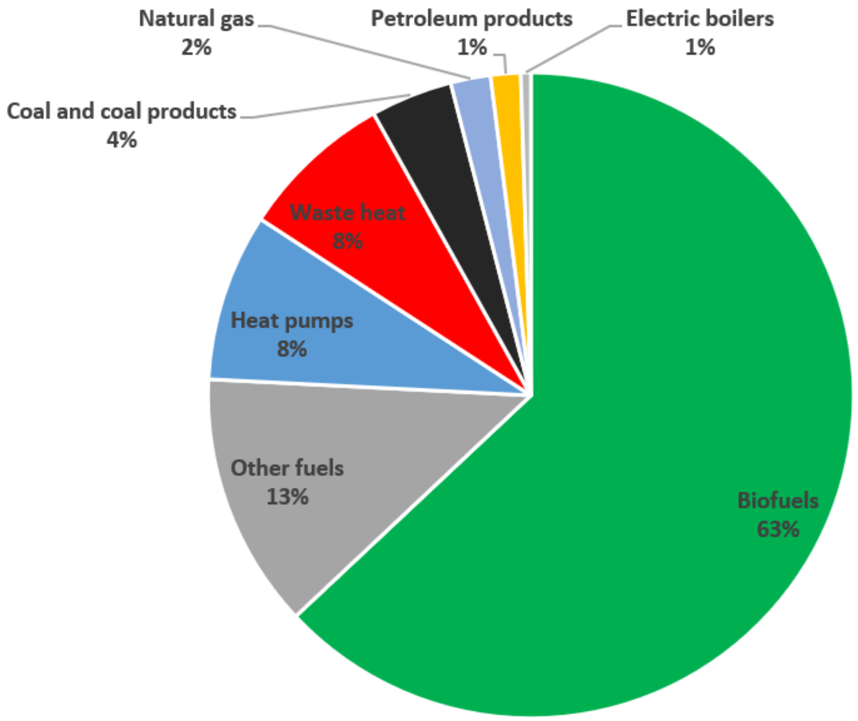

Figure 6: Fuel sources in the Swedish district heating system as a percentage of the total added energy. Organic waste is categorized under biofuels and other non-organic waste fall under other fuels. Statistics from Energimyndigheten (2017).

The base for the energy supplied to the Swedish district heating system has switched from almost exclusively oil in the 1980's to biofuels and recovered heat from waste incineration today. This was in large part due the the two international oil crises that drove up the price of oil and lead to nations seeking a greater self-reliance on fuel. This switch has contributed to a greater, domestic self-sufficiency for Sweden as well as an increase in the share of renewable energy used for heat production. The trend of increasing taxation of CO_2 emissions during this period has also been a contributing factor (Werner and Frederiksen, 2014).

The same has also been true for the DH grid in Lund. Today the net run by Kraftringen in Lund is almost completely free from direct CO_2-emissions, directly releasing 3.5 kg of CO_2 for every MWh heat delivered to the grid and a total rate of emissions of 13 kg of CO_2 per MWh (Kraftringen, 2019b).The fuel sources are almost exclusively biofuels, waste heat recycling, heat pumps and geothermal, except for imported heat from neighbouring DH-grids. The DH systems of Lund and two other Swedish cities, Landskrona and Helsingborg were connected in 2015 to provide greater security of energy supply as well as total economical and environmental gain (Kraftringen, 2016). This means that the production of heat for the other grids may impact the data for the grid in Lund.

The Danish district heating system covers 64 % of all households in the country (Dansk Fjernvarme, 2018). The fuel is comprised of just over 52 % renewables as well as natural gas, oil, coal, electric boilers and non-biological waste (Energistyrelsen, 2016). An overview of of the total energy from each fuel and the percentage of their total mix can be seen in Figure 7.

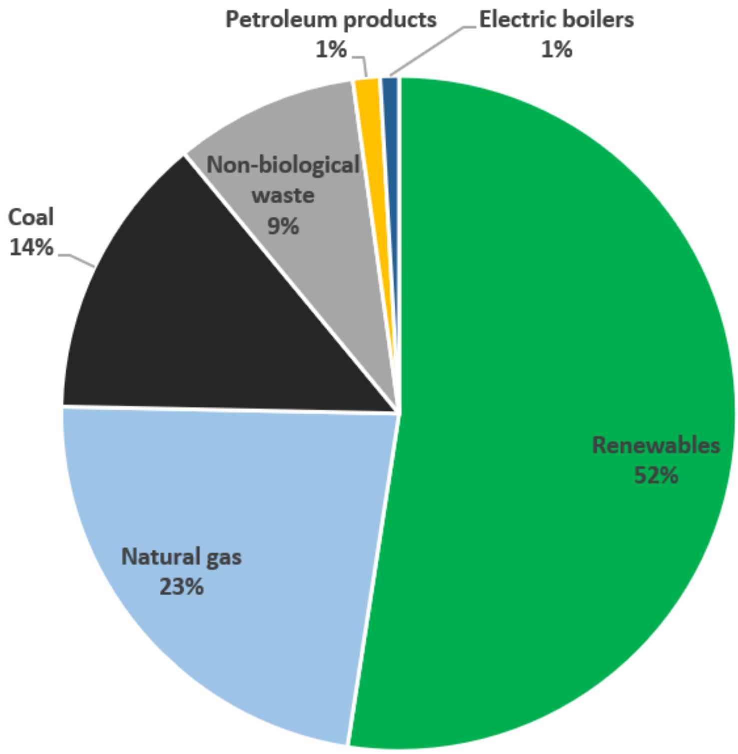

Figure 7: Fuel sources in the Danish district heating system as a percentage of the total added energy. Data from Energistyrelsen (2016).

Denmark has transitioned from using coal for just below 50 % of the energy production in the district heating system in 1990 to just 13.7 % in 2016. In the same period the petroleum and bio-oil use has decreased by 76 % and 67 % respectively. The share of renewables and natural gas has instead increased with the renewables increasing their share by over 200 % (Energistyrelsen, 2016).

The specific district heating supply in Høje Taastrup does however have a slightly different mix with 49 % fossil fuels, comprising of 19.8 % Coal, 2 % oil, 19.6 % natural gas and 7.6 % non-CO2 neutral waste. The remainder consists of 35.5 % biomass and 15.4 % CO2-neutral waste (European Commission, 2018). This composition can be seen in 8

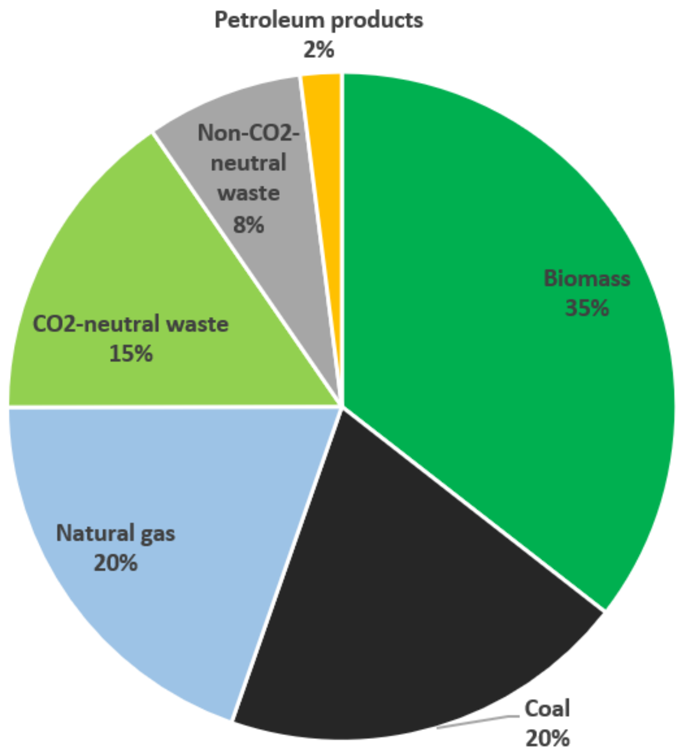

Figure 8: The present fuel sources for the DH heat supply in Høje-Taastrup.

3 Theory

In the following chapter, information regarding technical aspects of a DH system is presented to provide context for the DH systems of Brunnshög and Høje Taastrup. Firstly, a more general description of the role of district heating is given to provide a point of reference for the two systems presented in this thesis. It is followed by descriptions of the 4th generation of DH and some challenges in regards to transforming heat grids to the 4th generation. Lastly, information on the thermal efficiency of DH grids and the technicalities of heat pumps is presented.

3.1 District Heating

District heating systems consist of a network of pipes connecting buildings with a demand for heat, such as offices, apartment buildings, and industries in a localized area together with heat production facilities. These facilities provide heat to the network and can range from large centralized CHP-plants to smaller distributed units. Waste heat from different sources and industrial processes may also be fed into the grid and thus energy, otherwise gone to waste, can be used for space heating or industrial processes (Lund et al., 2014). The distribution grids should preferably be kept relatively short in order avoid large heat losses and for the energy transfer to be competitive. Thus major urban areas with high population densities are an ideal location for this method of heating (Werner and Frederiksen, 2014).

One of the main benefits from using a district heating grid for meeting urban heating demands is the potential for utilizing waste heat as an energy source. Waste incineration and industrial excess heat are great examples of district heating contributing with more benefits than just providing heat. By implementing a system for capturing and re-using this, otherwise lost energy, the efficiency of the energy system improves (Fang et al., 2013).

Globally the largest district heating systems exists in Russia, China and the European Union with coal and natural gas being the greatest sources of energy worldwide (Werner, 2017). The European Union has however shifted towards the use of biofuels and waste, at the expense of coal and oil products, splitting the supply into three approximately equal slices of natural gas, biofuels and waste and coal.

The majority of newly built district heating systems from the 1980s and forward uses what is known as the third generation of district heating. Pressurized water with temperatures often below 100 °C act as the heat carrier and construction or replacement of networks are made with pre-fabricated pipes alongside an all-round more compact and lean system. The trend and development for these systems have been towards lowering the distribution temperature, aiming towards optimizing components to use less materials and to reduce the requirements on manpower (Lund et al., 2014).

3.1.1 Low Temperature District Heating (4th Generation District Heating)

Future district heating systems will have to contend with shifting factors surrounding the competition on the heating market. Emission trading schemes such as the European Trading Scheme (ETS) and greater focus on reducing climate impact will incentives a shift towards a larger fraction of renewables and a greater need for energy-efficient systems. In order to keep the customer costs from increasing and stay competitive, district heating systems will need to adapt and increase their effectiveness and integration with the rest of the energy system (Persson and

Werner, 2011). In the paper *4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems*, Lund et al. argues for five main challenges to overcome in the transformation to the new 4th generation of district heating and they are as follows:

- Ability to supply low-temperature district heating for space heating and domestic hot water (DHW) to existing buildings, energy-renovated existing buildings and new low-energy buildings
- Ability to distribute heat in networks with low grid losses
- Ability to recycle heat from low-temperature sources and integrate renewable heat sources such as solar and geothermal heat
- Ability to be an integrated part of smart energy systems (i.e. integrated smart electricity, gas, fluid and thermal grids) including being an integrated part of 4th Generation District Cooling systems.
- Ability to ensure suitable planning, cost and motivation structures in relation to the operation as well as to strategic investments related to the transformation into future sustainable energy systems.

The first of these challenges touches on one of the key aspects of the 4th generation of district heating, mainly lowered operating temperature. Lowering grid losses and integrating input from renewable, low-temperature heat sources both depend on future district heating systems having a reduced operating temperature.

3.1.2 District Heating Thermal Efficiency

The thermal efficiency of a system is a term that specifies how much of the total energy that is put in to a system, is used as work (Çengel and Boles, 2010). It is calculated with equation 1 (Çengel and Boles, 2010).

$$\text{Thermal efficiency} = \frac{\text{Net work output}}{\text{Total heat input}} \tag{1}$$

In the case of a district heating system the *net work output* is the loads on the system. This includes domestic heating, DHW and, in the case of, Brunnshög ground heating. The *total heat input* is the output from the production facilities. The *total heat input* is calculated by adding the net work output and all the heat losses. The district heating companies will only get paid for what they sell to the customer. If the district heating company lower their heat losses they can either lower their prices or increase their profit. A normal total efficiency over year in western and northern Europe is 85 - 92 % in a normal district heating system. In areas with low linear heat density the efficiency can drop to 65 %. Linear heat density is measured in GJ/m and is a measurement of how much heat demand per meter pipe there is in the district heating system. A district heating system with low linear heat density has a value of 2-5 GJ/m (Werner and Frederiksen, 2014).

The heat losses in a district heating system are calculated with equation (2) (Werner and Frederiksen, 2014).

$$P_{hl} = 2\lambda_i \pi L \cdot (t - t_a)/\ln(D/d) \quad (2)$$

Where:

- P_{hl} = the heat loss in the district heating network.
- λ_i = the thermal conductivity of the insulation material.
- L = the total length of pipes.
- t = temperature of the hot fluid.
- t_a = ambient cold temperature.
- D = outside diameter of the insulated pipes.
- d = outside diameter of the pipe without insulation.

This means that the heat losses increases with longer pipes, if the relationship between the insulated and non insulated diameter is small, if the fluid temperature is high or if the pipes use an insulation material with high thermal conductivity. The relationship between the diameters co-relates to the thickness of the insulation. The thickness is divided into insulation series. For district heating, series 1, 2 and 3 is used, were a higher series means thicker insulation.

Temperature loss in the flow direction is another factor to take into account. Velocity is one of the factors used when calculating temperature loss in the flow direction, were a lower velocity means a higher temperature loss. In some systems the temperature loss in the flow direction can be up to 20°C in far away substations during a summer night. The dimensioning velocity in the pipes is bigger with larger inner diameters. For a DN250 with 273 mm inner diameter pipe the dimensioning velocity is between 1.5 m/s and 3 m/s and for a 50 mm pipe it is between 0.5 m/s and 1.2 m/s. The lower and higher limits are basically linear between the values of 50 mm and 273 mm inner pipe diameter (Werner and Frederiksen, 2014).

3.1.3 Heat Pumps

A heat pump works by utilizing the large energy transfers that occurs when the refrigerant evaporates and condensate in the heat pump. The refrigerant enters the evaporator in liquid form. The return from the district cooling system is used to evaporate the refrigerant. This transfers energy from the district cooling water lowering its temperature. The refrigerant, now in vapor form, enters the compressor and gets compressed to the condenser pressure. In the process the temperature is also much higher, higher than the district heating supply temperature. The compressed vapor now enters the condenser where the return from the district heating system is used to condense the refrigerant and this transfers heat from the refrigerant to the district heating water. The refrigerant, now in liquid form, expands, which lowers the pressure and temperature. The cycle now starts over in the evaporator. The performance of a heat pump is measured as coefficient of performance or COP and a the higher this value is, the more efficient the heat pump will be (Çengel and Boles, 2010).

4 Methodology

The methodology chapter describes the general method with which the aim of this thesis is reached and how the questions related to it are answered. The two main methods of mapping the energy systems of Brunnshög and Høje Taastrup and simulations performed with NetSim and LOGSTOR calculator are described here.

4.1 Mapping of Energy Systems

In order to gather information and seek to answer the research questions about the customers, production units and the variation of loads and production over time a information was gathered from a multitude of sources. This study had a primary focus of finding information regarding the cooling demand and operational cycles of MAX IV and ESS, data on future energy demand in Brunnshög and Høje Taastrup as well as information about construction projects in the demo areas, COOL DH, the two city districts Brunnshög and Høje Taastrup, technical information about the LTDH grid and 4th generation district heating systems.

Most of the information about the production, buildings and the grid in Høje Taastrup was provided through interviews and mail conversations with representatives at COWI and Høje Taastrup Fjernvarme. The same is true for Brunnshög where representatives at Kraftringen contributed with information about the current production units, grid and the heat demand in future buildings. The developers of the buildings were contacted via mail, and official documents from Lund Municipality and the European Union were gathered to supplement the information from Kraftringen. More information about the production units of Brunnshög was gathered from internal documents from MAX IV and ESS.

A substantial quantity of information was gathered from internal documents such as technical annexes distributed within the partner group working with COOL DH and in-house presentations from associated commercial partners Kraftringen, COWI and LOGSTOR. Parts relevant to this thesis have been lifted from these sources and are presented here referencing information which the reader may have trouble finding. The choice to not display these documents here is with respect for the involved parties privacy in regards to their business practices.

Linear models was used to make prediction of how the energy-systems will perform at the end of COOL DH in 2021 and further in the future. The choice of using linear models is mostly due to the limited information about the ramp up of production units and expansion of the heat demand in the grid.

4.2 Simulations

Several simulations were performed in the program NetSim and the LOGSTOR calculator in order to answer "*Simulations to provide estimations of how the low temperature district heating grid in Brunnshög will perform by 2021, at the end of COOL DH, in regards to linear temperature drop, heat loss and efficiency and how future additional heat demand will affect these parameters*" in section 1.1.

NetSim is a simulation program for grid simulations created by the company Vitec. With NetSim a model of the district heating grid can be created with the help of a map from a GISprogram (geographic information system). In the model of the grid the production units and customers are placed with respect for their real geographical connection to the grid. The program can then be used to do simulations of the grid and its performance. It can also be used to optimize different parts of the system. This could, for example, factors such as pipe sizes and placement as well as the dimensions of pumps. In this study it was used to determine the velocity of the water in the pipe grid. This was done to evaluate if the grid will be oversized in 2021. Simulations of the grid further in the future is also done to put the values of 2021 in perspective (Vitec, 2018).

A model of the grid in Brunnshög has been provided by Kraftringen. This model did not include South Brunnshög nor the correct pipe sizes. A DWG-file was also provided by Kraftringen to be able to add South Brunnshög and change to the correct pipe sizes. The DWG-file adds a picture of the LTDH grid and the pipe dimensions to NetSim which can be used to draw the grid. The loads has been placed with the help of information from Kraftringen and documents from the Lund municipality. In chapter 5.2 the different locations and sizes of the loads are presented. The simulations were done with the loads at their maximum value. NetSim has the ability to handle seasonal variations if customer data is provided. Since no buildings has yet been built in Brunnshög no customer data exist. If only the heat demand is known the conversion between heat demand and full load is done by dividing the heat demand with the full load hours. For all the heat demand except for the ground heating systems, 1 800 of full load hours was used. The ground heating system only use 250 full load hours (Gierow and Falkvall, 2018).

The heat loss calculations were done using the LOGSTOR calculator. LOGSTOR is participant in COOL DH and is also the supplier of pipes for both Brunnshög and Høje Taastrup. The calculator needs the supply, return, and ambient outside temperature, the soil cover depth and thermal conductivity of the soil and lastly information regarding the properties of the pipes to perform the heat loss calculations. Information about the pipe diameter, length and insulation series was provided by Kraftringen.

In chapter 5.3 the results of these simulations are presented alongside a detailed description of parameters and assumptions.

5 Brunnshög

This chapter intends to present a comprehensive view of the results related to Brunnshög. It includes an energy mapping of Brunnshög in regards to production units and heat demand connected to the LTDH grid as well as time estimates of the construction projects' construction dates and geographical locations. It also includes a performance analysis of the grid at the end of COOL DH in 2021 as well as further into the future. The final part concludes by presenting the balance between produced heat and heat demand in the LTDH grid.

5.1 Production

5.1.1 MAX IV

The cooling of Max IV is divided in two different temperature levels 7 °C and 23 °C supply temperature. The cooling is handled by three heat pumps, two for the lower cooling temperature and one for the higher. Each heat pump is cascade coupled with four condensers in series on the hot side and two series evaporators in parallel on the cold side. The COP of the heat pumps are 3 for the heat pump with 7 °C supply temperature and 3.7 for the heat pump with 23 °C supply temperature. Without cascade coupling the COP would be 2.7. This would result in almost 30 % higher electricity use. The heat pumps at MAX IV can be set to either output 65 °C for the LTDH system or 80 °C for the conventional district heating system. The COP will rise to 4 with the output set to 65 °C (Gierow et al., 2018).

The heat pumps at MAX IV can produce up to 3 MW of cooling for the processes at MAX IV. This cooling will co-produce up to 4.5 MW of heat for the district heating system. During the revisions, the cooling need is much lower but MAX IV did not produce less than 1 MW during the winter break 2017 and was higher during the summer break due to the higher outside temperature (Gierow and Falkvall, 2018).

MAX IV have two big scheduled revision breaks per year, one in the summer and one around Christmas. The summer break will last from late June until the middle of August and the Christmas break from the middle of December and 25 days forward. Every Tuesday will also be downtime. This result in 120 day of off time, and therefor 245 day of full operation. In 2018 MAX IV will not have a revision break in December. This is seen as a one time thing and MAX IV is presumed to have the December revision break in the coming years (Gierow and Falkvall, 2018).

According to the 2017 environmental statements from MAX IV they produced 12 662 MWh of heat for the district heating grid of Lund in 2016. In 2017 they produced 17 009 MWh (MAX IV, 2017a). The projected heat output from MAX IV in 2035 is 28 GWh (Gierow and Falkvall, 2018). Since no other projection are available, the ramp up until 2035 is assumed to be linear between the 2017 value and the 2035 value. The 2017 value is chosen because its the only year with operation for a whole year. This will result in a heat production of 19 451 MW when the COOL DH project will is estimated to finish in 2021.

Since no definitive value of the heat production during the summer and during the Tuesday breaks has been gathered the worst case scenario that MAX IV only produce 1 MW during all off times is assumed. This is used in the calculations as a base production for all days of the year. For 245 days of the year MAX IV is in full operation and will produce more heat. To calculate heat production during full operation the equation below was used:

$$Q_{\text{total}} = 24 \cdot (365 \cdot Q_{\text{base}} + 245 \cdot Q_{\text{operation}}) \tag{3}$$

$$Q_{\text{operation}} = \frac{\frac{Q_{\text{total}}}{24} - 365 \cdot Q_{\text{base}}}{245} \tag{4}$$

Where

- Q_{total} = the total amount of heat produced by MAX IV in a year (MWh)
- Q_{base} = base production per day (MWh)
- $Q_{operation}$ = production during the days of full operation (MWh)

This gives the operational part of the heat production in 2021 as 1.82 MW and a total heat production during operation as 2.82 MW. This results in the heat production pattern in Figure 9. The pattern in Figure 9 does not display any seasonal variance in regards to outside temperature.

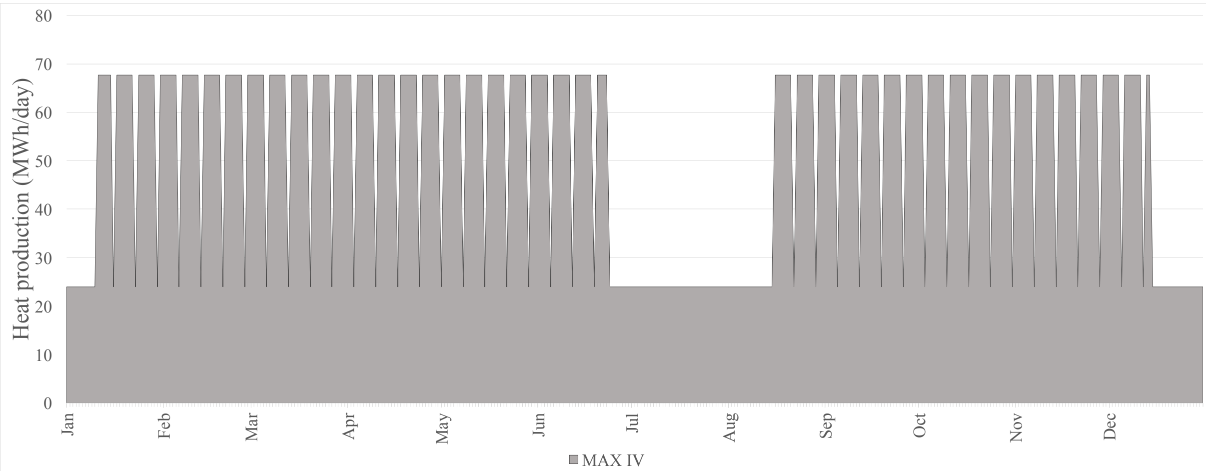

Figure 9: The variation of MAX IVs projected heat production at the end of COOL DH in 2021

In june 2018 only three beamlines were in user operation and another five in commissioning. A review of the MAX IV project management by the Swedish Research Council states that:

> The organization does not employ a proper project management structure; the interactions between the line management and the project owners, with a well-defined method of allocating resources, are not properly set up.
> (Halleröd et al., 2018)

This in turn has delayed many of the beamlines for 2 - 2.5 years and might keep delaying beamlines if not dealt with. If the beamlines are delayed further this might impact the production of heat for the LTDH system (Halleröd et al., 2018).

The amount of heat that MAX IV has produced for the conventional district heating each month of 2018 are shown in Table 2. These values were acquired in February 2019 and has not been used in the models but is included here to evaluate the accuracy of our presented model.

Table 2: The predicted values of the waste heat production in MAX IV during 2018 compared to the real values for 2018 acquired in February 2019 (Gierow and Falkvall, 2018).

Month	**Predicted value (MWh)**	**Real value (MWh)**
January	1 395	1 768
February	1 539	1 680
March	1 720	1 838
April	1 660	2 038
May	1 684	2 319
June	1 443	2 219
July	744	1 265
August	1 250	1 889
September	1 660	2 156
October	1 684	2 179
November	1 660	2 057
December	1 178	2 046
Totalt	**17 619**	**23 454**

The data reveals that the real values for 2018 are much higher than the predicted values, especially in the summer. They also show that, in July, MAX IV will have a revision break for the whole month. The predictions put that value at 1 MW and the real value is 1.7 MW. In 2018 MAX IV did not have a revision break in December which makes the values much higher. These discrepancies partly arise from the choice of a linear model for the growth of the cooling demand in MAX IV and a discussion regarding this is carried out in chapter 8.

5.1.2 ESS

The temperature levels at MAX IV is similar to the supply temperature of the CWL and CWM at ESS. Therefore a similar COP can be assumed.

Acording to the ESS Energy Design Report the research facility will have three operating modes. The first is full operation and is, as the name indicates, when ESS is in full operation and produce its full amount of heat. The second one is intermediate operation and describes the situations where ESS is not running fully but still requires more cooling than in no operation mode. The intermediate operation mode is for example used during start up and shutdown of the beam. The last one is no operation mode, and is where the beam is fully offline. During no operation, the different parts still require some cooling to keep the system easily available to be started again (Parker et al., 2013).

The different modes of operation will have different cooling needs and therefore different heat production. When the the facility is in full operation mode ESS estimates that their total heat output over a year will be 203 196 MWh/y of heat for the district heating systems of Lund. As seen in Table 4 ESS is in full operation 5 400 hours per year. This results in an average power of 37.6 MW during full operation. Similarly, in intermediate operation the facility will produce 18 410 MWh/y in 1260 hours per year and in the case of no operation will the facility will produce 10 734 MWh/y in 2100 hours. This will result in an average power of 14.6 MW during intermediate operation and 5.1 MW during no operation. This is displayed in Table 3. Table 4 also shows the suggested pattern of operation from the ESS Energy Design Report. All the numbers above and in Table 4 is for 2025 when ESS is fully operational (Parker et al., 2013).

Table 3: Power for the district heating system from the different operation modes of ESS.

	Full operation	**Intermediate operation**	**No operation**
Heat production (MWh/y)	203 196	18 410	10 734
Hours per year (h)	5 400	1260	2100
Average power (MW)	37.6	14.6	5.1

The pattern in Table 4 and the values for the different operation modes is shown in Figure 10. The monthly pattern has been estimated as no information exists on exactly how the daily cooling demand fluctuates. The pattern of MAX IV is used as a guide with two long revision breaks and one day of per week off. Kraftringen also predicts ESS to have similar pattern to MAX IV (Gierow and Falkvall, 2018).

Table 4: Suggested operation pattern of ESS in 2025 (Parker et al., 2013)

Month	**Full operation (h)**	**Intermediate operation (h)**	**No operation (h)**	**Total (h)**
January	72	72	600	744
February	576	96	0	672
March	504	144	96	744
April	600	120	0	720
May	504	144	96	744
June	624	96	0	720
July	288	48	408	744
August	120	120	504	744
September	600	120	0	720
October	504	132	108	744
November	624	96	0	720
December	384	72	288	744
Totalt	**5 400**	**1 260**	**2 100**	**8 760**

The output of ESS to the LTDH system is projected to be above 5 MW (COOL DH, 2018a) before the EU-project ends in 2021. Also the "No operation" heat production lies close to this value at 5.1 MW. With all this information we assume that the heat output for 2020 is 5.1 MW for the whole year and that the yearly production will increase linearly until 2025. This will affect full operation and intermediate operation which will also increase linearly. This will result in a Full operation and intermediate heat output of 11.6 MW and 7 MW in 2021. This together with the pattern of operation in Table 4 results in the projected heat production in Figure 10. The total amount of waste heat produced in 2021 is projected to be 82 170 MWh.

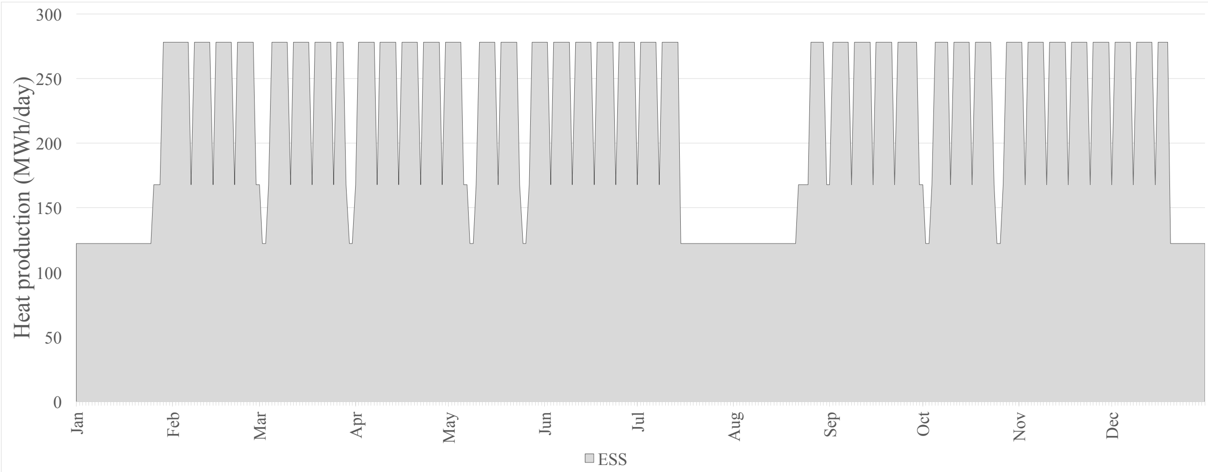

Figure 10: The variation of ESSs projected heat production at the end of COOL DH in 2021.

The energy company E.ON has been contracted to develop the cooling and compressed air system of ESS. They will also handle the waste heat being generated from the cooling. The waste heat will be sold to Kraftringen and will be used in the district heating system of Lund. The LTDH grid is prioritized and the waste heat not used there will be used in the conventional district heating system. Kraftringen has the ambition that all the heat, except for the internal heat demand, being produced at ESS will be sold to Kraftringen (Gierow and Falkvall, 2018).

5.1.3 Science Village

Kraftringen has projected that, in the future, the facilities in Science village will produce the same amount of heat of waste heat as that they will consume. The heat produced and consumed by the actual buildings may however not be balanced in the future and thus it might contribute to the heat demand or the heat production. As with many other co-producing systems the cooling demand is highest when the outside temperature is high and therefore the production of heat is also highest during that time. However, the heat demand is highest when the outside temperature is low (Gierow and Falkvall, 2018).

Since still only three buildings have a known heat demand it is hard to make estimates of how much heat Science Village might produce.

5.1.4 Total Heat Production

Figure 11 shows the summed production of MAX IV and ESS in 2021. The orange line is the amount of heat available to LTDH system from the two science facilities together.

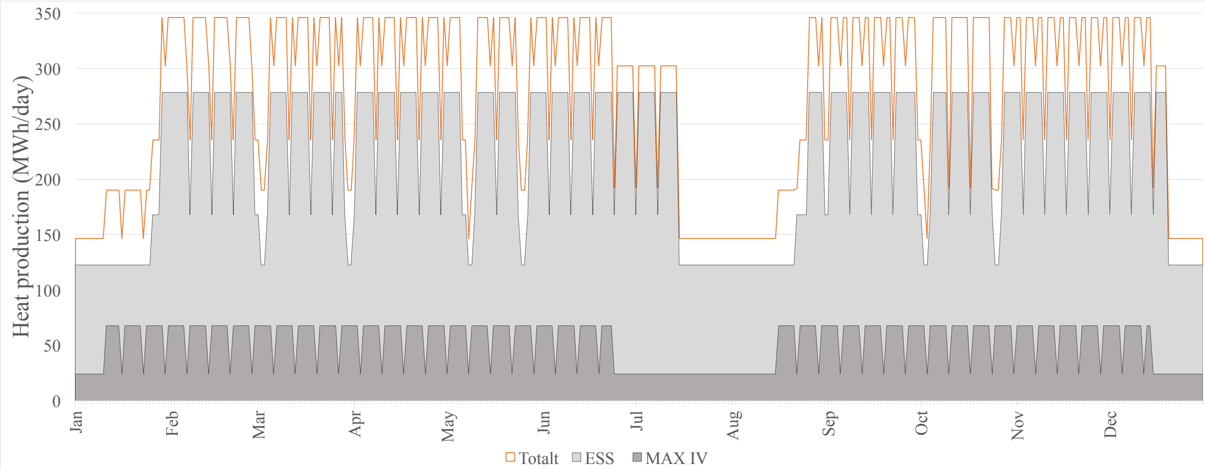

Figure 11: Summed variation of the projected heat production at the end of COOL DH in 2021.

5.2 Inventory of Future Heat Loads

The construction projects currently being planned for Brunnshög will consist of several residential buildings, a school and a smaller subset facilities for commercial and research use (Gierow and Falkvall, 2018). In this section they are split up between different categories, dealing with Central Brunnshög, South Brunnshög, Science Village and the ground heating systems separately. Later in this section they are presented together in a scenario regarding the future expansion of Brunnshög.

5.2.1 South Brunnshög

South Brunnshög is currently just on the verge of entering a phase of heavy development. Multiple buildings in the area have planned start date for the construction in 2019. Initially these buildings were not intended to be connected to the LTDH but since some of the contractors have specifically requested to be a part of the low temperature grid, Kraftringen has decided to try to incorporate South Brunnshög into the LTDH grid (Gierow and Falkvall, 2018). According to Kraftringen, the potential customers in South Brunnshög is as follows: LKP AB which will construct a parking garage with additional service functions, Hauschild & Siegel and LKF will build apartments and offices, PEAB and Slättö will construct residences for housing societies and Solbjers Bostad will build eight townhouses.

The values of the gross total area, heat demand and required effect can be seen in Table 5 alongside the names of the contractors and the estimated time of the start of construction. The location of the properties is diplayed in Figure 12. The values in Table 5 and the location of the properties was provided by Kraftringen (Gierow and Falkvall, 2018).

Table 5: Contractors in South Brunnshög together with data on yearly heat consumption, area and construction dates for their projects.

Contractors	Heat demand (MWh/y)	Area (m^2)	Construction start	Nr
LKP AB	116	3 318	2020	1
Hauschild&Siegel	175	5 000	2019	2
PEAB	70	2 000	2020	3
Slättö	160	4 584	2019	4
LKF	310	8 860	2019	5
Solbjers Bostads	74	2 100	2019	6
Gryningen 1	179	5 100	2021	7
Gryningen 5	280	8 000	-	8

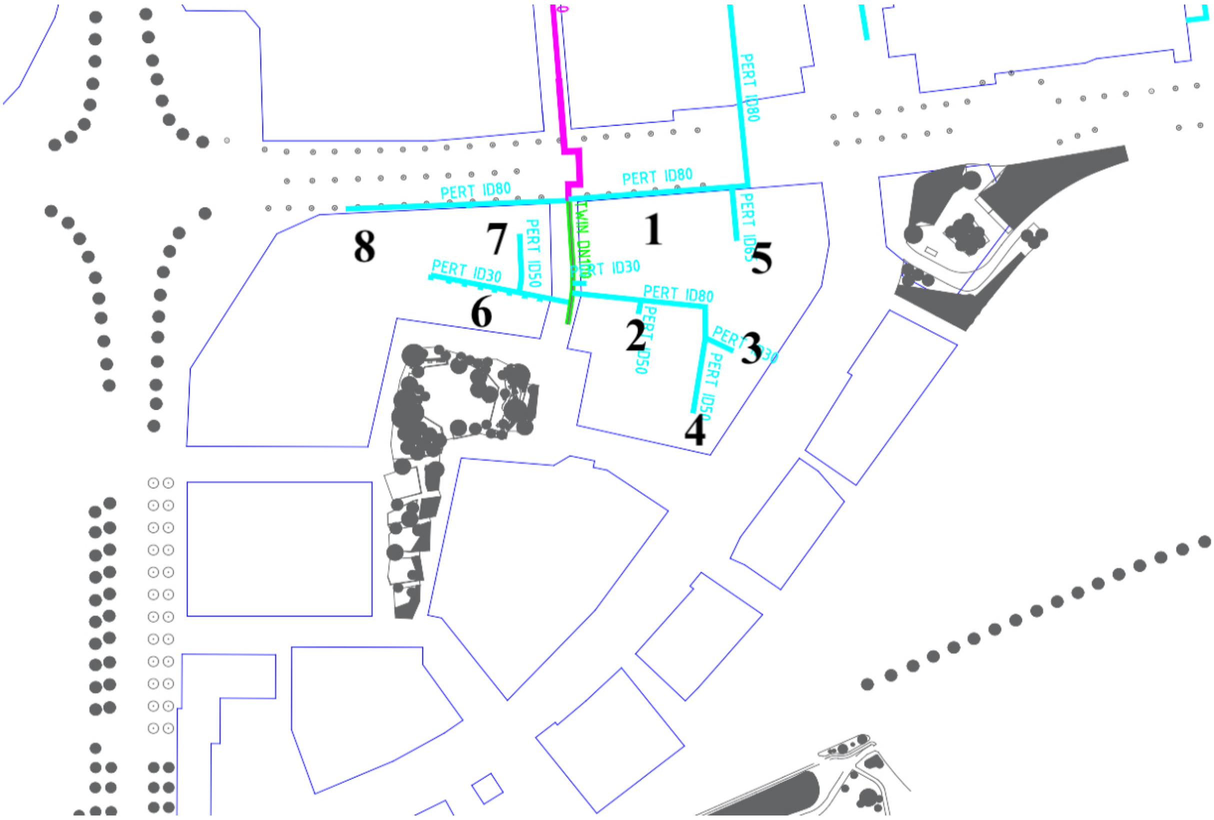

Figure 12: Map of South Brunnshög. The numbers show where the buildings in Table 5 will be located.

LKF is constructing a building called Xplorion in South Brunnshög which will consist of rental apartments and will also act as a demonstration building for COOL DH. LKF states that the construction project will begin in the beginning of 2019 and be ready for tenants in late 2020 (LKF, 2018). The building will receive heat from the conventional DH-grid but use a heat exchanger to bring the temperatures down to 45 °C. The flow will then be heated to levels above this within the building itself (Gierow and Falkvall, 2018).

5.2.2 Central Brunnshög

The relevant land allocations currently in place for the Brunnshög area include Central Brunnshög with the following contractors chosen to develop the area: ICA Fastigheter, Sydö Property, Sundsprojekt, Midroc, Wästbygg, Kärnhem, Lundafastigheter and Serneke. (Lunds Kommun, 2018b). These properties will all include buildings related to housing, commercial activity and, in addition, one school. Plans regarding the specifications of the projected buildings have been drafted and accepted by the municipality for the majority of these projects.

Energy demand, planned area of living space and construction end dates was gathered for the properties in Central Brunnshög and can be seen in Table 6. Some of these buildings lack information regarding the planned date of construction start for the project. This is both because of contractors not being certain of the construction start and end dates for their projects and there simply being no set date for construction start. Information on the energy consumption and area of these buildings were provided by Kraftringen. Construction dates estimates were also provided by Kraftringen but som of these dates were shown not to be attainable within the time-frame stated by Kraftringen, when re-examined and researched using information from the contractors. Because of this information regarding construction dates were also gathered from the contractors themselves, where available, in order to provide more accurate estimates.

Table 6: Projected buildings in Central Brunnshög and technical specifications.

Contractors	**Consumption (MWh/y)**	**Area (m^2)**	**Construction end**	**Nr**
Serneke	1 500	50 000	2023	1
ICA Fastigheter	500	20 000	Q3 2021	2
Kärnhem	330	9 500	2020-2021	3
Sydö Property	260	6 500	2021	4
Sundprojekt	260	6 500	Q1 2022	5
Lundafastigheter	200	2 500	2023	6
Wästbygg	200	9 500	-	7
Midroc	75	2 500	2021	8

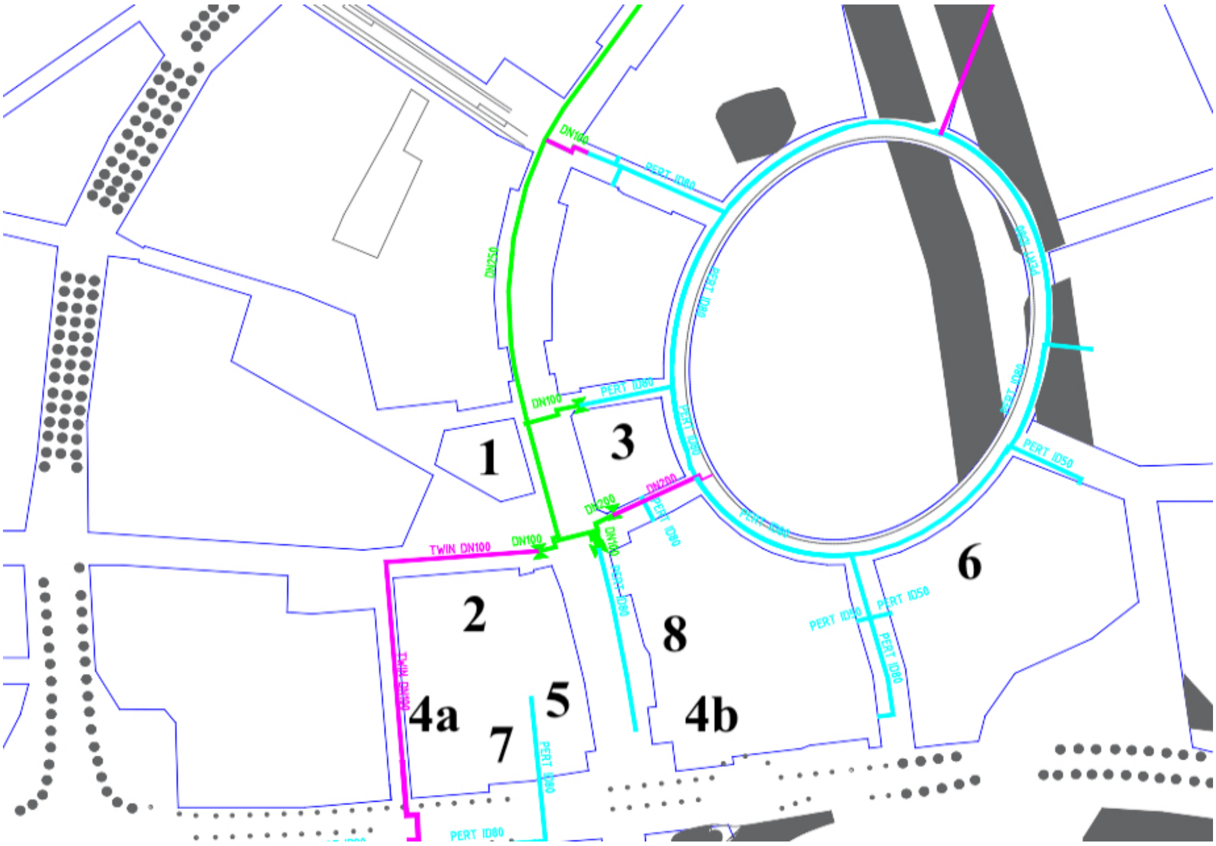

Figure 13: Map of Central Brunnshög. The numbers show where the buildings in Table 6 will be located.

The properties provided by Serneke were shown to have a projected date for construction end of 2023 as provided by information on their website (Serneke, 2019). The same holds true for ICA Fastigheter (ICA Fastigheter, 2019) and Kärnhem (Kärnhem, 2019) but with different dates for the end of construction. Sundprojekt stated that they will have their projects finished and ready for the first quarter of 2022 (Dahlström, 2018). Wästbygg could not start their construction in 2019 as they had planned from the beginning and have stated that they currently cannot give a definitie statement on when construction will be finished (Törnblom, 2018). The remaining dates for construction end dates are estimations provided by Kraftringen.

These properties will mostly contain housing for the residents of Brunnshög but some will also provide commercial spaces on the ground floor (Lunds Kommun, 2018b). The residential houses are designed to use a small quantity of energy for their space heating needs. Estimates from Kraftringen puts the total need for heating to about 35 kWh/m^2/y to 45 kWh/m^2/y where about 10 kWh/m^2/y of this is for domestic hot water and 30 kWh/m^2/y is for space heating (Gierow and Falkvall, 2018). Since the space heating in these houses will make up a smaller portion of the buildings heating needs the variance in tap water usage will play a larger role in contributing to load spikes in the net.

The location of the properties shown in Figure 13 is determined from documents from the municipality (Jönsson, 2018a)(Jönsson, 2018b)(Fennhagen, 2018a)(Fennhagen, 2018b)(Fennhagen, 2018c)(Stadsbyggnadskontoret Lund, 2016). Serneke is the only property on the list where no land allocation could be found. The location was determined by comparing models of other areas and the renderings of the building.

5.2.3 Science Village

The three buildings in Science Village currently planned to be connected to the LTDH grid within 2021 are Möllegården, Space and The Loop Skanska. Möllegården is an old building from the 17th century that has recently been restored while Space and The Loop Skanska is currently projected to be finished in 2021. Möllegården is the first building planned to be connected to the new DH grid with the first heat delivery schedueled for the autumn of 2019. It is estimated to have a heating need of 18 MWh per year (Ideberg, 2018).

Space, the first building that will be built within the actual area of Science Village is projected to be finished around 2021. It is however fully possible that its first heat delivery will take place outside the time frame of COOL DH (Ideberg, 2018). Space is designed to be the most iconic building in the Science Village and will be comprised of a heated area of 7500 m^2 that has a heating need of 300 MWh a year (Science Village Scandinavia AB, 2018). The Loop Skanska will accommodate business centres, labs, conference rooms, a green space as well as a concert hall. The building will have an area of 13 000 m^2 and a heating demand of 500 MWh (Skanska, 2018).

A depot for tramcars is planned in the northernmost part of Brunnshög. This depot has suffered major delays and it is currently unclear when it will be finished but Kraftringen estimates the initial opening to be in the second quarter of 2020. It is projected to have a space heating need of 230 MWh a year with an area of 4 000 m^2 (Gierow and Falkvall, 2018). The location and values for heat demand, total area and construction start and finish for the three buildings in Science Village and the tram car depot can be seen in Figure 14 and Table 7.

Table 7: Projected facilities in Science Village together with data on yearly heat consumption, area and construction dates for their projects.

Building	**Consumption (MWh/y)**	**Area (m^2)**	**Construction end**	**Nr**
Space	300	7 500	2021	1
The Loop Skanska	500	13 000	2021	2
Möllegården	18	-	Q3 2019	3
Tramcar depot	230	4 000	Q2 2020	4

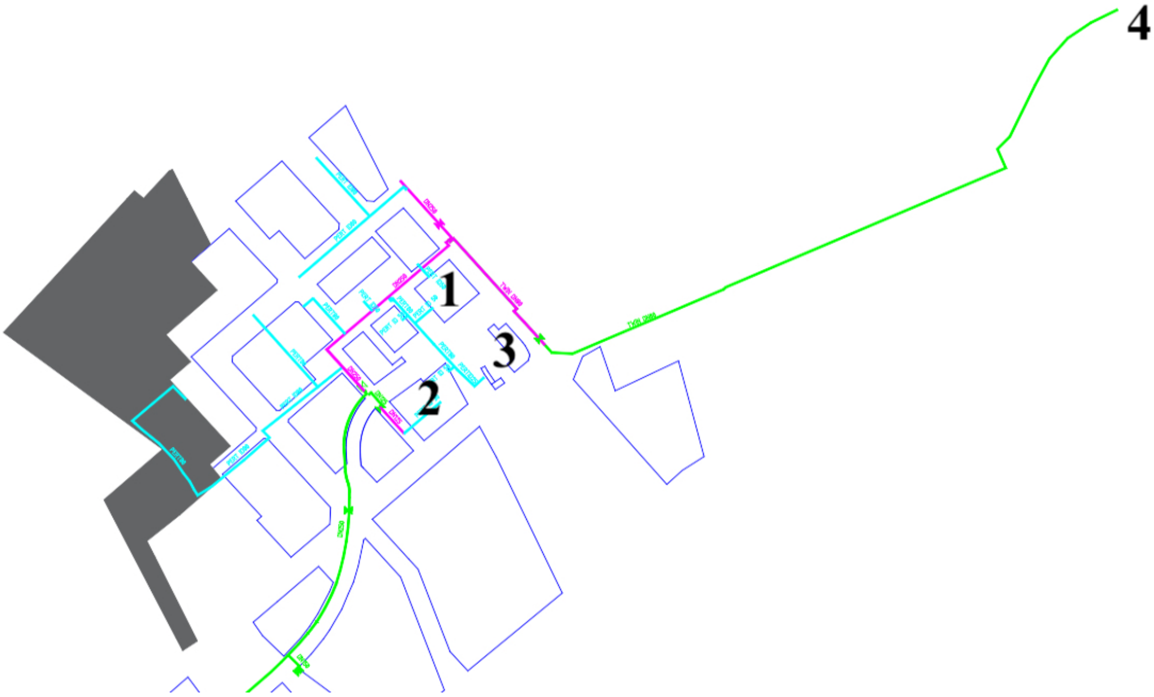

Figure 14: Map of Science Village. The numbers show where the buildings in Table 7 will be located.

5.2.4 Ground Heat

In addition to delivering heat for buildings, the low temperature district heating grid will also be connected to soil heating systems placed underground. Beneath four tram car stations around Brunnshög they will deliver heat to the ground in order to counteract icy and snowy roads during the winter. The power and energy delivered to these stations are shown in Table 8. The ground heat systems will be built at the same time as the stations (Gierow and Falkvall, 2018). The tramcars will start operating in 2020 so it can be assumed that heat will be delivered from that point on.

Table 8: Power and energy delivered to tram car station ground heating systems.

Ground heating system	Load (kW)	Heat demand (MWh/y)
A	680	170
B	180	45
C	120	30
D	120	30

5.2.5 MAX IV and ESS

The internal heating demands of MAX IV and ESS will be provided by their own respective cooling facility, the same as is responsible for delivering waste heat to the LTDH grid (Kraftringen, 2019a).

In connection to MAX IV a hotel for researchers is already up and running and will be expanded upon in the future to include more guest, from a current capacity for 20 guests up to 50

(Lunds Kommun, 2018a). This hotel was however found to be supplied by heat from its own geothermal heat pump and is thus not subject to being included in the low temperature district heating system (Skånska Energi, 2018).

5.2.6 Future Scenario

In order to review the variance in the energy demand from customers over time, a heat demand profile was created based on the several newly constructed buildings from around Lund. The true energy demand from the buildings in Brunnshög is difficult to accurately estimate and the status of current construction plans are prone to change. Therefore a linear model was created with 2025 as a start date and 2050 as an end date. The heat demand from the buildings that, with a high degree of certainty, will be built before 2025 constitutes the heat demand for this starting point. The heat demand in 2050 was estimated using the expressed vision from the municipality in Lund that 40 000 people will live and work in Brunnshög within a time frame of 40 years. This model builds on an estimate of 41 m^2 heated living space per person (SCB, 2019), an average of the predicted heating need per area for the new constructions in Brunnshög of 37.6 kWh/m^2 (Gierow and Falkvall, 2018) and the assumption that all of the 40 000 needs as much heated living space as the average person in Sweden.

This value for the heating need per area is consistent with statements from Kraftringen regarding the heating need of the planned construction projects in Brunnshög. The value was referred to be around 35-45 kWh/m^2 and 37.6 falls neatly into this range. The buildings will also have a different heat demand profile to most other buildings due to being very energy efficient and thus other newly constructed buildings are the basis for the heat demand profile used here.

The projected seasonal variance of the heat demand can be seen in Figure 15 and follows a similar look to traditional seasonal variance within district heating systems.

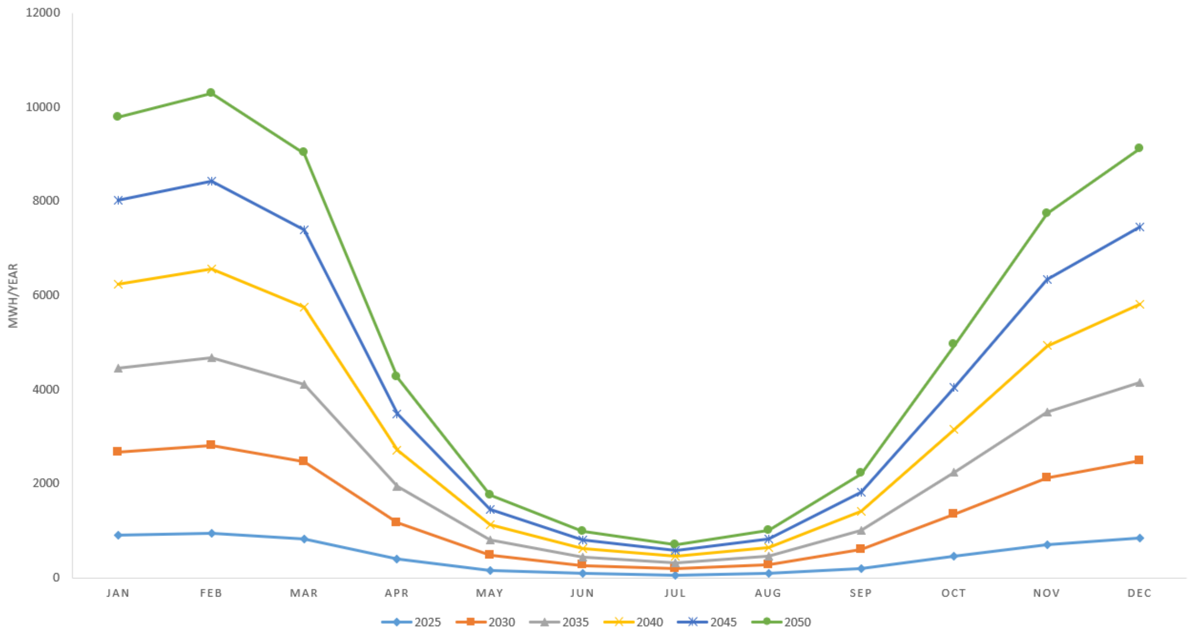

Figure 15: Projected heat demand for Brunnshög from 2025 to 2050, showing 5-year intervals. Estimates based on heat demand profiles from newly constructed buildings with Brunnshög's total heating demand overlaid.

In this scenario of 40 000 inhabitants the model shows an energy demand of over 10 000 MWh a month during the highest peak of the year and almost below 700 MWh a month during the lowest.
In this scenario of 40 000 inhabitants the model shows an energy demand of over 10 000 MWh a month during the highest peak of the year and almost below 700 MWh a month during the lowest.

5.3 Grid and Pipe Design

In Brunnshög the low temperature district heating grid is planned to start delivering heat to the first connected customer in 2019 and is already under construction. The finished grid will span 4.4 kilometers, making it the largest LTDH grid in the world, and have an operating temperature of 65 °C and a return temperature of of 35 °C (Lunds Kommun, 2018c).

There are two pipe types that will be used in the district heating grid in Brunnshög. A main line, which will use steel piping, DN250, and is dimensioned for a pressure of 16 bar will run along the tramway line going through Central Brunnshög all the way to the Science Village and ESS. In Figure 16, the main pipe is coloured green except for the top right part. This part is the pipe that connects the Tramway Depot. The tramway depot and South Brunnshög will be connected with DN80 and DN100 steel TwinPipe, respectively. The pipe that connects Central Brunnshög with MAX IV will be a DN200 steel pipe. The other will be made of PE-RT (Polyethylene of raised temperature) pipes with a maximum inner diameter of 80 mm that can withstand a pressure of 10 bars, which will connect to the main steel line and fork out to deliver heat to local commercial and residential buildings (Gierow and Falkvall, 2018). These plastic pipes also have a built in leak detection by utilizing copper wires.

Due to limited space in the ground under the tramway the main pipe will only have insulation series 1. All other planned pipes will have insulation series 2 (Gierow and Falkvall, 2018).

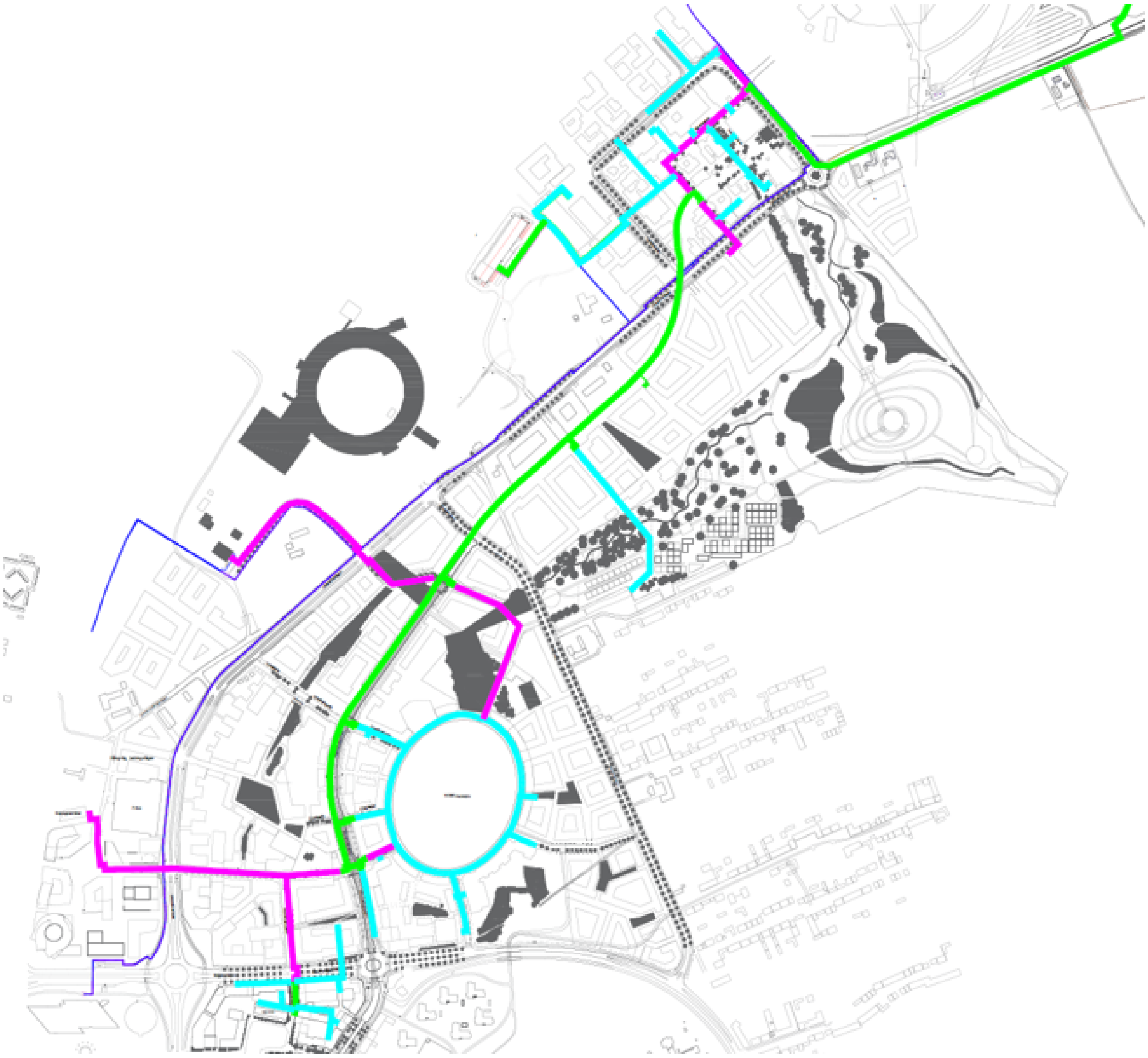

Figure 16: The current pipe layout in Brunnshög. Green lines indicates finished steel pipes pipes, purple lines indicated planned steel pipes and turquoise lines indicate planned plastic pipes Source: (Gierow and Falkvall, 2018).

The construction of the main steel line that runs from Central Brunnshög to the tram depot is finished, while the plastic PE-RT pipes have not yet been put in place because there currently is no heat demand present in Central Brunnshög or at the Science Village, due to the current lack of buildings. The PE-RT pipes will branch out from the steel line and connect buildings which energy needs do not require a larger capacity than can be handled by the PE-RT pipes (Gierow and Falkvall, 2018). The PE-RT pipes from Logstor is also still in the final phases of development.

5.4 Grid Performance

With the help of Kraftringen, a model of the LTDH network has been created in the simulation software NetSim. This model will in our case be used to evaluate the performance of the LTDH grid in the year 2021 when the COOL DH project ends as well as in the future. Note that the values in the legend are different in the different figures that shows the result of the NetSim simulations. The scale in the legends does not represent what the pipes are capable of, but rather just the scale that the values fall into.

5.4.1 2021

When determining what the heat demand on the system will be for a whole year of measuring for the COOL DH project only some of the buildings were included. The buildings that are projected to be finished before 2021 and all the buildings that does not have a projected finish date but with a projected building start in 2019 were included. This allow for a years worth of data for the buildings included in this simulation. The ground heating systems has also been included. The projected heat demand for the year 2021 is summed in Table 9.

Table 9: Projected customers in the system in 2021.

Building	**Full load (kW)**	**Heat demand (MWh/y**	**Start**	**Finish**
Hauschild & Siegel	97	175	2019	2020
Slättö	89	166	2019	2020
LKF	172	310	2019	2020
Solbjers Bostad	41	73.5	2019	-
Kärnhem	183	330	2019	-
Möllegården	10	18	-	2019
Tramcar depot	128	230	-	2020
Ground heating system A	680	170	-	2020
Ground heating system B	180	45	-	2020
Ground heating system C	120	30	-	2020
Ground heating system D	120	30	-	2020
Total	**1820**	**1580**		

The NetSim model has been drawn with the help of a DWG-file aquired from Kraftringen with the routes and dimensions of the pipes. The customers has then been placed according to Figure 13, 12 and 14. The simulations were performed with the full load value of each building.

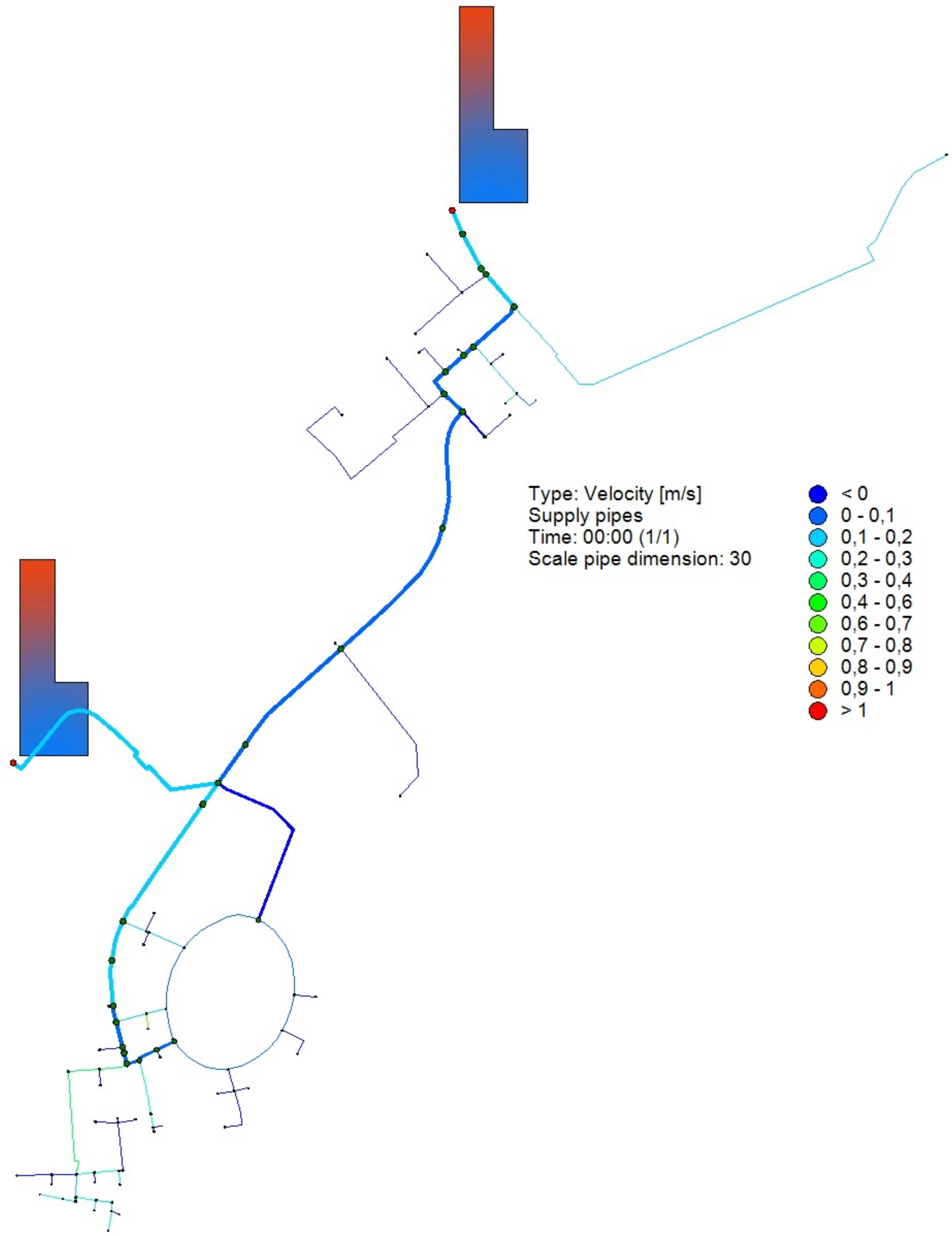

Figure 17: NetSim simulation of velocity with the projected heat demand in 2021.

Figure 17 shows the velocity in the different pipes. In most pipes the velocity does not exceed 0.25 m/s and many pipes does not even go above 0.1 m/s. The only large pipe with faster velocity is the distribution pipe down to South Brunnshög. The low velocity is due to a very oversized network for the heat demand situation, that will occur in the first years of the districts development, because many buildings have not been erected yet. A low velocity will make the district heating water cool down much more than what is desirable. The main pipe with an inner diameter of 273 mm has a dimensioning velocity between 1.5 and 3 m/s. This is 10 times higher than the values shown in Figure 17. Most of the other pipes follow the same pattern. It is hard to calculate an actual value on the linear flow temperature drop but it could be a problem in the beginning, especially during the summer.

5.4.2 After COOL DH

To calculate the velocity in 2025, 2035 and 2050 the predicted heat demand that was calculated earlier was used. A value of 1800 full load hours was used for all the buildings and 250 full load hours for the ground heat. These are the values that Kraftringen uses to switch between full load and yearly heat demand(Gierow and Falkvall, 2018). Table 10 shows the heat demand and full load values in 2025, 2035 and 2050.

Table 10: Projected total heat demand and full load in 2025, 2035 and 2050.

Year	**Heat demand (MWh/y)**	**Full load (MW)**
2025	5 700	4.1
2035	28 200	16.6
2050	61 900	35.3

The years 2025, 2035 and 2050 are the years displayed in the chapter 5.5. The year 2025 is chosen because all the customers described in chapter 5.1.2 will hopefully contribute with a load to the system. 2035 is the year when the projected heat demand will catch up to the projected production of MAX IV and ESS when they both have a winter revision break according to our future estimations detailed in section 5.5.

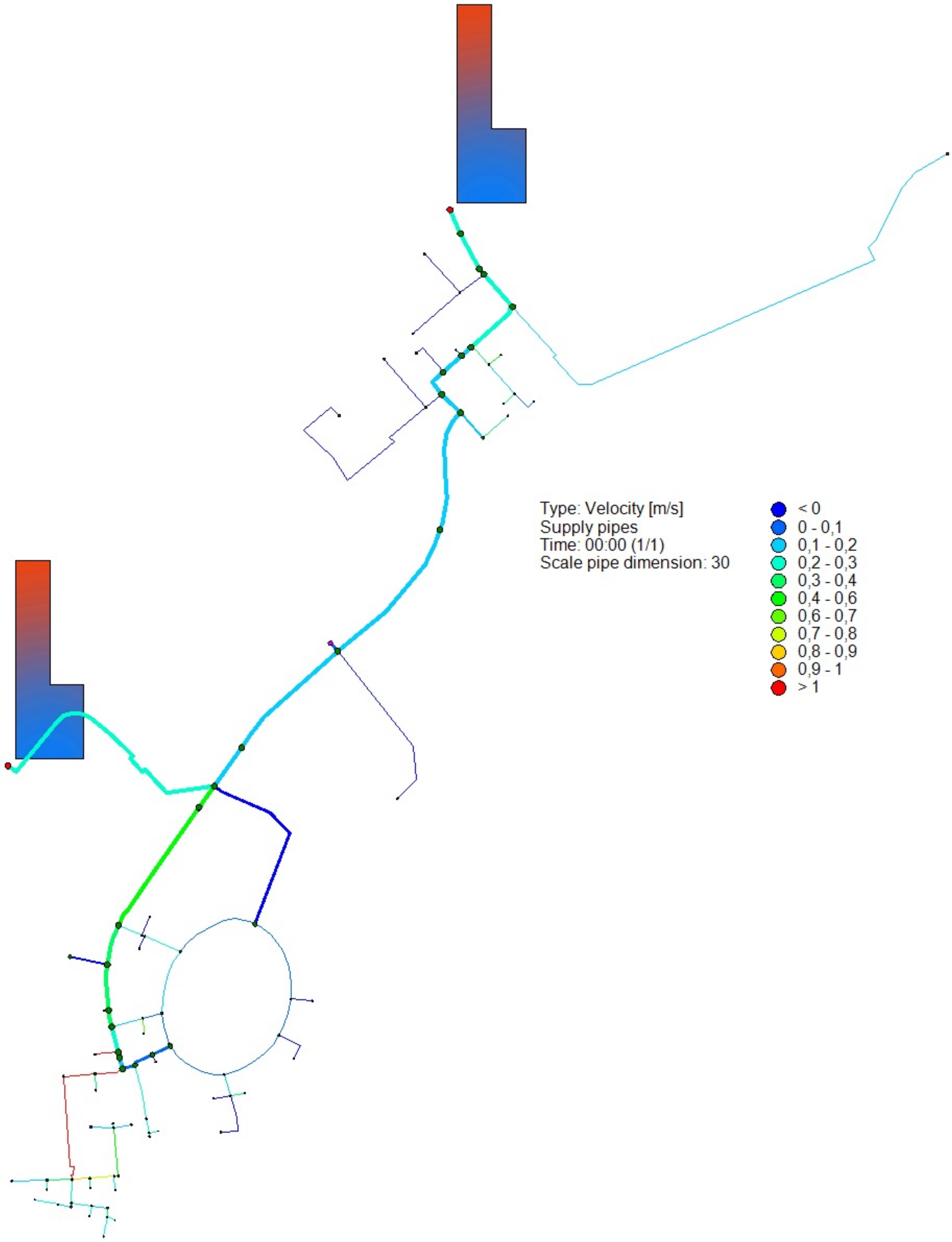

Figure 18: NetSim simulation of velocity with the projected heat demand in 2025.

The simulations for 2025 in Figure 18 shows that the velocity in most of the used pipes has at least doubled. The velocity is still low in many places and still a fair bit below the dimensioning velocity. This means that the temperature drop in the flow direction could still be an issue. As in the simulation for 2021, South Brunnshög is closest to the dimensioning velocity. The pipes in South Brunnshög should by now be fully populated.

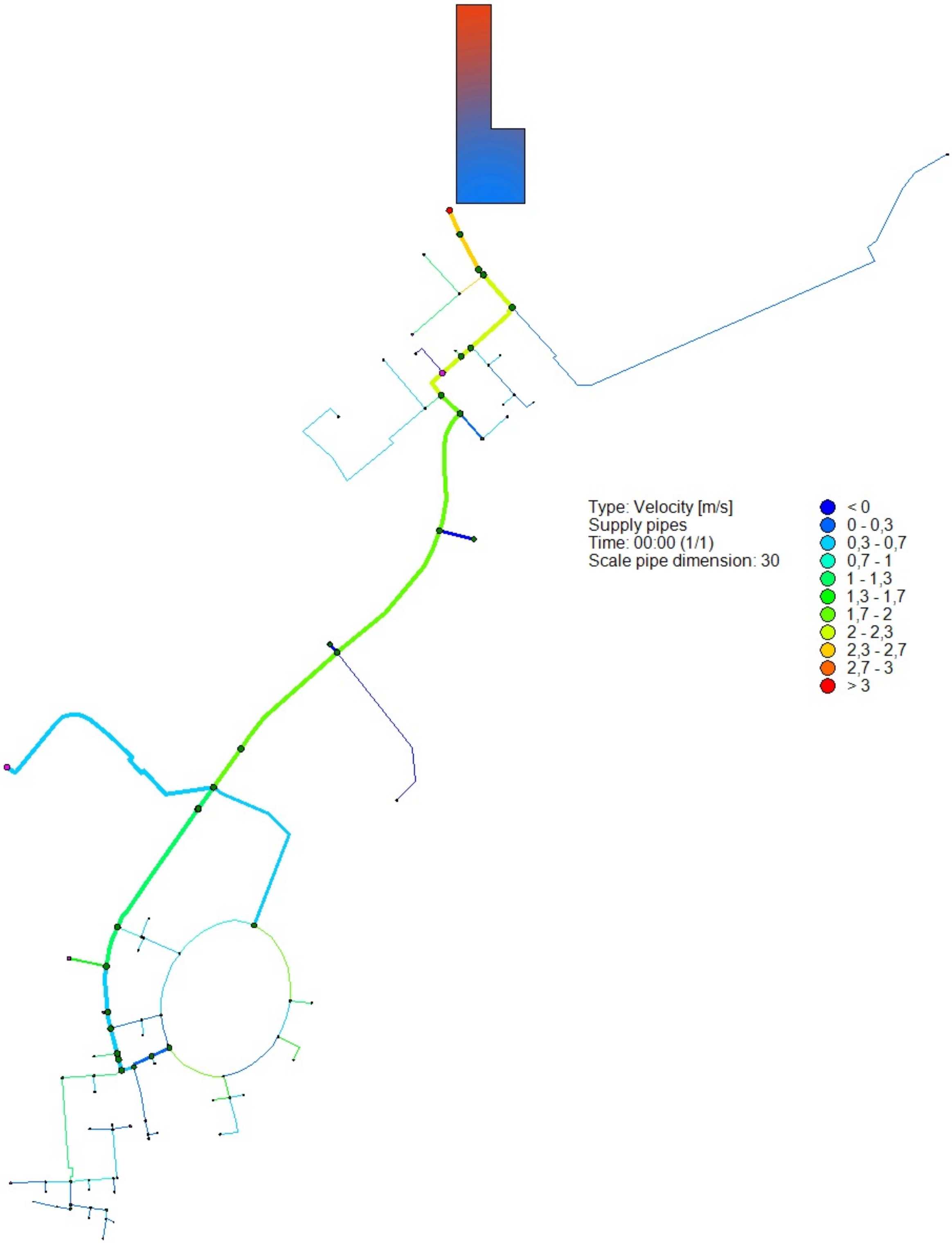

Figure 19: NetSim simulation of velocity with the projected heat demand in 2035.

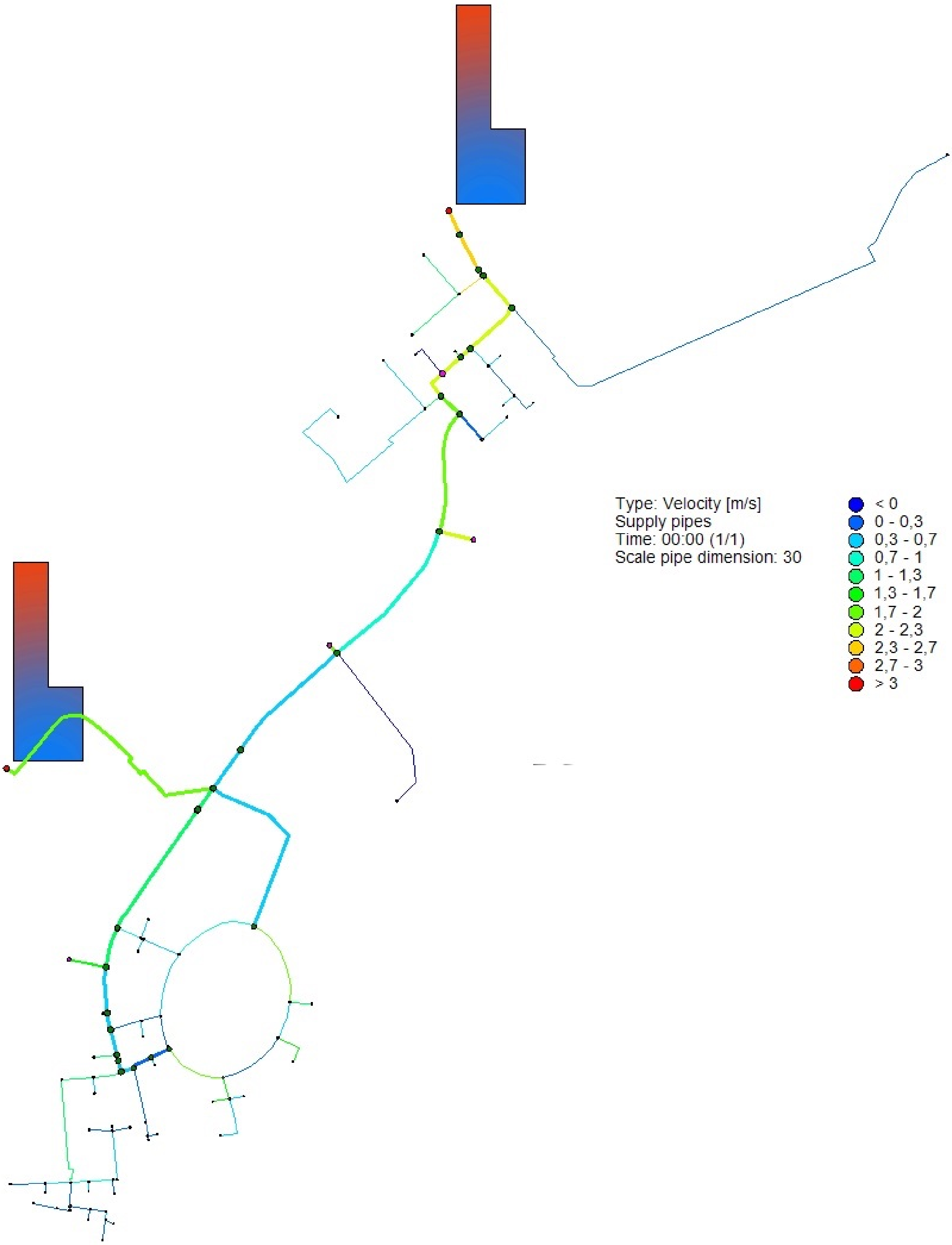

Figure 20: NetSim simulation of velocity with the projected heat demand in 2050.

In the simulations for 2035 and 2050 in Figure 19 and 20 the customers have either been placed on ends of pipes where no earlier customer has been placed or right on the main pipe. This is because there are no definitive plans of where new buildings will be placed. Since only the total heat demand on the system is known and not the location of the loads on the grid, the main pipe is most interesting part of Figure 19 and 20. For 2035 the values seem just a little below the dimensioning velocity for a 273 mm inner diameter. In Figure 20 it can be seen that the flow out of ESS is close to maximum of the dimensioning velocity. The rest of the of the main pipe is well within the dimensioning velocity. The simulations for 2035 and 2050 is uncertain due to it being so far in the future and little information about the plans further away than 2025.

5.4.3 Heat Loss and Efficiency

The calculations for the heat loss in the system has been done using the Logstor calculator. The calculator needs the dimensions of the pipes used, the length, insulation series and distance between the pipes of each dimension. The program also need the supply and return temperature in the district heating system, the outside temperature, the heat transfer of the soil cover and information about the soil cover height. The heat transfer of the ground is set to 1.5 W/mK (Werner and Frederiksen, 2014). If the exact diameter is not present the closest diameter was chosen. The value for soil cover has been left as the default value of 1000 mm as no information about pipe depth is known. The distance between the pipes is also not known and is left as the default value of 150 mm. When testing different distances between the pipes the changes are only marginal.

The calculations has been done for a whole year with the outside temperature set to 9.1 °C which is the average temperature in Lund between 2006 and 2016 (Sydsvenskan, 2015). The length of the pipes and their dimensions is taken from NetSim and all the unused pipes has been subtracted as they are assumed either to be closed or not built yet. Table 11 shows the pipe diameter, pipe type and material, insulation series, length and heat loss for each diameter used for the simulations.

Table 11: The length and type of pipe projected for 2021.

Dia. (mm)	**Pipe type**	**Insulation series**	**Pipe length (m)**	**Heat loss MWh/y**
250	Individual, Steel	1	2220	**566.0**
200	Individual, Steel	2	93	**19.2**
100	TwinPipe, Steel	2	330	**32.3**
80	TwinPipe, Steel	2	952	**94.3**
80	Individual, PE-RT	2	1341	**207.7**
65	Individual, PE-RT	2	23	**2.6**
50	Individual, PE-RT	2	139	**14.0**
32	Individual, PE-RT	2	84	**7.53**
Total			5184	**943.6**

Table 11 show that the total heat loss in the LTDH system is 987 MWh per year. It also shows that the main pipe with 250 mm diameter is responsible for more than half of the heat losses. If Kraftringen would be able to use insulation series 2 on the main pipe the heat losses for it would be 449 MWh/year instead of 566 MWh/year.

Equation (1) is used to calculate the efficiency in the LTDH system.

$$\text{Thermal efficiency} = \frac{1580}{1580 + 987}$$

$$\text{Thermal efficiency} = 0.63$$

This shows that the LTDH system will have a 63 % efficiency in 2021. This is considerably lower than most district heating systems. The biggest reason for this is the low linear heat density in Brunnshög 2021. The linear heat density in the LTDH system is only 1.1 GJ/m. This is even lower than the lowest value for how a low linear heat density area is defined. A low linear heat density area according to (Werner and Frederiksen, 2014) is between 2 and 5 GJ/m.

If the 2025 scenario is considered the heat demand is 5 700 MWh/year instead of 1 580 MWh/year. With the same amount of heat loss this will result in an 85.2 % efficiency and a linear heat density will be 3.75 GJ/m. These values are a little high, as the heat loss will be higher in 2025 than 2021 due to more pipes being used in the whole system. The new customers are close to the pipes being used in 2021 and therefore the length of pipes will not increase much. This also means that the heat loss won't be much higher than the 2021 value.

Since the information on the location of the customers in 2035 and 2050 the heat loss and efficiency calculations are very difficult to do and the increase in pipe length and it's diameter would only be a guess. Therefor no calculations of this has been made.

5.5 Energy Balance

Based on the data from the combined production and heat demand from Brunnshög an energy balance was composed to illustrate the conditions of supply vs. demand in the Brunnshög grid. The balance for 2025 can be seen in Figure 21 and the data quite clearly demonstrates that the energy output from MAX IV and ESS dwarfs the demand, even during the winter when the demand are at its peak and MAX and ESS are in low-operating conditions.

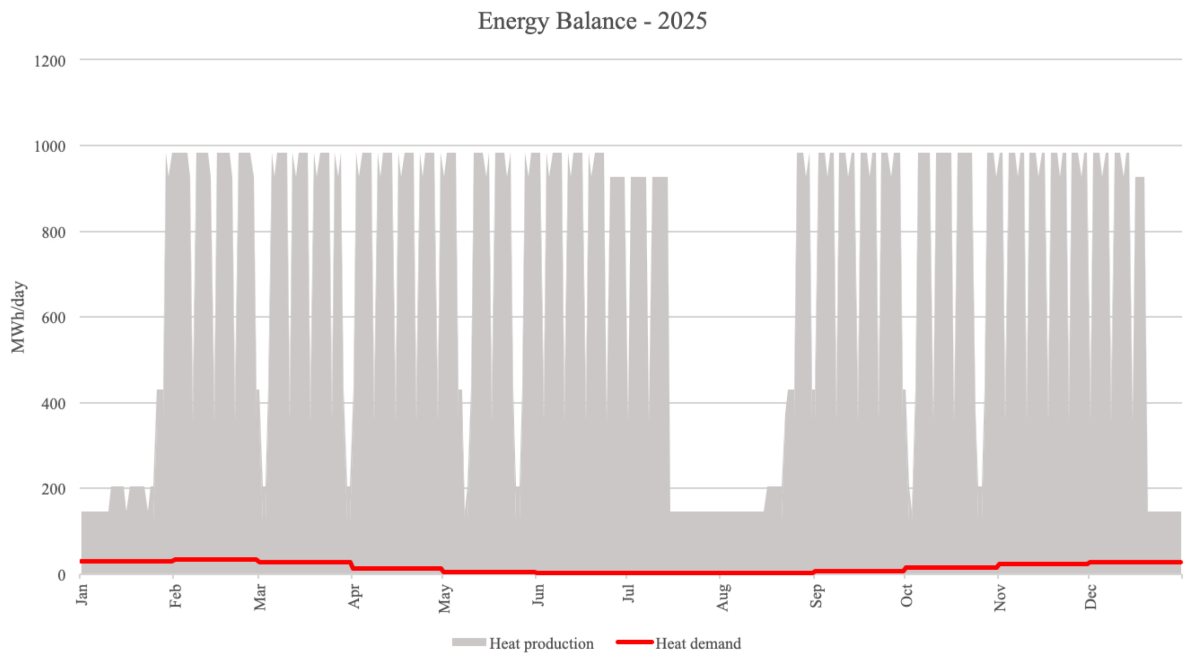

Figure 21: Energy balance in the Brunnshög grid at 2025

It isn't until 2035 that the heat demand exceeds the output from the research facilities by a small margin during January, as illustrated in Figure 22. The data upon which the customer heat demand is based are from monthly values and as such does not accurately portray heat demand spikes that may occur during the course of a day. Due to this the heat demand may very well exceed the production during a greater time frame in winter and thus require input from the conventional district heating grid.

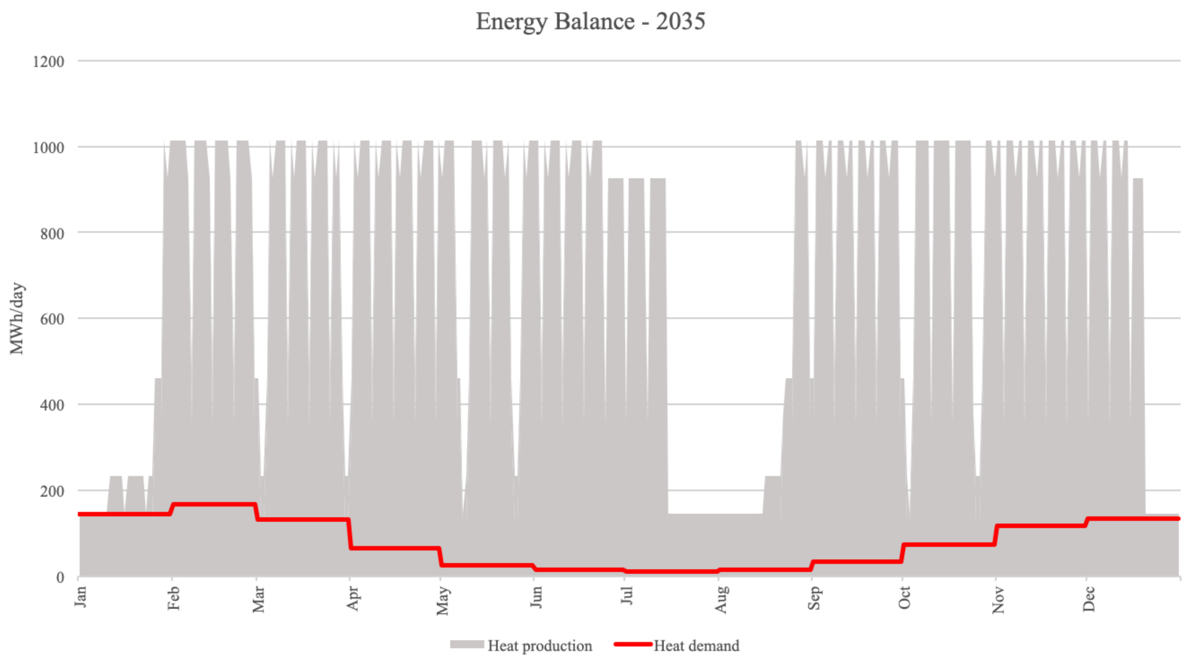

Figure 22: Energy balance in the Brunnshög grid at 2035

When the year 2050 is reached the customer heat demand is clearly higher during several parts of the year, during no operation mode at the research facilities (mainly ESS) when they have a decreased cooling demand. This far-future scenario can be seen in Figure 23. Since this scenario is over 30 years into the future it mainly provides a hint about the conditions of the energy balance in 2050 due to the many uncertain parameters that exists this far into the future. New heat-producing sources such as waste heat from ICA or Science Village and uncertainty regarding the future number of inhabitants in the district may change the energy balance by quite a lot. It indicates however that the additional heat input needed for the Brunnshög grid is primarily going to be required during the winter.

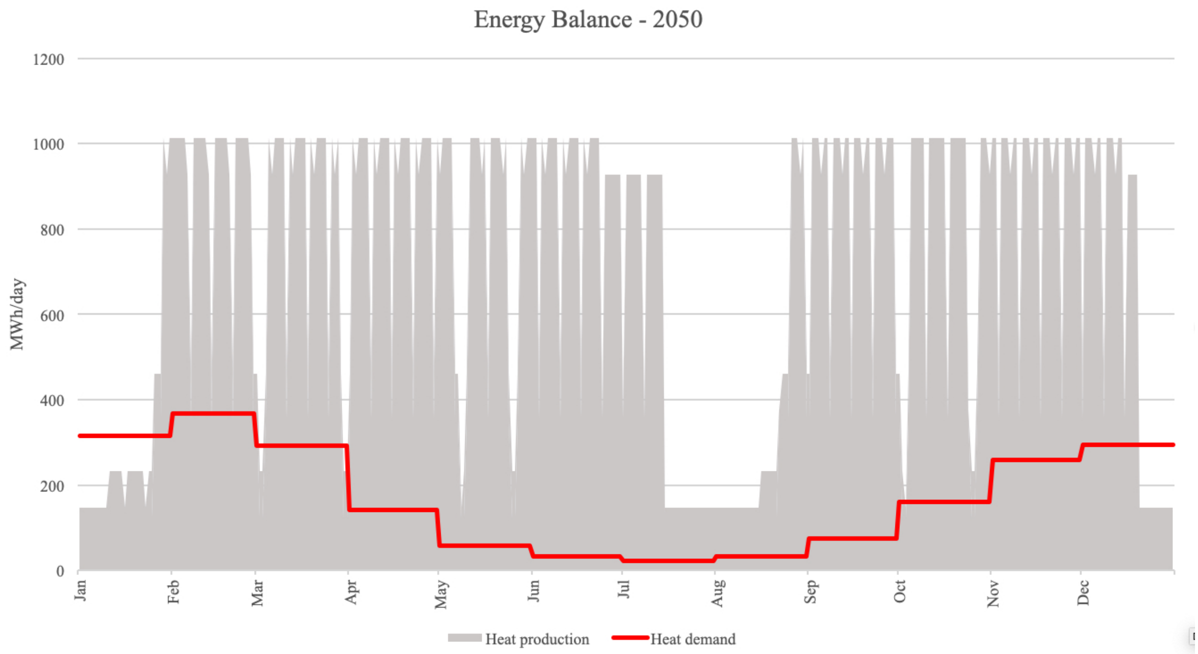

Figure 23: Energy balance in the Brunnshög grid at 2050

One big caveat for these estimates is the exclusion of potential cooling demand from Science Village. There is no information present with which to make a competent prediction regarding future experiments and processes that will take place here. Therefore it has been excluded from these scenarios.

6 Høje Taastrup

This chapter presents the energy mapping of the LTDH system of Høje Taastrup. It is based around what will be possible in the time frame of COOL DH and the information currently available for assesment. Firstly it provides a section about the production units, then one about the buildings and their heat demand and lastly a section about the grid and pipe design.

6.1 Production

The heat production, that will supply the low temperature heating grid in Høje Taastrup with energy, is at the present not clearly defined. There are 3 different possibilities for the origin of the heat and which one of these 3 sources that will provide the heat is currently not decided. Høje Taastrup Fjernvarme is pursuing the possibility of installing a heat pump on the mall CITY2 which will provide cooling for the mall and allow for the waste heat to be used in the low temperature district heating grid. (Gravenslund Olesen and Schleiss, 2018).

If the negotiations with CITY2 will not allow for the heat pump to be connected to the district heating grid, Høje Taastrup Fjernvarme will feed heat from the conventional heating grid into the low temperature grid of Østerby. This can be achieved through two different means. The first is to route the piping through CITY2 which allows for a possible future setup of using waste heat from CITY2. The other is to exchange heat directly from the conventional grid in Østerby and use that energy for the low temperature grid. Negations with CITY2 is still ongoing and what course of action will be taken in regards to the three different possibilities has not yet been decided. The potential heat production from the mall is unknown as well, as is a estimation of when it will be installed (Gravenslund Olesen and Schleiss, 2018).

Plans regarding further expansion of the LTDH by converting residential areas, besides Østerby, around CITY2 to LTDH have been discussed but will not fall under the time-frame of the COOL DH project. These areas include 350 houses from neighbouring residential districts (COOL DH, 2018b). These plans are however not concrete enough to warrant a study of potential sources for waste-heat production from within these areas.

Several areas of central Høje Taastrup are, or will be, in the process of development in the near future. This means that future facilities with a cooling demand probably will be constructed in Høje Taastrup, including buildings for DSB and Danske Bank. These facilities might be in need of cooling and a future prospect would be to use the waste heat from their internal cooling processes as a supply for the LTDH in Høje Taastrup. These facilities will however not be completed during the timespan of the COOL DH project and will thus not be taken into account in this energy mapping (Gravenslund Olesen and Schleiss, 2018).

6.2 Customers and Heat Demand

6.2.1 Østerby

The first connected customer will be the small district of Østerby. The tenants of 159 dwellings has signed and agreed on converting the current local district heating system to a LTDH system. Each of the dwellings will be connected to the district heating system and have one heat exchanger for space heating and one for DHW. The heat exchangers will be a standard Danfoss model for individual dwellings and will be serviced for 20 years by Høje Taastrup Fjernvarme.

The current local district heating system in Østerby is poorly insulated and has large losses, therefore the supply temperature at the dwellings will not change significantly with the new LTDH. Since the temperature is similar, the dwellings will not need any improvement in energy efficiency to to function properly.

Only four out of five housings societies have agreed on converting to LTDH. The last society will keep the old system. Table 12 and Figure 24 shows the four Societies that have agreed on adopting LTDH and their heat consumption as well as other relevant information about the dwellings. The heat consumption is measured at the dwellings. This means that the heat losses are not included in the values (Gravenslund Olesen and Schleiss, 2018).

Table 12: Normalized heat consumption in the different housing societies (Gravenslund Olesen and Schleiss, 2018).

	Torstorp	Torstorp II	Torstorp III	Egeskovgård	Total
Total heat consumption (MWh/y)	223	178	183	295	879
Average heat consumption (MWh/y)	6.6	4.6	5.2	5.8	5.5
Total living area (m^2)	2 621	3 015	2 744	4 312	12 692
Average living area (m^2)	77	77	78	85	79
Number of dwellings	34	39	35	51	159
Heat consumption/ living area (kWh/m^2)	85	59	67	68	70
Nr	1	2	3	4	

Figure 24: The different housing societies in Østerby (Gravenslund Olesen and Schleiss, 2018).

6.2.2 Høje Taastrup

The residential area to the east of CITY2 with 350 dwellings has not been mentioned in the interviews and is not projected to be connected during the time frame of COOL DH (Gravenslund Olesen and Schleiss, 2018).

Høje Tasstrup C is a new area of construction that are going to be developed in the coming years. At the time of the interview, no decision of heating system had been made. Høje Taastrup Fjernvarme is trying to convince the developers to choose LTDH. This will not fall into time frame of the COOL DH project even if the developers choose to join the LTDH system (Gravenslund Olesen and Schleiss, 2018).

6.3 Grid and Pipe Design

The first part of the grid will consist of a innovative heat recovery pipe from the heat pump at the CITY2 mall to Østerby. Due to competition, the development of the new pipe is a business secret so far, and no more information than that the heat losses are considerably lower the a normal district heating pipe. The distribution pipes will be plastic PE-RT pipes and will run all the way into the houses(Gravenslund Olesen and Schleiss, 2018).

The LTDH system in Høje Taastrup will have a year-round supply temperature of 55 °C at the customers and is designed for a return temperature of 30 °C. The goal of having 55 °C at the customer means that the supply temperature out of the heat pump will be a bit higher. The pipes are designed for 10-12 bar. The other components are designed for 16 bar (Gravenslund Olesen and Schleiss, 2018).

The result of the switch to a lower supply temperature and newer and better pipes will probably be comparable to the results in Sønderby were the efficiency of the system went from 56 % to 87 % after the switch to a LTDH system. As mentioned in the background, Sønderby underwent a similar conversion as the one planned in Østerby, where they switched from older poorly insulated pipes to modern, plastic district heating pipes and lowered the supply temperature (Li et al., 2017).

The building of the LTDH system in Østerby will start in april or may 2019 and is planned to be finished in October the same year. This means that about a total of two years of measurements should be possible to achieve within the time frame of COOL DH. As stated previously no dates are known about the future heat producers and customers in the grid (Gravenslund Olesen and Schleiss, 2018).

7 Evaluation Analysis

This chapter puts a critical eye on, and examines the feasibility and potential challenges with the COOL DH project goals of monitoring and evaluating the overall energy, CO_2-reductions, social impacts and energy performance. The two tasks of monitoring energy flows and evaluating energy flows are analyzed in turn with respect to their different parts detailed in chapter 2.3. This analysis is performed with the background of the energy mapping performed in chapter 5 and 6 in an attempt to visualize what can be evaluated and which parts of the tasks that might prove difficult to evaluate.

7.1 Monitoring of Energy Flows

One of the goals of the COOL DH project is to monitor the energy flows in both test sites. Based on information and analysis in chapters 5 and 6 the different monitoring categories and concise comments about challenges regarding their monitoring are displayed in Table 13. Further details regarding each category follows.

Table 13: Summarized analysis and comments regarding the feasibility of the monitoring of energy flows.

Monitoring category	**Measurable**	**Challenges/Comments**
Monthly metering values for energy generation and consumption	Yes	None. Data will most likely be collected by the operators of the grids.
Weather data	Yes	None.
Metering of energy flows and temperatures in RES-plants heat pumps and poly-generation plants.	Yes	Requires cooperation and transfer of information from operators of RES-plants, heat pumps and poly-generation plants.
Metering of energy consumption in demonstration buildings (total LTDH heating, DHW heating, electricity for heat pump / electrical topping, PV contribution, cooling if relevant).	Yes	Demonstration buildings require metering equipment data to be relayed to COOL DH participants. Construction delays may impact the data available.
Where relevant more detailed sampling will be performed in periods to support different analysis.	Yes	None.

To obtain monthly metering values for energy generation and consumption, information of this will have to be gathered from metering stations in the respective facilities. This will most likely be handled by the companies that run the DH grids, in this case Kraftringen and Høje Taastrup Fjernvarme and is data that undoubtedly needs to be collected in order to run the grids themselves. This then becomes a matter of aggregating the data from the different partners and delivering it.

Weather data can be gathered from weather institutes such as the Swedish Meteorological and Hydrological Institute (SMHI), (SMHI, 2019) or Denmarks Meteorological Institue (DMI) (DMI, 2019) which has weather stations making measurements in Lund and Høje Taastrup respectively. The data could also be gathered from on-site weather measurement installations, should such stations exist.

Data of energy flows and temperatures in RES-plants heat pumps and poly-generation plants will most likely be collected by the operators/owners of the plant i question. Whether this includes just Kraftringen and Høje Taastrup Fjernvarme or extends to the operators of the cooling system in CITY2 Mall or the cooling plants of MAX IV and ESS is hard to say. The metering itself is in all likelihood a non-issue and the coordination and sharing of information is the primary endeavour required for the other participants.

In regards to the metering of energy consumption in demonstration buildings it will probably, within the time-line of the COOL DH prject, be possible in for example Xplorion in Brunnshög which is planned to be ready in late 2020. As the COOL DH project is set do end in September of 2021 this allows for a window of a couple of months of metering before the end of the project. As the system in Denmark is replacing an existing system, connected buildings with metering equipment already exists. It is however unclear which demonstration buildings are refereed to in Høje Taastrup. But the gathering of electricity data from the heat pumps in CITY2 will not see any foreseeable difficulties as long as the heat pumps in the mall are properly connected and provides heat to Høje Taastrup in cooperation with Høje Taastrup Fjernvarme. To ascertain the contribution of PV to the heat/cooling production the amount of electricity used in heat pumps in Høje Taastrup and Brunnshög must be determined. From there the quantity of heat generated from this electricity can be calculated if wanted. This is most relevant in Høje Taastrup as the roof-mounted solar installation probably will generate a rather large share of electricity for the heat pumps. Cooperation and data transfer from CITY2 is essential if metering of PV contribution is to be made. Some of the projects in Brunnshög, Xplorion included, are planned to house solar PV installations. The larger the scale of PV contribution that is taken into effect the more arduous this metering becomes, but if limited in scope to PV contribution in Xplorion, as in terms of a demonstration building, only the electricity balance for this particular building needs to be established.

7.2 Evaluating Energy Flows

The COOL DH project also includes goals of evaluating the data collected on energy flows, analyzed in the previous section, for both demonstration sites. The specifics of the task are detailed in chapter 2.3 and a summary of the attainability and challenges with achieving these tasks are summarized in Table 14.

Table 14: Summarized analysis and comments regarding the feasibility of the evaluation of energy flows and associated categories.

Evaluation category	Measurable	Challenges/Comments
Method of monitoring and evaluation	Yes	None.
Energy savings achieved	Partly	Low load in an oversized system will impact the metering results in Lund. Probability of a low and unfair measurement of energy efficiency is high. In contrast to the grid in Høje Taastrup where an existing system will be replaced by LTDH, Lund is a new system and will not perform optimally by the end of this task.
CO_2-reductions	Partly	Evaluating CO_2-reductions in Brunnshög might prove difficult due to non-optimized system at the end of COOL DH. Lund's DH grid currently have low CO_2-emissions thus potential reduction may be small or non-existent. The primary energy source in Høje Taastrup is waste heat from a solar powered cooling system and thus will be a major upgrade from the Danish national average.
Costs and economic feasibility	Partly	Parts of a finalized analysis of operational costs might prove difficult in Lund where a large part of the customers will not be connected at the end of COOL DH.
Comfort and user satisfaction and other social impacts	Yes	Good prospects in Denmark where the replaced system provides contrast with the new as a basis for changes in user satisfaction.

In order to evaluate the energy savings achieved, firstly "savings" have to be defined. That is to say, there needs to exist a reference system with which to compare it with. Whether that is a different form of heating system such as a one fueled by gas combustion, which is a standard practice in Europe, a heating system based purely on individual home-installed heat pumps or a regular DH net is not a part of this study and will need to be addressed by the authors of the monitoring reports. There is however evidence to show, in chapter 5, sections 5.2 and 5.3 primarily, that the customer heat demand on the grid in Brunnshög will be rather low with respect to the available waste heat produced by MAX IV and ESS. This may initially lead to a low thermal efficiency for the grid, mainly due to a low linear heat density as the grid is designed to accommodate a greater customer heat demand than will be present in 2021. As the project ends in 2021 the monitoring report from Brunnshög therefore runs the risk of misrepresenting the benefits of a LTDH net. Care should be taken to clearly explain that the grid is designed for a new district that is still under heavy development and which will see a greater heat demand in the future and, in turn, a higher efficiency. The evaluation of energy savings in Høje Taastrup may be more representative of the possible benefits of LTDH grids as the grid is designed around customers that are already in place and have a heating need.

The current CO_2-emissions from the DH-grid in Lund and Sweden in general are quite small when put in an international perspective as is shown in the chapter 2.4. The heat production is based on renewable fuels almost exclusively and thus have low levels of CO_2-emissions. It might therefore be difficult to witness a reduction in emissions at all for the Brunnshög grid as the efficiency for the grid will be quite low for the duration of the COOL DH project. The heat will be produced solely on recycled heat from facilities which drive their cooling systems by electricity. Thus an analysis of the carbon emission impact from this electricity might be needed, depending on the type evaluations that will be made. Reductions from using different piping is however an analysis that might yield better results due to its lack of dependency on system efficiency.

In Høje Taastrup an analysis of the CO_2-reductions will probably be easier to make, at least in terms of looking at a comparison of conventional DH and LTDH, as a direct comparison can be made to the grid previously installed to the buildings. The fuel sources for the system in Høje Taastrup also contains a larger portion of non-renewables, and thus a potentially interesting analysis can be made of the benefits, or disadvantages, of running a DH-grid run on waste heat with electricity as the primary source in contrast to heat delivered from conventional district heating supply in Høje Taastrup. The results of this evaluation is however largely dependent on the grid being delivered waste heat from the cooling of CITY2. Is the cooling system for the mall is not made avaliable to produce waste heat for the LTDH grid in Østerby the supply will instead come from the conventional DH grid and is then solely dependent on an increase in efficiency to provide CO_2 emission reductions.

The cost and economic feasibility can be approached from multiple angles. If analyzing the operational costs of the two systems consideration should be taken not to make a crude straightforward economic comparison between the two systems. As we have shown in chapter 5 and 6 they have different outlooks in terms of efficiency as a result of their different linear heat densities, among other factors. Thus analyses of the operational costs that involves heat loss or the cost of fuel may vary wildly between the two demo sites. These conditions should however not be a hindrance for the actual evaluation and calculation of interesting analyses regarding costs and economics but an awareness of these issues are necessary in order for the analyses to be representative.

Capital expenditures are likely to be more easy to evaluate as both the demo-sites will have installed a majority of the piping during the time frame of COOL DH. Economic analyses of material costs, net investments and similar parameters will probably run into few issues, granted that the information is easily available to participants.

The comfort and user satisfaction is a measurement that have good prospects, primarily in Høje Taastrup where a clear comparison can be made to the previous situation of being provided with conventional DH. In Brunnshög these studies can be partially hindered by the low amount of customers available for sources of information. Social impacts studies can be made of the ground heating systems in Brunnshög and, for example, be related to snow clearance.

8 Discussion

In this chapter a discussion is held regarding the results of the thesis. First, discussions about the results from the chapters about Brunnshög and Høje Taastrup is presented, in the same order as the original chapters provide their results. In addition these sections provide discussion about the analysis of the monitoring and evaluation goals of the COOL DH project. The chapter ends with a discussion about the thesis methodology.

8.1 Brunnshög

8.1.1 Production

The large cooling systems in the two science facilities in Brunnshög will have a massive amounts of waste heat production in comparison to the heat demand, especially from ESS. This is partly due to the great need for cooling, but also due to the initially low level of heat demand on the the new LTDH grid. Neither overproduction or underproduction will, however, be a functional problem for the cooling systems in MAX IV or ESS. This is because the heat pumps can either be set to output deliver 65 °C for the LTDH system or 80 °C for the conventional district heating-system. Underproduction is dealt with by a heat exchanger from the conventional district heating system.

One problem that might be more difficult to deal with is the reduced heat output that reoccurs about once a week for both research facilities. If the dips are as big as our models show and in the case were ESS is working in its full capacity its a change of more than 20 MW down from full power. To put it into perspective, this is a quarter of the power of Örtoftaverket. Since the production is oversized compared to the heat demand in Brunnshög for the foreseeable future, large dips in heat production should mostly affect the conventional district heating system and not the LTDH grid, as the heat produced, even with low production, will satisfy the heat demand for the LTDH system.

The heat production pattern for MAX and ESS is also merely an estimation and it is by no means a certainty. This means that the reduction in heat production very well could come to be both larger or smaller and even longer or shorter than estimated. The value of the power for the different operation modes are just the average for that operating mode. This means that the spikes in heat output may not be as sharp as depicted in sections 5.1 and 5.5. It should be noted that it is difficult to make predictions regarding the time-variance of the cooling need since ESS is yet to be completed and there exists no data on the exact nature of the power curves.

A problem when determining the heat production and the customer heat demand in Brunnshög, with regards to the aspect of time, is that there have been a significant amount of delays on both the production and the customer side. MAX IV has had considerable problems with their management. This has had an impact on how many beamlines that have been able to go into operation. Many of the beamlines have been delayed for 2 - 2.5 years. This will impact the amount of heat delivered to the district heating system in Brunnshög. Luckily the production system is very large in relation to the amount of heat demand. As for now ESS seem to be on track for reaching its completion date on time but, as mentioned before, even if ESS does not start producing heat on time and the amount of heat from MAX IV will not be sufficient, Kraftringen can always get power from the conventional district heating system. This means that the LTDH system will probably never run out of power for the consumer.

8.1.2 Inventory of Future Heat Loads

The inventory of future heat consuming customers in Brunnshög shows some uncertainty regarding the construction end dates for building projects. Wästbygg's project is an example of this where the project was delayed from its initial starting point in 2019 and currently has no estimated date for the end of the construction project. The dates that are given for the other construction projects are the best estimates of the participants involved and, of course, comes with a natural degree of uncertainty. The finalization of these projects are however important for the evaluation of the new LTDH grid in Brunnshög. Without enough customers and heat demand for the grid, the data available for the metering and evaluation of the LTDH system at the end of the COOL DH project can become inadequate or skewed. If we entertain the thought that the participants responsible for the metering and evaluation would need a year's worth of data to provide a representative result, only one construction project from Central Brunnshög would be able to be included, namely that of Kärnhem. The situation looks better for South Brunnshög and Science Village but given that the customer heat demand would be small, compared to the scale of the LTDH grid, even if all currently projected buildings were completed one year before the end of the COOL DH project, it becomes even smaller without them.

8.1.3 Grid Performance

The lack of connected customers in the early stages of the COOL DH projects will have impact the grid performance. This is shown in the NetSim simulations where the velocity in the pipes is very low and will be even lower in the summer. This might result in temperature drops in the direction of flow. It is also shown in the grid efficiency calculation with an efficiency of only 63 % in 2021. The low efficiency is due to the low linear heat density of the LTDH grid in Brunnshög in 2021. However, in just a few years the efficiency will rise as more customers are connected to the grid. With the projected heat demand for 2025 the efficiency will rise to around 85 %. We have not calculated a value for the linear flow temperature drop but anticipate it to be a problem in the first period of the districts development. A solution would be to increase the velocity in some way. This could be some kind of active cooling or just a bypass valve from the supply side to the return side. This will hurt the efficiency even more, but if the customers have problem with low temperatures it might be necessary.

The restriction of only being able to use insulation series 1 for the main distribution pipe will increase the heat loss by more than 100 MWh/year. Kraftringen didn't have choice but to use the lower insulation series due the size restrictions under the tramway.

When looking at the grid simulation for 2035 and 2050 the velocity in the pipes are more in line with the dimensioned velocity. It's hard to draw any definite conclusions about both 2035 and 2050 since the values that the model is built upon are uncertain. The result of the NetSim simulations should more be seen as an indication rather than a definite scenario.

8.1.4 Energy Balance

The estimation for the future energy balance in Brunnshög for 2025 to 2050 comes with an large, inherent degree of uncertainty. Firstly it is based of an expressed vision of the future state of Brunnshög's population from the Municipality in Lund. This vision may not come to pass or may be exceeded due to future, currently unknown causes. Nevertheless, to some extent the capacity of the infrastructure reflects this decision and somewhat validates that the actual future probably will fall somewhere close to this estimate as the systems in the city districts, the roads, living spaces, offices and so forth, are sized according to the vision. The vision is however not for 40 000 people to live in Brunnshög but also for them to work there. To clarify, the meaning behind this sentiment seems to be that 40 000 people should live and/or work in Brunnshög, indicating living space within the district itself will not have to accommodate 40 000 people. The model for the energy balance does however assume that this is the case and that 40 000 people will be in need of about 41 m^2 of living space and heat deliveries for that space. In reality, this space will probably be greatly reduced for people who will only work in Brunnshög as their offices will require a smaller quantity of heat deliveries per person occupying that space, in contrast with somebody living in a house or apartment. A significant portion of these people will might also work within MAX IV or ESS which will cover their own heat demands. With all this in mind the customer heat demand will probably be smaller than what is depicted in section 5.5.

8.1.5 Evaluation Analysis

Data collected on the dates when the construction of the buildings receiving heat from the LTDH grid in Brunnshög will be completed points to most projects finishing after, or just before, the end of COOL DH. This may be somewhat problematic for the COOL DH goals of monitoring and evaluating energy flows in the demo area. It will probably not be detrimental to the tasks and they can still be completed but the amount of data available on the customer heat demand of the system may impact the analyses in various ways.

The analyses in chapter 7 points to certain challenges regarding the metering and evaluation, especially in regards to energy savings achieved, CO_2-reductions and costs and economic feasibility. These challenges mostly arise in Brunnshög due to an initially oversized DH-grid and construction projects finishing to close to, or after the COOl DH project deadline.

The method of evaluating the reductions in the emissions of CO_2 in Brunnshög can be done in a lot of ways. In chapter 7.2 we state that an analysis of the carbon emission impact from the electricity that powers the cooling machines in MAX IV and ESS might be needed to evaluate the CO_2-reductions in Brunnshög. This however depends on how to value the CO_2-emissions from waste heat. Basing the analysis on the polluters pay principle would mean that MAX IV and ESS should be responsible for the emission since the energy has already served a purpose in the research facilities. The waste heat would then not be associated with emissions at all, thus providing a carbon-free energy source as the basis for analysis regarding CO_2-reductions. Whether this approach provides a fair comparison or not, in relation to other heating systems, is up for debate but it could be argued that the methodology with which to measure the CO_2-reductions in Brunnshög should be carefully chosen, with considerations for accuracy and fairness.

8.2 Høje Taastrup

8.2.1 Production

The potential source of waste heat production in Høje Taastrup is planned to come from the waste heat produced from cooling at the CITY2 mall. The negotiations regarding the heat pump, and whether it will provide waste heat for district heating grid in Østerby, is, however still ongoing between CITY2, Høje Taastrup Fjernvarme and COWI. Additionally the cooling demand, and subsequently, the waste heat available is not known. This results in an uncertainty regarding the waste heat production in Høje Taastrup that propagates to the analysis of metering and evaluation as well. Far-reaching plans of incorporating other waste heat sources from other parts of Høje Taastrup such as Danske Bank and Copenhagen Markets exist, but a clear time-line for their potential connection to the LTDH grid does not.

Because of the lack of information regarding potential waste heat input into the grid, it is difficult to draw conclusions about the balance in heat demand and the waste heat production capabilities of the grid. The aspect of how the waste heat input to the grid may vary over time is also difficult to predict because of this. If the heat is delivered from the waste heat from cooling processes for CITY2 it would probably be quite a bit lower during the winter than during the summer because of the general lack of cooling when outside temperatures drop but, again, without data on the cooling need from CITY2 we can only speculate.

8.2.2 Heat Demand

The heat demand in Østerby is likely to stay about the same after the new LTDH system is installed. No new buildings are planned to be constructed and connected to the grid within the timespan of the COOL DH project, so no new loads will be added to provide additional heat demand. New heat exchangers are, however, being installed in the buildings and they might improve the energy efficiency somewhat for the customers and lead to a slight reduction in heat demand for the grid. The houses in Østerby does not need to have any upgrades in terms of energy efficiency to be able to receive and use the low temperature grid since, in the old system, the temperature at the customer side was close to 55°C even before the conversion. This was likely due to poor performance of the grid.

8.2.3 Grid and Pipe Design

If the results from Sønderby are repeated in Østerby the efficiency may rise to over 85 %. This is a likely scenario as the buildings similar and the local district heating system should also be similar. The difference between the systems is that Østerby might get their heat from CITY2 and Sønderby gets their heat from the return of another poorly functioning building with very high return temperatures. The source of the heat should not matter but the distance between the heat source and the user might be different.

The grid down to, and in, Østerby is also designed for a heat demand that is already know. This will have the consequence that the system should be functioning as planned, with a high thermal efficiency from the start in contrast to Brunnshög where the grid initially will be oversized to allow for expansion and the addition of new customers in the future.

8.2.4 Evaluation Analysis

The improvements in CO_2-reductions should be very noticeable for the LTDH grid in Høje Taastrup if the heat delivered to the houses in Østerby comes from waste heat from CITY2. In addition to this, the electricity coming from the solar panels on CITY2 may be powering the cooling system for the mall to a substantial degree, providing a much less CO_2-intensive source of energy than the conventional district heating in Høje Taastrup, where almost half of the fuel comes from non renewable sources. If the waste heat isn't delivered from CITY2 and heat from the conventional DH grid is used instead, this advantage will be lost. The predicted increase in efficiency for the system should however still result in CO_2-reductions due lower energy losses for the system. The bump in energy efficiency that comes with the new grid will probably also have notable economical improvements due to not as much energy being wasted as heat losses. The evaluation process will have to tell if the economical benefits of higher efficiency will surpass the potential of higher construction cost for the new system.

When compared to Brunnshög the challenges for monitoring and evaluation in Højje are fewer. The issue of a low thermal efficiency due to an oversized grid will likely not be present here and thus the challenges associated with it will be avoided as well.

8.3 Discussion of Methodology

The use of linear models in MAX IV and ESS makes our results quite uncertain, especially the estimations far ahead in the future. The linear model can be thrown of a lot if one of the values are wrong. This can be shown in the results for MAX IV were the real value for the produced heat in 2018 is much higher than the predicted value. A model with the real values for 2018 as the starting values in the model will have a much more gentle slope but have higher values for each year. The problem might also be the use of a linear model altogether but since little information is known it's hard to use a more complex model.

The problem with the model of ESS might be as with MAX IV that the ramp up of does not follow a linear model. If the time line in the background is considered the different events is not evenly spaced. The different events might not contribute withe same amount of heat either. We choose the linear model because the information is limited and any other prediction are impossible to make.

The calculations of the production pattern of MAX IV and ESS does not include any seasonal variations. A seasonal variation would probably change the look of the curve, with more production during the summer than the winter due to higher cooling need. It would not change the result regarding the time where the production would be to small to support the load. This is due to that the greatest heat demand will be during the winter and the lowest production, which was used for the scenario, is also located during the winter. The period referred to is if both MAX IV and ESS has winter revision breaks at the same time in December. In 2018 however, MAX IV didn't even have a break over Christmas. This shows that the information about the operational patterns might not be trustworthy. If a seasonal variation was added this would only increase the heat output of the production facilities during the summer so it isn't a big problem. The information that MAX IV produce at least 1 MW even during the winter break is still accurate.

The projected heat demand over time for the buildings in Brunnshög is based on the customer heat demand data in chapter 5.2 and the variation over time is based on data from real, newly constructed buildings around Lund. Its purpose is to provide data representative of how the heat load may vary over time in newly constructed buildings so that the seasonal load variations for the estimated customer heat consumption are better represented. This data is however taken from a single year and variations in temperature for that year impacts the distribution of the load.

The reason the heat use for residential and service sector buildings in the EU is used in chapter 2.4, and not the heat supplied to the district heating systems of the EU, is to provide background regarding the analysis of the challenges in evaluating CO_2-emissions. Comparing the LTDH system i Brunnshög with conventional DH systems in the EU might yield results that are not representative of the grid's final environmental impact and the potential benefits of LTDH. It can, however be put in relation to the rest of the EU:s heating systems and provide a basis for discussion around the potential of LTDH as a replacement for other more CO_2 intensive systems of heating in the EU.

9 Conclusions

The aim of this thesis was to map the LTDH grids in Brunnshög and Høje Taastrup to provide a basis for monitoring and evaluation of energy flows in the two demo sites. The results showed that the LTDH grid in Brunnshög will perform sub-optimal in regards to efficiency within the time frame of the COOL DH project because of a low linear heat density in the early development of the district. This may cause the evaluation results to be non-representative of the potential benefits of LTDH systems. The LTDH system of Høje Taastrup will be finished in time and results of the evaluations should show an increase in performance compared to the current DH system.

- Energy mapping of Brunnshög and the creation of an energy balance for the LTDH grid shows that there will be enough waste heat to cover the customer heat demand until the end of the COOL DH project in September 2021.
- Thermal efficiency in the Brunnshög LTDH grid was estimated to be 63 % at the end of the COOL DH project. The low efficiency is due to the low linear heat density at the early stages of Brunnshög's development.
- Low thermal efficiency in the Brunnshög grid may lead to unfair results when evaluating energy savings, CO_2-emission reductions and costs and economic feasibility in the COOL DH project. Several construction delays will further compound this effect.
- NetSim simulations of the velocity in the LTDH grid show a low velocity which signals that the linear temperature drop in the grid will be high.
- Heat demand for the customers will probably not change significantly in Østerby, but the is a high chance that the overall grid efficiency will increase based on results from similar projects.
- Lack of data regarding the waste heat production from the heat pump at the CITY2 mall makes estimations of the balance in heat demand and production in Høje Taastrup difficult to perform. Energy input from the conventional district heating grid will however be able to compensate for any potential lack of waste heat.
- Waste heat production from CITY2 heat pump required for large CO_2 emission reduction in Høje Taastrup. Heat input from the conventional DH grid may impact the assessment.

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