Property owners' attitudes to connecting to the low temperature district heating network at Brunnshög

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Thesis for the degree of Master of Science in Engineering
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Abstract

District heating from renewable energy sources is a sustainable heating solution that allows electricity to be used for other purposes. The low temperature district heating (LTDH) network at Brunnshög is currently under construction, and connection is not mandatory. Ensuring that the LTDH alternative is attractive would increase the willingness to connect. There is no natural forum for discussion with property owners on their experiences of being connected, or for learning why they chose another heating option. For this thesis, property owners have been interviewed regarding provisions that they have made for their buildings, the motivations to build at Brunnshög, and why they have chosen either LTDH or another solution. The purpose has been to increase the replicability of the LTDH network construction. Of the ten respondents, nine chose to connect. The chief findings of the interview study are that there are three factors that determine whether or not the property owners connect to the LTDH network: previous experiences of district heating, environmental concerns, and an ambition towards innovation. Good relations between the district heating company and the customers are also instrumental.

Sammanfattning

Fjärrvärme från förnybara energikällor är ett hållbart uppvärmningsval som möjliggör att elektricitet används där den gör större nytta. Det lågtempererade fjärrvärmenätet på Brunnshög håller på att anläggas, och det är inte obligatoriskt att ansluta sig. Det finns inget naturligt diskussionsforum för fastighetsägare för att ta del av deras upplevelser av att vara anslutna till det lågtempererade fjärrvärmenätet, eller för att förstå varför de valde en annan lösning. I syfte att öka replikerbarheten av anläggningen av det lågtempererade fjärrvärmenätet så har fastighetsägare intervjuats för den här uppsatsen för att ta reda på hur deras byggnader ser ut, vad som motiverade dem att bygga på Brunnshög, och varför de antingen har anslutit sig till det lågtempererade fjärrvärmenätet eller låtit bli. Av de tio som svarade så valde nio att ansluta sig. Huvudresultatet av intervjustudien är att det finns tre faktorer som avgör huruvida fastighetsägarna ansluter sig: tidigare erfarenhet av fjärrvärme, miljöskäl och en ambition att driva innovation. Goda relationer mellan fjärrvärmebolaget och kunderna är också centralt.

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Abbreviations and definitions

4GDH	Fourth Generation District Heating
BEUC	The European Consumer Organisation (Bureau Européen des Unions de Consommateurs)
BBR	Boverkets byggregler (The Swedish National Board of Housing, Building and Planning's building regulations – mandatory provisions and general recommendations)
BRF	Bostadsrättsförening (a housing cooperative owned by the inhabitants)
CHP	Combined Heat and Power
COOL DH	**C**ool ways of using low grade Heat Sources from **Coo**ling and Surplus Heat for heating of Energy Efficient Buildings with new **L**ow Temperature **D**istrict **H**eating (LTDH) Solutions (an EU Horizon 2020 project)
DHW	Domestic Hot Water
Energiforsk	The Swedish Energy Research Centre
ESS	European Spallation Source
EU	European Union
HEX	Heat Exchanger
LKF	Lunds Kommuns Fastighets AB (the municipal housing company in Lund)
LTDH	Low Temperature District Heating

MAX IV	Synchrotron radiation facility in Lund
PBL	Plan- och bygglagen (The Planning and Building Act)
PE-RT	Poly Ethylene Raised Temperature
PV	Photovoltaics
Region Skåne	The regional council of Skåne
RES	Renewable Energy Sources
SVS	Science Village Scandinavia

Contents

1

Introduction

The development of district heating technologies is instrumental in fulfilling more and stricter emissions targets and environmental policies [1]. The reason is that they are able to make use of renewable energy sources (RES) and forgo the use of fossil fuels; since oil fueled heating systems in Sweden have largely been replaced by district heating, this has been the largest single contribution to lowering Sweden's total emission of greenhouse gases [2].

Making use of residual heat sources that would otherwise have been released into the air or water from industries and other facilities is also contributory to the net zero greenhouse gas emissions goal by 2045, as dictated by the national Swedish climate policy framework [3]. Similarly, lowering the supply temperatures in the district heating systems to enable low temperature district heating (LTDH) makes it possible to utilize sources of lower grade heat. The residual heat sources also have the benefit of reducing reliance on fossil energy from foreign countries [4].

In order to make LTDH networks more commonplace, their benefits need to be established among the end users: building developers, property owners, etc. Since it is illegal for municipalities to force adoption of any heating solution in buildings in Sweden due to competitive considerations [5], other methods are needed to promote informed decisions by the developers. This pertains to both technical considerations that need to be made to accommodate LTDH, and economic incentives such as the components of the LTDH price model. An exchange of experiences and expectations between legislators, the district heating companies and their potential customers is therefore critical [4]. The ongoing construction of the LTDH network in the urban district Brunnshög in Lund provides the possibility to collect insights into why consumers choose to connect to the network. This thesis aims to help bridge the knowledge gap regarding the features of being connected to an LTDH network by gathering experiences from the property owners.

1.1 Objectives

The COOL DH project, financed by EU Horizon 2020, has labored to gather experiences of the different demonstrations from its participants with replicability in mind, but has not had a natural forum for the end users of the LTDH network in Brunnshög. The aim of this master's thesis is to collect property owners' insights about the success factors and limitations associated with connecting to and operating under the LTDH network. These insights would increase replicability of the COOL DH project by highlighting the consumer perspective, and thereby advance the possibilities of implementing more LTDH networks elsewhere. The motivations behind connecting to the network as well as the cases where the property owners decided upon another option, such as heat pumps, have also been of interest.

The following research questions have guided the investigation:

- What factors affect whether or not the developers choose to connect to the LTDH network?
- How is the attitude to LTDH among property owners related to their environmental policies?
- What limitations of the LTDH network in comparison to standard district heating have the respondents encountered? For example, has LTDH affected how they handle *Legionella* concerns, how they dimension and optimize the building's heating system, or the process of connecting their building?
- How has the LTDH price model affected developers' willingess to connect?
- What is the attitude to the district heating company Kraftringen, and what is communication with them like?

1.2 Scope

The scope of the thesis has been limited to gathering impressions from the property owners who have received a land allocation from Lund Municipality in the area of Brunnshög where a connection to the LTDH network is possible, as well as the land owners in Science Village where a connection is mandatory. This selection comprises seventeen candidates. Furthermore, the property owners are anywhere in the process of having planned the project of building the house to actually having completed the building. The construction phase affects the extent of the respondents' experience of the LTDH network. Out of seventeen property owners relevant to this study, I received responses from ten. Nine of the respondents had connected or were going to connect to the LTDH network, and one had decided to use another heating solution.

1.3 Report outline

Chapter 2 provides background information relevant to the premise of the thesis by expanding on the environmental aspects of district heating in Sweden, the EU project COOL DH, and the urban district Brunnshög in Lund where the LTDH network is located.

Chapter 3 gives a theoretical overview of previous research on different aspects of LTDH networks, and sets the thesis into an academical context as well as provides a framework from which to interpret the results of the interview study. The theory includes fourth generation district heating and its characteristics, the specifics of the LTDH network at Brunnshög, factors that affect consumers' heating solution preferences, and space heating technologies available for use with low supply temperatures.

Chapter 4 describes and motivates the research method used in this thesis, and details the respondents and the buildings they are constructing.

Chapter 5 contains the results of the interview study, and integrated analysis reflecting the theoretical framework from Chapter 3. There is also a critique of the limitations of the study in terms of the responses and choice of method.

Chapter 6 presents conclusions from the analysis and suggestions for future investigations.

2

Background

This chapter gives background information regarding district heating in Sweden, and the network in Brunnshög in particular. Section 2.1 elaborates on the environmental aspects of district heating in the context of the Swedish national climate policy framework in contrast with European Union (EU) goals, and motivates the transition to LTDH. Section 2.2 describes the EU funded project COOL DH, which has provided the basis for this thesis. Section 2.3 gives an overview of the Brunnshög area in Lund where the LTDH network is located, which frames the answers in the interview study.

2.1 Environmental aspects of district heating

Over the years, district heating in Sweden has developed into a environmentally conscious alternative: as of 2021, the fossil component of the energy used to generate Swedish district heating was 2.2 %, which is the result of a steady reduction since the 1980s [6]. This figure however makes the assumption that all of the waste in the district heating fuel mix counts as non-fossil. Residual heat from industrial processes and recovery measures such as flue gas treatment constitute around 26 % of the district heating fuel mix [1].

One of the sixteen environmental quality objectives formulated by the Swedish Environmental Protection Agency (Naturvårdsverket) concerns the use of RES [7]; in 2020, 60 % of the total energy used in Sweden came from RES, thereby surpassing the EU goal of 49 % [8]. A contributing factor to the fulfillment of this goal is the combustion of household waste in combined heat and power (CHP) plants, since 50–60 % of the waste counts as bio-based. In Sweden, CHP accounts for the production of 8–10 % of the country's electricity, and the heat is distributed to district heating networks [9]. Moreover, using district heating networks allows electricity to be used for other purposes [10]. The usefulness of an energy form may be expressed with an exergy factor, denoting the amount of work that can be done before reaching thermodynamic equilibrium. This factor is generally a number between 0 and 1, with a low number indicating that little work can be done. Electricity is a high grade energy form with an exergy factor of 1.0, compared to 0.17 for third generation district heating [11].

Sweden is ahead of the EU at large concerning the use of RES for district heating: 43 % of the supplied energy for district heating in Sweden comes from RES, as opposed to 23 % for all of the EU [1, 12]. However, making provisions for continued development of district heating technology is crucial to be able to reach the EU-wide energy objectives. Since May 2022 there is an EU plan to reduce reliance on Russian fossil fuels at an accelerated rate, and to increase the goal to 45 % RES in all sectors by 2030 (from 32 % after the recast directive in 2018) [13]. The end goal is climate neutrality in the EU by 2050. Since the heating and cooling sector accounts for 50 % of the total energy use in the EU, low grade heat sources in LTDH networks are a key part of the EU Heating and cooling strategy [4]. Among benefits such as heat efficiency gains and reduction in overall pollution and emissions, LTDH networks are estimated to generate annual economic savings that exceed the costs of the technology by 400 % [14, p.25].

2.2 COOL DH

The abbreviation COOL DH stands for Cool ways of using low grade Heat Sources from Cooling and Surplus Heat for heating of Energy Efficient Buildings with new Low Temperature District Heating (LTDH) Solutions. COOL DH is a project supported by a consortium consisting of COWI, Kraftringen Energi AB, Høje-Taastrup Kommune, City of Lund, Lund University, Euroheat & Power, Logstor, Høje-Taastrup Fjernverme amba, Cetetherm, and Lunds Kommuns Fastighets AB (LKF). The purpose is to conduct research on and demonstrate the next generation of district heating and cooling in real-world settings. The motivation for the research is that the residual heat generated in the EU could potentially heat all buildings in the EU, so by making use of low grade heat there would be less need to buy fossil fuels for heating, resulting in both saved money and lower environmental impact [15].

The project is financed by the EU program Horizon 2020, the aim of which is to facilitate research and innovation in Europe, thereby increasing global competitiveness. COOL DH has two demonstration sites where the research is implemented and evaluated: Brunnshög in Lund, Sweden, and Høje-Taastrup in Denmark. The project was initiated in 2017 and is at the time of writing in its final phase, where the success factors and limitations of the demonstrations are being evaluated. This includes gathering experiences from all parties: the district heating companies, the pipe manufacturers, the municipalities, etc. Portions of this thesis will be published in a COOL DH report.

2.3 Brunnshög

Located in the northeast of Lund, Brunnshög is an expanding urban district that constitutes the connection between the existing city of Lund and the two research facilities MAX IV (a synchrotron radiation facility) and ESS (European Spallation Source) (see Figure 2.1). A central feature of the area is the LTDH network which is supplied by residual heat from MAX IV, and managed by the local energy company Kraftringen. The area is currently under development, and is projected to be completed around 2050. The area called Södra Brunnshög (South Brunnshög) is almost completed, and the second phase consists of Centrala Brunnshög (Central Brunnshög). Buildings are also being erected in Science Village, located between MAX IV and ESS. Lund municipality have made an overarching plan for the proportions of different kinds of buildings, and hold piecewise land allocation competitions to portion out the land among developers [16]. The building types include commercial facilities, offices, multi-storey parking, apartment buildings, and single family dwellings.

The land allocation competitions have had different focus areas in their selection criteria, for example architecture and carbon neutrality, but have also had hard criteria such as bicycle parking possibilities and solar panel installations. While it is illegal for municipalities to make technical requirements for buildings (according to PBL, the Swedish Planning and Building Act), they can formulate requests from developers to help the municipality meet its goals in relation to sustainability and other endeavors. Lund municipality can therefore not demand that new buildings connect to the LTDH network, only strongly suggest that connecting is in line with their environmental goals [17].

Lund municipality does however not allocate land in Science Village. The purpose of Science Village is to provide educational and research facilities, and to connect the academic world with business interests as well as society at large. The land is owned jointly by Lund municipality, Lund University (LU) by way of a trust fund called Akademihemman, and Region Skåne (the regional council) through the company Science Village Scandinavia (SVS) AB [18]. As a corporation, they may sell their land to whomever they wish, and also demand that the buyers connect to the LTDH network [19].

Figure 2.1 The layout of Brunnshög in the northeast of Lund. The area called Södra Brunnshög (South Brunnshög) is almost fully developed as of 2022, and construction is under way in the second phase, Centrala Brunnshög (Central Brunnshög). Parallel with this, buildings are being erected in Science Village, located between the research facilities MAX IV and ESS. The LTDH network currently reaches from Science Village to the upper part of Södra Brunnshög (see Figure 3.2 for details on the network route). [16]

3

Theory

This chapter describes relevant theory behind LTDH networks. Section 3.1 is an overview of fourth generation district heating and its characteristics to provide context to the conditions of the LTDH network at Brunnshög. This includes *Legionella* considerations, and technical solutions to limit microbial growth specific to low temperature conditions. Section 3.2 describes the circumstances of the LTDH network at Brunnshög, which in turn provides context to the interview study responses. This includes the heat supply, specific technical solutions, and the price model used by the district heating company Kraftringen. Section 3.3 is a review of previous studies concerning consumers' preferences in relation to what heating solution they choose for buildings, the purpose of which is to understand why they choose district heating or some other solution. Lastly, Section 3.4 details the different space heating technologies available for use with low supply temperatures, with their respective advantages and drawbacks.

3.1 Fourth generation district heating

Several generations of district heating networks are currently in operation worldwide; a visual comparison of the different generations is shown in Figure 3.1. Existing networks in Sweden are generally of the third generation, which is characterized by supply temperatures under 100 °C at typical outdoor temperatures [20], and secondary system temperatures between 70 °C and 90 °C [21]. Fourth generation district heating (4GDH) networks are an emerging technology characterized by more than their temperature range, most notably by providing a use for low-grade heat sources and thereby minimizing environmental impact [22]. Not depicted in Figure 3.1 is the experimental fifth generation, based on ultra low temperatures, distributed thermal storage, low grade renewables, and heat exchange between buildings [23]. This section outlines 4GDH and its components and properties.

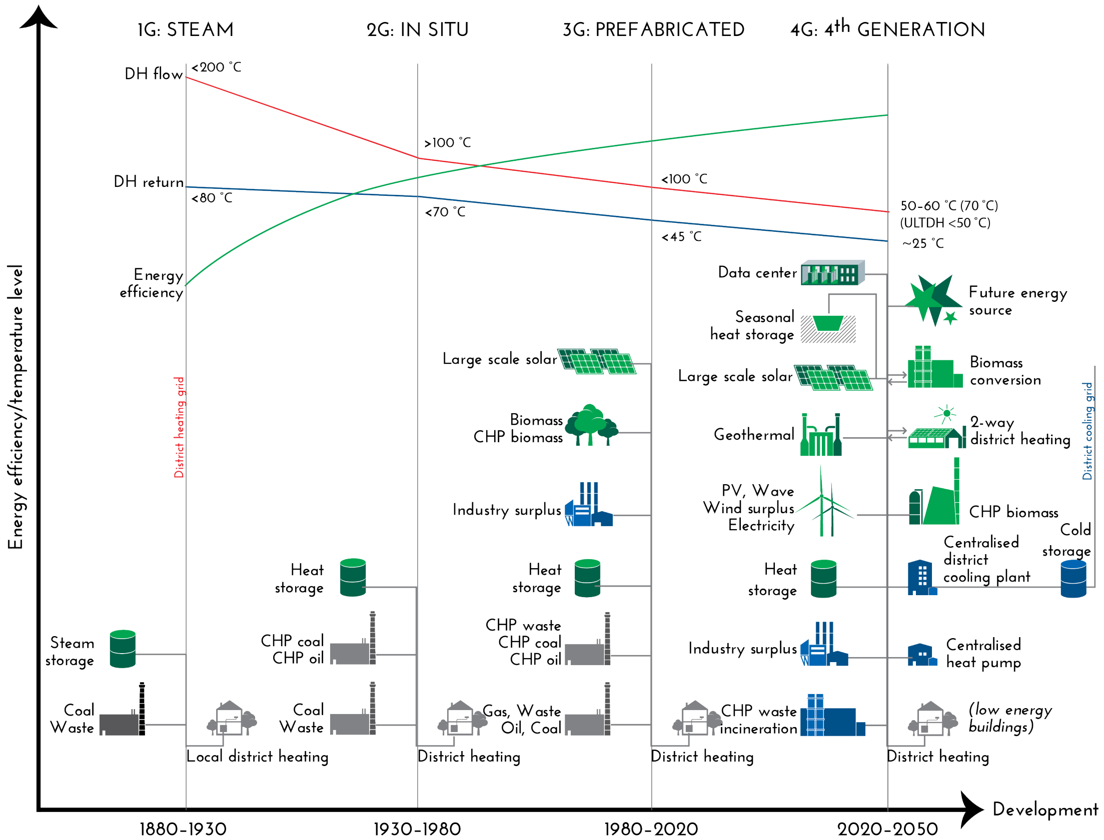

Figure 3.1 An illustration depicting the progression of district heating from the first to the fourth generation. The majority of networks in operation are of the third generation, with the fourth generation as an emerging technology. An integration with a district cooling network is depicted to the far right. The vertical axis relates to the graph in the top half, indicating that energy efficiency increases with decreasing temperatures. Illustration adapted from J. Thorsen, H. Lund, and B. Mathiesen [20].

Characteristics

There are several components to the concept of 4GDH. Firstly, the temperatures are significantly lower than in third generation networks, with supply temperatures below 70 °C [14, p.20]. Secondly, they utilize smart thermal grids in terms of both redistributing and storing produced heat [24]. Thirdly, renewable energy supplies are central to 4GDH, as well as increasing the use of residual heat [14, p.23].

A key characteristic of low temperature systems is that low supply temperatures result in lower transmission losses. A high linear density in the network is however essential. Linear heat density is described by Equation 3.1 where Q_s is the annual heat or cold delivered in MWh, and L is the total trench length (including service pipes) in meters [14, p.134].

$$\text{Linear heat density} = \frac{Q_s}{L} \tag{3.1}$$

The significance of Equation 3.1 is that in densely constructed areas such as city centers, transmission losses will be lower than in sparser areas, to the extent that having a high linear density is the most decisive factor in reducing transmission losses [14, p.135]. This characteristic supports the importance of constructing smaller grids that make use of locally available residual heat sources.

Further benefits apart from increased energy efficiency arise from lowering supply temperatures. One benefit is less cycle fatigue in steel pipes and less build-up of lime, which increases the serviceable lifetime of the pipes [14, p.43]. In newly constructed grids, the steel pipes may be complemented by new types of plastic pipes because the temperatures that they have to withstand are considerably lower (see Section 3.2). Another benefit is a significantly lower risk of scalding during maintenance, which can otherwise cause serious harm to maintenance personnel [14, p.48]. Lowering temperatures in CHP plants also results in more electricity generated: lower pressures in the turbine condensers yield higher power-to-heat ratios [14, p.38].

Smart thermal grids is another component of 4GDH networks. They can be seen as analogous to smart electricity grids, with methods for monitoring and metering in order to more efficiently regulate the heat supply and match it to the demand. There is also a capacity for feed-in from so called prosumers (consumers who also produce energy in their buildings), beyond the connection of larger centralized and smaller distributed energy plants [25]. Moreover, smart thermal grids are equipped to manage the intermittent nature of many RES; one possibility is to utilize thermal storage, both on a seasonal and more short-term basis [14, p.39].

The inclusion of RES is essential to 4GDH, as well as sources of residual heat. A decarbonization of energy systems in general and district heating networks in particular involve reducing the available primary energy sources in CHP generation to biomass and waste [14, p.21]. This necessitates harnessing geothermal and solar collector energy as well as integrating them into the aforementioned smart thermal grids [14, p.25]. For maximum heat recovery in CHP plants, flue gas condensation is significant: when energy sources with a high water content are combusted, heat can be condensed from the resultant gas provided that the water returning from the district heating network has a low enough temperature [14, p.36]. Therefore, CHP plant operators are concerned with keeping return temperatures as low as possible. Low return temperatures are also an indicator of efficient customer installations.

Domestic hot water and Legionella safety

Legionella is a genus of bacteria that thrives in water at temperatures around 25–45 °C, and is therefore a concern when dimensioning DHW systems. The species *Legionella pneumophila* is the primary cause of the lung infections Legionnaires' disease and the milder Pontiac fever. The diseases are caused by inhaling the bacteria as they are suspended in aerosols, not by drinking contaminated water. Legionnaires' disease has a fatality rate between 5–20 %; because the symptoms are similar to those of pneumonia, misdiagnosis is likely but potentially fatal since the range of antibiotics effective against Legionnaires' disease is smaller than for pneumonia. There are subsequently a number of methods used in different countries to minimize the risk of *Legionella* growth in DHW systems. One method is to legislate minimum temperatures: *Legionella* bacteria are inactivated around 46 °C, meaning they will not multiply, and die immediately at 70 °C. Another method is to impose water volume restrictions, because *Legionella* bacteria thrive in stagnant water with a high oxygen content. [26]

In Sweden, temperature levels are regulated by the National Board of Housing, Building and Planning (*Folkhälsomyndigheten*), and specified in BBR (*Boverkets byggregler*, mandatory provisions and general recommendations). Chapter 6, entitled 'Hygiene, health and environment', maintains that circulating DHW needs to have a temperature of at least 50 °C at the tap, and stationary water in boilers or accumulators needs to be heated to at least 60 °C in order to limit microbial growth [27, p, 102]. Hot water circulation is however the main cause of high return temperatures in the primary system, so other DHW solutions, such as apartment substations or volume restrictions, would be beneficial from a system perspective [21].

The Swedish Energy Research Centre (*Energiforsk*) made an analysis of a simulation of using 4GDH components in a newly built housing area [22]. The results of the simulation suggest that the use of apartment substations would eliminate the need for hot water circulation, and thereby be able to circumvent the 50 °Crequirement with no risk of *Legionella*. Installing apartment substations does however result in significantly higher costs for the property owner. Another exposure-minimizing method is in effect in Germany, and is called the 3-liter rule. For DHW systems with less than three liters of volume in the pipes between the heater and the farthest tap, the water does not need to be heated additionally. Otherwise the lower limit is 50 °C, as in Sweden [26]. There is however research to support that smaller water volumes do not eliminate the risk of *Legionella* to a great enough extent to be able to relax regulation regarding temperature levels [21].

More *Legionella* mitigation methods exist for use under the assumption that the incoming water has not been heated to a point where bacterial growth has definitely been stopped. These methods are in various stages between commercial viability and experimental design, and are either of a physical or a chemical nature, or involve changing the design of the secondary heating system [26]. The physical treatments involve different kinds of filters, whereas the chemical treatments aim to sterilize either through added chemicals, UV exposure or oxidation. Changes in the secondary system include the previously mentioned apartment substations, auxiliary heating devices, and changes in the pipe design to make the pipes less hospitable for *Legionella* biofilms.

3.2 Conditions at Brunnshög

The following section describes the conditions specific to Brunnshög and its LTDH network. This includes the characteristics of the LTDH network and its heat supply, and examples of research demonstrations performed there. It also includes the implementation of new pipe technology, and the price model aimed towards LTDH network customers.

LTDH network

The heat supply in the Brunnshög LTDH network comes from the research facility MAX IV, where large amounts of surplus heat are generated as a result of cooling a synchrotron light generation apparatus. The heat supply is more or less unlimited as research is conducted all year round. The network supply temperature is moderately high at 65 °C; this is a conscious decision by the network owner Kraftringen to make it easier for customers to choose to connect as there is no need for property developers to make special provisions for the heating system of their buildings compared to conventional district heating [28].

The municipal housing company LKF have nevertheless made significant alterations to their apartment building Xplorion to make it compatible with low supply temperatures. Xplorion was completed in 2020 and is a major demonstration site at Brunnshög in the COOL DH project. While technically not even connected to the

Brunnshög LTDH network as the building lies outside the reach of the grid, various temperature levels have been simulated in the building through a heat exchanger (HEX), including ultra low levels around 40 °C. The building also demonstrates other innovations such as apartment substations and a three-pipe system to avoid hot water circulation [29].

New LTDH pipe material

Even though the temperatures in the LTDH network in Brunnshög are moderately high in order not to interfere with the property developers designs, the decrease from traditional third generation supply temperatures has been influential. The lower temperatures have facilitated improvements both in terms of materials used and their environmental impact as well as processes and handling. An example is the choice of pipe material.

A new type of plastic pipe has been developed for use in the Brunnshög LTDH network, since the lower temperatures make other materials than steel feasible. These new PE-RT (poly ethylene raised temperature) pipes allow leakage detection while being less material intensive than steel pipes [30]. Since the PE-RT pipes are flexible, this allows for them to be stored on reels and installed into the ground faster than welding shorter lengths of steel pipes together, thereby shortening the amount of time that pipe trenches need to be kept open.

A map of the LTDH network is shown in Figure 3.2, and depicts the installed steel pipes in green, the installed PE-RT pipes in yellow, and the planned pipes in purple. The main paths from MAX IV to the different parts of Brunnshög consist of steel pipes, whereas the individual buildings are serviced by plastic pipes.

The LTDH price model

Kraftringen's price model for companies (as opposed to households) to connect buildings to the LTDH network differs from that of the standard district heating network, not counting the connection fee. The LTDH price model has two components: a baseline fee per MWh used, and a return temperature fee per MWh and degree over the minimum acceptable temperature, in two levels [31]. The 2022 prices are detailed in Table 3.1. The return temperature fee serves as an encouragement for the building owners to keep the secondary system (the internal heating system in the building, including the HEX from the primary system) in working order. It is in the best interest of Kraftringen to receive as low return temperatures as possible, but they do not have control over the customers' secondary systems. This nevertheless means that there are no fixed fees at all in the LTDH price model.

In contrast, Kraftringen's price model for the standard district heating network has three components: an energy fee, a peak load fee, and a flow fee [32]. The energy fee charged per MWh used varies depending on the season, reflecting changes in

Figure 3.2 A map of the district heating network in Brunnshög, with the installed steel pipes in green, the installed PE-RT pipes in yellow, and the planned pipes in purple. The steel pipes provide the main path from the supply at MAX IV, while the plastic pipes service the individual buildings.

Table 3.1 The 2022 price levels for Kraftringen's LTDH network, with a baseline fee and a return temperature fee in two levels. [31]

Baseline fee	Return temperature fee 20–35 °C	Return temperature fee 35–55 °C
475 SEK/MWh	5 SEK/MWh and °C	15 SEK/MWh and °C

the cost of producing heat at different levels of demand. The peak load fee is based on the load level in kW that the customer uses during the coldest months of the year, and compensates for the costs caused by peaks in usage. The flow fee is similar to the return temperature fee in the LTDH price model in that it aims to incentivize upkeep of the HEX, and is charged by the volume of water that passes through the HEX. The three components of the standard price model thereby generate both fixed and variable costs, compared to the LTDH price model that is strictly variable. From a customer perspective, variable costs incentivize energy efficiency measures to a greater extent than fixed costs do.

3.3 Consumer heating solution preferences

There is a multitude of factors surrounding consumers' choices of heating solutions. In Sweden, the choice varies considerably depending on what kind of building is to be heated. The main alternatives to district heating are currently air to water heat pumps, air to air heat pumps, ground source heat pumps (also called geothermal heat pumps) and biofuel-fired heating systems. District heating covers 90 % of the heat demand in apartment buildings and 77 % in commercial facilities, but only 18 % in single family dwellings [33]. European research concerning consumer satisfaction has identified seven factors in relation to experiences of being connected to district heating [34]. This section outlines the seven factors as they relate to Swedish conditions: price, pricing transparency, comfort, sustainability, flexibility, consumer protection, and service products.

The price is a very important factor, including consumer influence over the development of prices over time. In the research study reflecting European conditions, consumers reported that they experienced that the district heating alternative was not profitable for them. Rather, there was a sense of mistrust toward the district heating companies because they were believed by the consumers to overcharge to increase their own profits [34]. In a Swedish report on what motivates heating solution choices among consumers [35], mistrusting companies is cited as a common reason to select a different heating solution than district heating. The high cost of connecting is also a deterrent for middle income single family dwellings, but may be remedied by a payment plan over several years.

The price factor is also related to the transparency on the pricing, and the perceived unfairness of not having a detailed bill with a breakdown of prices that allows for comparisons [34]. In an attempt to resolve this problem, Sweden passed the District Heating Act in 2008 (*fjärrvärmelagen*), the first of its kind in the world. The aim of the act is primarily to strengthen consumers' trust in district heating companies by making district heating pricing mechanisms clearer and more available, and by providing extended protection of consumers' rights [36]. The act however appears not to have achieved the intended aim. While consumers have been provided more information on district heating prices and pricing mechanisms because of the act, a report by the district heating research program Fjärrsyn, a part of the Swedish Energy Research Centre, maintains that the District Heating Act does not increase trust [37]. The reason is that the act attempts to establish personal trust and system trust at the same time, which is not possible; the personal trust can not be forced by legislation, whereas system trust benefits from making stricter requirements of district heating companies. The further recommendation from the report is that the district heating companies need to assume greater responsibility for building personal trust vis-à-vis customers. In 2013 a process called Prisdialogen (The Price Dialogue) was established jointly by the organizations Svensk Fjärrvärme (now Energiföretagen Sverige), Riksbyggen and SABO (now Sveriges Allmännytta) [38]. It is voluntary for district heating companies to join the initiative, and the purpose is to promote local discussions and central review of district heating pricing. By 2019, 75 % of the district heating market in Sweden were members of Prisdialogen, and more than one third of the customers that had participated in the process at some point experienced that they had been able to affect the pricing mechanisms used by their district heating supplier [33]. Participation also contributed to greater overall customer satisfaction in the district heating supplier's services.

While prices and the their transparency are factors with a considerable impact on the attitude to district heating, the perceived comfort of district heating is high; the systems need little maintenance and are reliable [34]. Responsibility for problems in supply is assumed by the district heating company, which contributes to making district heating energy invisible to the consumer [39, p.19]. Complaints regarding comfort tend to arise when consumers can not control the indoor temperature [34], and when the DHW supply is insufficient [35]. The drawback to the high level of comfort is that consumers do not necessarily need to invest themselves in learning how it works, or how to interact appropriately with the system components. A consequence may be usage with unwanted consequences such as high return temperatures [35].

District heating is a sustainable choice in terms of efficiency, especially in densely populated areas, as long as the heat production itself is sustainable. However, sustainability is a complicated factor to consider: in a study conducted in Sweden in 2012, different kinds of customers regarded sustainability very differently [40].

Property owners held sustainability as very important for commercial reasons, because it affected how their business was perceived. On the other hand, the *bostadsrättsförening* (a housing cooperative owned by the inhabitants) representatives thought that it was unfair that they as small actors should have to take as much responsibility for making sustainable choices as the larger organizations. These are however attitudes that change over time and across geographical regions, in addition to across customer segments. In the European research [34], which was aggregated in 2016, the results indicate that consumers generally do not value the sustainability factor as highly as they do low costs, reliability, comfort, safety and an uncomplicated installation process. Another Swedish study from 2020 maintains that consumer priorities have shifted from simplicity, security and sustainability to flexibility and the possibility to make demands on district heating companies [41]. Moreover, in countries where district heating is the byproduct of industrial processes, the primary energy source is not sustainable, making the arguments for district heating as an environmentally friendly alternative difficult to support [34]. Since the residual heat would otherwise not have been used at all, there is an interest in methods for valorizing waste heat. The invisibility property of energy is relevant in this context as well, because unsustainably produced heat will be just as warm as a sustainably produced equivalent. This means that district heating companies need to make a greater effort to communicate any sustainability measures that they implement [39, p.19].

The flexibility factor concerns the choices the consumers have after choosing a heating solution. District heating connections have the distinct disadvantage for the consumer of having no alternative suppliers on the same network, unless it is a 4GDH network where the consumer could potentially become a prosumer, which is an advantage. This means that there are few incentives for district heating companies to improve their offer or provide transparency [34]. The Swedish initiative Prisdialogen stands out in its effort to create a forum for discussion and mutual benefit. There is a proposal from BEUC (The European Consumer Organisation) [42] to reduce the vulnerability on an EU level that consumers may face because of the natural monopoly that district heating companies have in a given area. Swedish consumers are deterred from connecting to district heating because they risk being subjected to price increases over which they have no control [40]. District heating companies on the other hand are not completely without competition despite their natural monopoly as the heat pump market is considerable in Sweden, so they would not be able to impose price increases wantonly. A district heating connection is however a large economic commitment, so consumers worry about locking themselves in and subsequently having less control, both of their own finances and their opportunities to make different choices in the future [35].

Similarly, not every EU member state has a central consumer protection service for district heating customers; when consumers have issues they do not have the option of changing suppliers, and the only point of assistance when there is no external service is the district heating provider itself. Sweden does however have the Swedish District Heating Board (*Fjärrvärmenämnden*) which is appointed by the government and a part of the Swedish Energy Agency (*Energimyndigheten*) [43]. The board is the last instance in the case of complaints, after contacting the district heating company directly [44]. Although this additional level of consumer protection aims to increase the level of trust in district heating in Sweden, as previously mentioned, this effect has largely gone unobserved among individuals [37]. A contributory factor may be that individual consumers are not able to affect district heating prices as they are set collectively, and the board does not have the authority to recommend price levels. The district heating companies carry considerable responsibility for dispelling false beliefs concerning the properties of heating systems and making their own case for the viability of their offer, thereby building trust in consumers [35]. Clear communication is essential to achieve this.

The last factor relates to what additional services are available when choosing a particular heating solution. District heating companies typically offer maintenance services, but research suggests that a diversification of the service offering could build more consumer trust and increase the competitive advantage of district heating [34]. The kinds of services range from closer energy usage monitoring, aimed at increasing transparency, to a full installation of a building heating system that would lower technical thresholds and make district heating more accessible to more consumers. An opportune offer and good customer service and handling are critical to ensure that consumers choose district heating [35].

3.4 Low temperature space heating technologies

Several space heating technologies are compatible with LTDH systems because indoor heat demands rarely exceed approximately 20 °C. The most common alternatives are radiators, floor heating, and forced-air heating [45], but ceiling heating and wall heating occur as well [46]. Combinations of the different technologies can be made depending on the properties of the building. The following section provides an overview of the space heating solutions and their benefits and disadvantages in a low temperature system.

Radiator technology is mature, and provides thermal comfort indoors by acting as a HEX between the water in the radiators and the air in the room, as well as preventing cold downdrafts by windows [45, 47]. When used in combination with low supply temperatures, the physical size of the radiator will often need to be increased to ensure a large enough surface area to provide enough heat for the room. However, this tends to be offset by the lower heat demand in new buildings. Radiators are also easy to operate and may be controlled individually, and give fast heat responses [47]. Despite being a well developed technology with adaptations made for more efficient use with low supply temperatures, radiators will perform poorly when the supply temperature is lower than 45 °C [47, 48]. Lowering the supply temperature to radiators by 12–15 °C to 45 °C will nonetheless generate energy savings of 17–22 % [48].

Floor heating systems are beneficial for use with 4GDH because they have large surface areas and result in low return temperatures. They can also make use of lower supply temperatures than radiators and require no extra space in the room, but do not prevent cold downdrafts and have relatively slow reactivity [47]. Since laying down a floor heating system is a large undertaking, it is often too expensive to retrofit existing buildings with it compared to installing it in new buildings. Nevertheless, if a bathroom is renovated, a floor heating system could be installed there while retaining radiators in the rest of the building [45]. It is essential for floor heating installations to be well adjusted, as they may otherwise use far more energy than intended [46].

Forced-air heating, or forced convection, can be used as a standalone solution or in combination with radiators or floor heating. Incoming air is heated before it is distributed throughout the building through ventilation ducts, resulting in surfaces being heated by the warm air [46], and with the possibility of rapid central temperature regulation [45]. There are however drawbacks: because the heating is central, the temperature is difficult to regulate from room to room [46]. The circulating fans also need to be monitored so that they do not use too much electricity, as the system would otherwise be less energy efficient than one with water as the heating medium [46].

Ceiling heating works mainly through radiation, and contributes to warmer surface areas in rooms [49]. Ceiling heating has the added advantage of working as a cooling system as well when used in combination with floor heating. Furthermore, when the supply temperature is kept within a narrow interval, the system is self-regulating [46]. Heating coils are imbedded in the concrete joists in the ceiling, and the high thermal inertia of the concrete shell of the ceiling is utilized. The self-regulation occurs in both directions: when the room temperature is lower than that of the joists, the joists will emit heat, and when the room temperature is higher than that of the joists, the concrete shell will act as a coolant. In multi-storey buildings ceiling- and floor heating may also be used in combination so that the floor heating of a higher storey provides ceiling heating for the lower storey. For those installations, the heating coil lies in an uninsulated concrete layer between the storeys. Because the supply temperature only needs to be around 26 °C, it is suitable for use with LTDH [47]. Installations may also be made externally, with panels mounted on the ceiling. The cold downdraft by a window may be eliminated with a panel mounted in close proximity to the window; the radiated heat will be absorbed by the coldest, closest surface [49]. Since ceiling heating is difficult to control, the most common application of ceiling heating is in large spaces such as sports halls, shopping centers and warehouses where comfort demands are not as high [46]. Other drawbacks include the damage risk when making holes in the ceiling for mounting purposes, and the difficulty of repair if some part of the internal installation malfunctions [47].

Wall heating installations are virtually non-existent in Sweden, and consist of wall plates with embedded coils or modules of coils plastered to the walls [46]. The construction is similar to that of floor heating, barring its placement, and likewise makes efficient use of low temperature water [50]. Wall heating provides the best indoor comfort when used on outer walls, but because wall heating increases heat losses through walls additional insulation may be necessary, as well as mounting wall heating on some inner walls and under windows to prevent cold downdrafts [46]. Wall heating installations make wall mounting of paintings or furniture difficult but not impossible, but the perceived risk of having water inside the walls has likely contributed to its unpopularity as a space heating technology along with the considerable initial cost of installation [50].

4

Method

The research method for the thesis has been qualitative, with in-depth semi-structured individual interviews. According to Danish Professor of Psychology Svend Brinkmann, semi-structured interviews allow the respondent to become “visible as a knowledge-producing participant in the process itself” [51], which is valuable when the respondents are the only ones who possess their particular knowledge. As the selection of interview candidates was limited, the chosen method provided opportunities to delve deeper into their responses and ask follow-up questions. This made it possible to better capture their thoughts and experiences. The initial sample size was therefore identical with the selection.

Ten of the seventeen candidates agreed to be interviewed. Of the seven who did not agree, one actively declined stating that they could not participate, one replied that they had not come far enough in the planning process to be able to answer my questions, and five did not respond to the request at all. Six of the ten interviews were conducted in person, one was an online meeting, and three were done by email correspondence.

The goal was to interview employees responsible for energy planning within each company, or third party consultants where applicable, because they were familiar with the process of choosing a heating system for their building; this has occasionally proven difficult when key persons have been replaced because the construction of buildings has been under way for several years. An eleventh interview was conducted in person with the project manager for the Brunnshög project, which is the division of Lund municipality which oversees the development of the Brunnshög area. This provided background information about the land allocation process and the municipality’s vision and aims for Brunnshög, as well as contact information to the winners of the land allocation competitions. The in-person interviews were recorded and transcribed, and all of the responses have been thematically analyzed using an inductive approach.

The inductive approach takes collected data and infers larger contexts; in qualitative research, it can be said to move from the specific to the general [52]. Since the aim of this thesis was to increase the replicability of the COOL DH demonstrations, identifying common themes in the attitudes of property owners would accomplish that aim to some extent.

4.1 Respondents

Table 4.1 provides an overview of the respondents in the interviews, including their positions, employers, which buildings they are constructing, what type of building it is, and which phase the buildings are in. It also includes the eleventh interviewee from Lund municipality, who consequently does not have an associated building.

Two of the respondents were third party consultants. In those cases, the company entry in Table 4.1 lists their primary employers first, and the property owner second – KTC is a control systems contractor, and GBJ Bygg is a construction contractor.

Table 4.1 A summary of the interviewees in the study.

Company	Name	Position	Building	Building type	Construction phase
GBJ Bygg/Wästbygg	Johan Törnblom	Project developer	Lagerkransen	Rental apartments	Finished
Granitor	Linn Runquist	Project manager	BRF Life	BRF apartments	Started
LKF	Henrik Adamsson	Energy manager	Skymningen	Rental apartments, offices	Finished
			Xplorion	Rental apartments	Finished
Lund municipality	Eva Dalman	Project manager	–	–	–
KTC/Tornet	Martin Sjögren	Control system planner	Gryningen	Rental apartments	Under planning
Region Skåne	David Nilsson	Energy manager	Tram depot	Tram depot	Finished
Slättö	Johan Roth	Project manager	BRF Futura	BRF apartments	Finished
Solbjer Bostads AB	Karin Adalberth	Developer	Kv. Solbjer	Single family dwellings	Finished
SVS AB	Susanna Ideberg	Property developer	Möllegården	Conference center	Finished
			Science Center	Offices	Under planning
Wihlborgs	Helena Pålsson	Project manager	SPACE	Offices, labs, restaurant	Started
Wihlborgs	Rickard Berlin	Project manager	CMU	Service building	Finished
			MAX IV	Research facility	Finished

5

Results and analysis

This chapter examines the results of the interview study and provides an analysis of the responses. The analysis reflects back on the research questions posed in Section 1.1, supporting the objectives of this thesis. The limitations of the study based on the rate of responses and the choice of method are also examined.

Of the ten connected buildings in this study, six use the district heating for both hot water supply and space heating; one building uses air to water heat pumps for hot water preparation in some parts and district heating for hot water preparation in other parts as well as for space heating everywhere; one building uses ground source heat pumps as the primary heat source with district heating for peak loads; one building has air to water heat pumps with district heating for peak loads. The tenth, unconnected building uses a combination of ground source heat pumps and a connection to a different network which distributes excess heat between buildings. These details are summarized in Table 5.1. Xplorion is included in the summary and analysis because even though it lies geographically beyond the reaches of the LTDH network, it has simulated the same conditions and has been an important demonstration site during the development of the Brunnshög area.

The research questions concerned the following five areas: what factors affect willingness to connect to the LTDH network; how the property owners' attitudes to LTDH relates to their environmental policies; what limitations the respondents have encountered with the LTDH network, for example regarding *Legionella* considerations, dimensioning the building heating system, or the process of connecting their building; how the LTDH price model has affected willingness to connect to the LTDH network; and how the communication process with Kraftringen has affected the property owners' building processes.

Table 5.1 A summary of the heating solutions used in the buildings examined in the interview study.

Building	LTDH connection	Other connection	LTDH use
Lagerkransen	No	Ground source heat pump & excess heat network	No
BRF Life	Yes	No	DHW & space heating
Xplorion	No	Standard DH	Experimental
Skymningen	Yes	No	DHW & space heating
Gryningen	Yes	Ground source heat pump	Peak loads
Tram depot	Yes	No	DHW & space heating
BRF Futura	Yes	No	DHW & space heating
Kv. Solbjer	Yes	No	DHW & space heating
Möllegården	Yes	No	DHW & space heating
Science Center	Yes	No	DHW & space heating
SPACE	Yes	Air to water heat pump	Space heating & DHW in some parts
CMU & MAX IV	Yes	Air to water heat pump	Peak loads

5.1 What factors affect willingness to connect to LTDH?

The interview study suggests that there are three principal factors that determine whether or not the property owners connect to the LTDH network. The factors are previous experiences of district heating, environmental concerns, and an ambition towards innovation. The following section expands on the three factors separately.

Previous experience of district heating

All of the respondents who had connected to the network reported having previous experiences of district heating in some capacity; among the largest companies it was common that they connected all their new buildings to district heating and cooling networks where those were available [53, 54, 55, 56]. The approach to learning more about LTDH differed between companies, however: the largest had entire divisions devoted to sustainability research, the middle-sized companies enlisted consultants, and the smallest did their own research online. In a long term perspective, particularly when the buildings are subsequently sold as a BRF, knowledge of how the building is constructed is dispersed.

The companies that have chosen to connect to the LTDH network in Brunnshög relate that the experience has been positive, regardless of what construction stage they are currently in. Overall, the interviewees view the communication with Kraftringen as efficient and helpful, and as an expedient to their choice to connect. However, many companies trust their own expertise, at the same time as they engage third parties for the different parts of construction; this results in many solutions not being as efficient as they could potentially be, since there is a tendency towards using tried and tested methods and components. This creates a discrepancy between the new conditions of the LTDH network and the capacity of the buildings to draw advantage of those conditions.

Having previous experience appears to be closely related to the environmental perspective, as all respondents described that they had environmental policies in place within their organizations, where several of them relate directly to the use of district heating in their buildings.

Environmental concerns

The factor environmental concerns is used as an argument both in favor of connecting and in favor of other solutions. As several respondents said, the residual heat from MAX IV will be available regardless of whether or not it is used, so harnessing it in a district heating network contributes to environmental sustainability, as well as being a reliable, local source which is less sensitive to fluctuating prices. However, the interviewed property owner who did not connect claims that they would not have been able to certify their building according to Miljöbyggnad Guld, a Swedish environmental certification system for buildings, if they had connected their building to the LTDH network [57]. Given that other property owners are certifying their buildings to the same standard even while being connected to the LTDH network, the reason rather appears to lie in the fact that they received better economic terms on their electricity supply from another supplier.

On the other hand, one of the companies whose primary heat supply came from a ground source heat pump related that since they intended to apply for investment support for low energy buildings from the Swedish government, they would not have been able to reach the energy requirements stipulated to obtain the support solely by district heating [58]. The support program has been repealed by the government for budget reasons, but the building is already planned and will be constructed as such. These kinds of conflicting incentives do not contribute positively to making informed sustainable choices.

As a further complication, the municipality has also had different focus areas during the land allocation competitions, the latest of which is carbon neutral construction [17]. This condition is weighed into whether or not the land allocation is granted, but as of yet there is no formal definition of what carbon neutral construction entails from Boverket, the Swedish National Board of Housing, Building and Planning. Visionary work like this further exacerbates the problem of providing property developers with clear guidelines while at the same time stimulating environmentally friendly solutions.

In the majority of Brunnshög, connection to the LTDH network is optional, but heavily recommended by the municipality [17]. The price model from the energy supplier Kraftringen is deliberately favorable. However, the area called Science Village in the north of Brunnshög is not owned and allocated by the municipality but by a separate company that demands that the developers that they sell the land to connect to the LTDH network. The developers there accept this condition from an environmental standpoint, as well as from the perspective that being located in Science Village means being at the forefront of technological development and innovation [54, 19, 55]. They subsequently recognize the LTDH network as an embodiment of these values.

Ambition towards innovation

From the onset, the Brunnshög area has been conceptualized as an innovative area, both in terms of the kinds of activities that it will contain (research facilities, both academic and commercial) and in terms of the demands that the municipality makes on prospective property buyers [17]. Science Village has similar requirements; property owners sign a sustainability agreement, and must incorporate a visible sustainability innovation into their building [19]. This general focus on innovation attracts developers with a sympathetic position. Connecting to the LTDH network has become a part of the same kind of sustainable solutions as the municipality and Science Village encourage, largely since the existence of the LTDH network is dependent on the research facility MAX IV and therefore closely associated with progress and innovation.

Out of the ten respondents in this study, four expressly stated that innovation was their main motivation to construct their building at Brunnshög [54, 19, 55, 59]. It is significant that all of those buildings are located in Science Village, which has a very prominent innovation profile. The respondent from LKF said that they have prepared their building for even lower supply temperatures [53], indicating an expectation of changing conditions – with more customers connecting once more buildings have been erected, they see a need to ensure a stable heat supply. These companies draw an implicit parallel between being innovative and connecting to the LTDH network, at the same time as consolidating these factors with their environmental policies.

5.2 How is connecting to LTDH related to environmental policies?

While all of the respondents cited environmental policies in place in their organizations, there needs to be a distinction between answers from respondents who are representatives of the property owners and the respondents who are third party consultants. It can not be inferred beyond reasonable doubt that the consultants have been engaged by the property owners because their environmental policies intersect. The larger organizations have sustainability divisions that develop policies [53, 54, 55, 59], but even so the knowledge discrepancies among the respondents of the contents of the policies were considerable. However, Lund municipality make strict requirements as well as wishes regarding sustainability in the land allocation process [17]. Therefore, the companies' environmental policies in combination with the high rate of connection to the LTDH network among the respondents indicate that the attitude to connecting is supported by the environmental policies, especially where these policies explicitly relate to district heating use.

The property owner that chose not to connect to the LTDH network likewise has an environmental policy. The respondent on their behalf was a third party consultant that referred back to the property owner when asked questions about the environmental policy [57]. In Section 5.1 I proposed that economic incentives were a stronger motivator in this case than sustainability concerns. In the course of several interviews, the respondents reported that the buildings had to pay themselves off for the project to even be considered [53, 56, 59, 58, 57]. This is especially important when the property owners build BRF buildings where they have to make sure that the apartments are attractive enough to be able to be sold to the inhabitants. The one exception in this interview study is the tram depot which is owned by Region Skåne, which is motivated by public benefit [60].

5.3 What are the limitations of the LTDH network?

The Brunnshög area is still under construction, and there are subsequently several problems that have to be solved at the same time. It is therefore difficult to isolate limitations, and ascribe them to either the LTDH network or other factors. In the study, overall limited infrastructure was cited as causing delays in the building process [55], particularly when there were several projects under way at the same time, which led to one building not being connected on time [56]. Also, the limited amount of space under the streets, where all sorts of piping needs to be placed, may lead to slight widening of roads and diminishing of building plots in Science Village [19]. These problems will however decrease in severity as Brunnshög develops. Nevertheless, the respondents reported problems that could be directly related to the LTDH network.

In two instances among the respondents, the supply temperature into the buildings was too low, under 60 °C [61, 60]. In the tram depot this led to concerns that there would be *Legionella* growth, and it took time to resolve the problem with Kraftringen [60]. The other affected building is a series of townhouses where every house is owned by its inhabitants, and where every house has its own heat exchanger [61]. This means that there is no central substation where *Legionella* growth is a concern, but the low supply temperature affected comfort levels. Kraftringen have since solved the problem. In both of these instances, the buildings were located in the far reaches of the LTDH network, which may have contributed to the problems.

According to Kraftringen, the LTDH supply temperatures are high enough that the property owners should not have to make significant changes to how they would usually design their buildings' heating systems. Radiators are the most common choice for space heating [61, 53, 54, 55, 56, 59, 58], but in some of the buildings they are supplemented with floor heating [54, 59] or forced-air heating [58]. Only Möllegården in Science Village uses floor heating exclusively, as the installation was already there when the building was converted and connected to the LTDH network [19]. Generally, floor heating is considered a too extensive installation which makes it difficult to repurpose spaces and move walls [55], or too slow for control purposes [61]. The apartment building BRF Life, which combines floor heating and radiators, has the floor heating on the top floor and in the basement only. The reasoning was fourfold: the return heat passes through the basement first, and they wanted to make use of the residual heat; the basement was awkwardly planned which made placing radiators difficult; floor heating in the basement helped prevent excessive moisture; and the top floor has terraces, so there was already an extra insulating layer between that floor and the one underneath [55]. Ceiling heating without a separate installation was deemed undesirable because it would have been difficult to control and distribute, which is why there is no floor heating in the floors between the top floor and the basement. To have floor heating everywhere there would have had to have been extra insulation between all floors, which would have increased material use and made every floor higher. Radiators are otherwise the standard solution for that developer [55], which is recurring among all respondents. The alterations that they have to make to accommodate for a moderately low supply temperature include larger radiators [54, 56], larger hot water storage tanks [58], and a different HEX than normal [61]. Xplorion is the only building that uses low temperature technologies such as apartment substations because it creates the low temperature conditions itself experimentally. As previously mentioned, LKF have prepared for lower temperatures, but are the only property owner to have done so. To some extent, a limitation of the LTDH network at Brunnshög is that its relatively high supply temperature does not fully encourage the adoption of low temperature technologies insofar as they are feasible. This stands in contrast to the innovative identity that the area wants to communicate.

5.4 How has the LTDH price model affected willingness to connect?

The knowledge levels of the LTDH price model varied among the respondents. While the majority felt that the model was easy to understand, it did not appear to have affected the property owners' attitudes to connecting to the LTDH network. The LTDH price is also lower than the standard district heating price. In one case, a respondent replied that they accept the monopoly that Kraftringen have because an LTDH connection is the most sustainable option [61], an example of prioritizing environmental values. For the buildings at Science Village that have no choice but to connect to the LTDH network, the values of being connected also outweighed the particulars of the price model [55]. Furthermore, the largest organizations had framework agreements with Kraftringen for all of their district heating needs, which are likewise large, which means their price model may differ [54]. One respondent expressed that the price model does not really incentivize saving energy and money, and requested a more dynamic model that would reward low loads and the possibility to use the building as a thermal battery [53]. This is what the peak load fee of Kraftringen's standard district heating price model aims to accomplish. Instead, when the installation in the building connected to the LTDH network is running efficiently and the return temperature is as low as possible, there are no further economic incentives.

A different perspective on the attitude to the price model is that even in Science Village there are buildings that use LTDH for peak loads, and heat pumps for their primary heating needs. In the case of MAX IV and CMU the motivation was that the heat pumps are solar powered and can produce both heat and cold, and would save more energy overall [54]. Moreover, the heat supply is critical for the facility and the behavior of LTDH was deemed unreliable in case of a blackout, compared to the facility's reserve power. One respondent suggested that the LTDH price model punishes heat pump solutions that use LTDH for peak loads [58], and there are more examples of district heating companies actively amending their price models to deter from those kinds of combinations [62].

5.5 What is the attitude to Kraftringen?

In light of the theoretical review of consumer attitudes to district heating companies, Kraftringen have a very good reputation among the respondents in this study. They were cited as responsive and accommodating by a respondent whose project had issues with low supply temperatures [61], with one interviewee remarking that they usually are [55]. It is clear that Kraftringen have fostered customer relations, at least with corporate customers. The respondents' experiences had different character depending on the scope of the building project and the size of the property owner's organization; the project manager for MAX IV had discussed building a district cooling facility with Kraftringen [54], indicating extensive collaboration; the control system planner from KTC said that they were able to discuss pipe routes together, something that is not a matter of course with every district heating company [58]; and the property developer for Science Village reported that they had meetings with Kraftringen on a more comprehensive level to make processes more streamlined [19]. These settlements and mutual benefits are conducive to the high level of trust in Kraftringen, and likely a significant contributor to the willingness to connect to the LTDH network.

5.6 Limitations of the study

The following section expands on the limitations of the study by way of a critique related to the quality and quantity of the interview responses, the theoretical framework and how it intersects with the results, and the chosen research method. The purpose is to establish a context for the replicability of the study and the generalizability of the results.

The rate of responses from property owners who have decided to use another option than the LTDH network is very low. This affects the generalizability of the conclusions that can be drawn from the interview material from the unconnected party. However, out of the seventeen property owners who fit the scope of the study, only two have chosen other heating solutions (not counting the three buildings that have hybrid solutions). This is in itself an indicator of the general attitude to the LTDH network. The LTDH price level makes alternatives less attractive, but it is difficult to draw any general conclusion on attitudes to district heating companies because the sample size is so small and not composed of a large enough variety of consumers. The most notable absence is that of single family dwellings where the inhabitants make an active choice to connect.

In the process of data collection it became evident that in some instances, the collective memory within the different companies was rather short, and in others knowledge disappeared when key persons moved on; many of the projects have taken several years to plan, and it was more common for the interviewees to have joined the projects in all stages between the end of the planning to construction already having been completed than for them to have seen it through from beginning to end. Accordingly, they were sometimes unable to answer matter-of-fact questions, and in other cases unable to argue for the decisions made by others. This problem signifies poor or non-existent documentation within organizations which results in poorer quality data, or no data at all. It also hampers future development and innovation efforts, both for those interested in handling the data and for the organizations themselves.

While examining previous research on consumer heating solution preferences, it was difficult to find up to date information that was well structured and geographically relevant. Several of the studies were five to ten years old and did not reflect current conditions well, and many sources came to contradictory conclusions. Investigations into consumers' wishes and ideals are inherently subjective, and the expressed preferences of the limited samples may not necessarily reflect actual conditions; people may say one thing and do another. Relating this study to previous research was therefore a challenge.

The correspondences were more difficult to process and analyze than the interviews as there was no possibility of immediate clarifications or unscripted follow-up questions, but as the answers were valuable in light of the limited sample size, correspondence was preferable to no response at all. However, all the responses need to be viewed in the context of the conditions at Brunnshög in particular as well as of Sweden and its environmental policies at large.

6

Conclusions

The main conclusion from this thesis is that the responses from the property owners indicate that connecting to the LTDH network is a choice that intersects with their environmental policies. These policies in turn tend to reflect an innovative standpoint that is solidified by a connection to the LTDH network. Nevertheless, there are occasionally conflicting incentives, chiefly economic. Having clear systems in place that allow for energy efficiency and innovative solutions, both on a municipal and a national level, would mitigate these conflicts. The total effect would be a district heating solution that is attractive both from an economic, environmental, and innovative point of view.

In the interest of replicability, it can be difficult to separate limitations of the LTDH network from limitations due to other factors in an urban district that will continue to be under development for another thirty years. Insofar as the problems arose due to the LTDH network however, the respondents felt that they were supported by the district heating company. The attitude to the district heating company Kraftringen as well as to the LTDH price model are generally favorable, and they both contribute significantly to the willingness to connect to the network. Building customer trust as well as communicating the environmental benefits of district heating are instrumental factors when it comes to encouraging connection in a sector exposed to competition.

Economic concerns tend to rise to the top when managing the capital intensive endeavor that is constructing a building. One respondent expressed that an exceptional solution, effectively an innovative one, will not balance a budget under current conditions, especially not if it is to be sold off as a BRF. This means that innovative measures are sidelined by questions of economic viability, even when the measures will result in lower costs over time. An LTDH network that exacerbates this point by keeping supply temperatures at a level where no significant alterations need to be made to a standard building plan does not appear to be in line with the innovative focus that the Brunnshög area wants to project.

6.1 Future ideas

Sweden has favorable conditions with incentives for lowering emissions, making it less risky for developers to use new technologies and methods. An investigation into the viability of new technologies at Brunnshög and the acceptance among property developers to work with them could be the basis for further work, considering Kraftringen already use their LTDH network as a test bed for research.

The Brunnshög area is projected to be under development until 2050, with conditions expected to change throughout that time. Considering some of the buildings in this interview study have not yet been completed, returning to the premises of this study (success factors and limitations of connecting to the LTDH network) could result in new insights after the buildings have been in operation for a while.

The question of thermal energy storage arose during the interviews, especially concerning using an entire building as a thermal battery. Research into how this can be combined with lower supply temperatures would be interesting for the purpose of evening out peak loads on a daily basis as well as a seasonal basis, and for expanding the amount of connections that can be made to the network because of reduced loads.

The project manager for Brunnshög expressed that the heat supply in the LTDH grid was enough to supply all planned buildings there, yet several property owners choose other solutions or hybrids. An investigation into how the municipal land allocation process works could lead to it being augmented to further incentivize connection without breaking the law.

Since Brunnshög is completely new there have not yet been any instances of converting the buildings from one heating solution to another. In the future, some of the buildings that were not constructed to use the LTDH network may choose to do so, in which case it would be an adaptation of an existing building. Furthermore, the buildings in the southernmost part of South Brunnshög cannot connect to the LTDH grid, but have the option of being connected to the standard district heating grid. If the grid were to be extended, collecting data on the attitudes of new customers could be an extension of this thesis.

There are currently a number of environmental certification systems for buildings that property owners can choose to apply for. In some instances, property owners plan their buildings according to the certification demands without applying for the certificate because it is expensive and usually needs to be renewed. Exploring if the different certificates favor certain heating solutions and how could make it clearer for the property owners how the certification affects the planning of their building.

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Appendix

A

Interview questions

Background

What kind of company do you represent?

Has the company constructed the building as well as owns it?

What kinds of buildings has the company built/do they want to build?

What has motivated you to build at Brunnshög?

Do you have a stated environmental policy, and how do you work towards its aims?

Technical solutions

What is your experience of district heating?

How do you go about learning more about how low temperature district heating works?

What is the district heating used for in the building?

What heating solutions are used inside the building, and why have they been chosen?

How much of the heat goes to tap water and space heating, respectively?

How was the heat demand calculated?

What assumptions were made for that calculation (indoor temperature, hot water use, etc.)?

Have you needed to change the design of the heating system because of low temperature district heating compared to otherwise?

What is your attitude to the risk for *Legionella*?

Is there a difference in this attitude compared to when you plan buildings for conventional district heating?

Is the building adjusted to optimize the heat flow in different parts according to existing needs?

Do you use individual metering units?

In that case, what measurements do you take?

What is the main approach to lower the return temperature?

The price model

Has the price model been easy to understand?

What is your attitude to it parallel with the standard price model?

Lessons learned

What have you learned from building at Brunnshög?

What would you have done differently if you would do it again?

Have there been any issues with the district heating so far?

What feedback have you received regarding your project after the land allocation from the City of Lund?

What is your communication with Kraftringen like?