ANALYSIS OF 4TH GENERATION DISTRICT HEATING TECHNOLOGY COMPARED TO 3RD GENERATION

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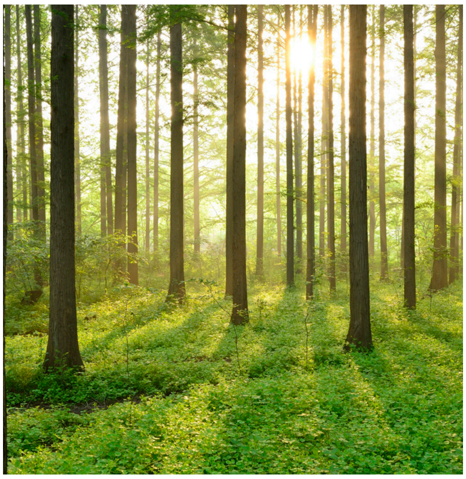

FUTUREHEAT

Energiforsk

Analysis of 4th Generation District Heating Technology Compared to 3rd Generation

Simulation of a secondary network in an area of new construction

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Foreword

The project) has compared two different district heating distribution solutions for a new construction area at Särö, one according to today's conventional third generation technology and one with the untested 4DGH. The project fills a knowledge gap when it comes to practically applying 4GDH technology and raises important issues regarding the installation and comparison, that comes along when preforming a case study. Continued demonstration areas are needed to be able to draw conclusions about where and how 4GDH should be designed to be the number one investment option before today's technology.

The project was led by Kristina Lygnerud at IVL Swedish Environmental Institute, together with Helge Averfalk at Halmstad University, Sebastian Welling, IVL Swedish Environmental Institute, Christer Kilersjö at EKSTA and Bengt-Göran Dalman at BG Dalman AB. This report has also been translated into Swedish and published as, *Analys av 4e generationens fjärrvärmeteknik jämfört med 3e generationens, Energiforskrapport, 2018:547.*

A reference group consisting of Magnus Ohlsson (Chairman) Öresundskraft; Ted Edén, Norrenergi; Henrik Landersjö, E.ON Local Energy Solutions AB; Patrik Nilsson, E.ON Local Energy Solutions AB; Per Bonnevier, Norrenergi; Shahriar Badiei, Vattenfall AB; Björn Larsson, Mälarenergi AB; Ingemar Andersson, Mälarenergi AB; Lars-Erik Hammarström, Tekniska Verken i Linköping AB and Holger Feurstein, Kraftringen has followed and quality assured the project.

The project is part of the FutureHeat R&D-program, with the long-term goal to contribute to the vision of a sustainable heating system with successful companies using new technology opportunities, and where the investments made in district heating and district cooling are utilized efficiently.

The program is led by a steering comity consisting of Charlotte Tengborg (Chairman), E E.ON Local Energy Solutions AB, Lars Larsson, AB Borlänge Energi; Magnus Ohlsson, Öresundskraft AB; Fabian Levihn, Stockholm exergi; Niklas Lindmark, Gävle Energi AB; Jonas Cognell; Göteborg Energi AB; Lena Olsson Ingvarsson, Mölndal Energi AB; Anna Hindersson, Vattenfall Värme AB; Anders Moritz, Tekniska verken i Linköping AB; Staffan Stymne, Norrenergi; Holger Feurstein, Kraftringen; Joacim Cederwall, Jönköping Energi AB; Maria Karlsson, Skövde Värmeverk AB; Sven Åke Andersson, Södertörns Fjärrvärme AB; Svante Carlsson, Skellefteå Kraft AB, Henrik Näsström, Mälarenergi AB och Fredrik Martinsson (adjungerad) Energiforsk

Deputies were Peter Rosenkvist, Gävle Energi; Johan Brossberg, AB Borlänge Energi; Mats Svarc, Mälarenergi AB; Johan Jansson, Södertörns Fjärrvärme AB och AnnBritt Hansson, Tekniska verken i Linköping AB.

Fredrik Martinsson, programme manager FutureHeat

Sammanfattning

Bakgrunden till studien är att nya förutsättningar genom energieffektivisering, konkurrens från värmepumpar och nya krav på kundsidan gör en modernisering av fjärrvärmeverksamhet nödvändig. En del av denna modernisering är att kunna dra nytta av de fördelar som lägre temperaturer i näten medför. Därtill skapas genom den nya tekniken förutsättningar för att ta hand om värmekällor som idag inte utnyttjas (t.ex. värme från kylprocesser och annan infrastruktur såsom värme från avloppsvatten och värme från kollektivtrafik).

Befintlig teknik är beprövad och bygger på att det finns ekonomiska incitament att förbränna biobränsle och avfall. Steget till att pröva en ny teknik där andra värmekällor och en ny gränsdragning gentemot kund blir nödvändig är därför stort och förenat med ett antal frågor. *Det är just de frågor som uppkommer i ett fjärrvärmeföretag inför implementering av 4e generationens fjärrvärmeteknik som projektet försöker identifiera.* Det blir dock så att enbart en del av frågorna besvaras genom att studien har ett avgränsat fokus. Fokus är på jämförelse mellan ett 3GDH-tvårörsystem och ett 4GDH-trerörsystem i ett sekundärnät i ett nybyggnationsområde.

I projektet simuleras hur utfallet blir för olika parametrar om man hade valt att implementera 4e generationens teknik istället för 3e generationens teknik.

Resultaten påvisar att:

- 4e generationens lösning ökar energieffektiviteten i byggnader, detta främst genom att behovet av varmvattencirkulation försvinner.
- Beaktas enbart distributionsförluster i näten så är 4e generationen mer effektiv än 3e generationen.
- Genom lägenhetsväxlaren i 4e generationens lösning så elimineras risken för Legionella helt. En möjlig barriär för 4e generationens teknik består dock i att boverkets byggregler inte är konstruerade för att varmvattencirkulation inte finns.
- Lägenhetsväxlarna innebär en kostnad per lägenhet vilket begränsar lösningens kostnadseffektivitet jämfört med en större värmeväxlare i fastighetens bottenplan. Idag är 4e generationens teknik lämpad för fastigheter med 10-15 lägenheter, är det fler lägenheter blir 4e generationens lösning dyrare än den konventionella 3e generationens lösning.
- En viktig aspekt med 4e generationens lösning att värmeförlusten från huset förflyttas från fastighetsägaren till fjärrvärmeföretaget, genom att värmeleverans sker till varje lägenhet och inte vid husvägg. Initialt kan sådan börda på fjärrvärmeföretaget verka negativ med avseende på kostnad. Diskussionerna i projektet mynnade ut i att parterna enas om att affären blir mer rättvisande och att fastighetsägaren får ökad insyn i värmeförbrukningen vilket, med rätt affärsmodell, kan skapa ökat förtroende och en möjlighet att dela på förlusten mellan de två parterna.

Projektet har omfattat löpande dialog med EKSTAs VD vilket varit värdefullt för att skapa förståelse kring fastighetsägarens perspektiv och frågor rörande 4e

generationens teknik. Därtill har en workshop med EKSTAs driftspersonal hållits för att diskutera relevansen i de resultat som tagits fram. I projektet ingår Bengt-Göran Dalman med över 35 års erfarenhet av fjärrvärmeverksamhet vid Göteborg Energi. Projektets verklighetskoppling leder till slutsatsen att det inte föreligger någon särskild driftsproblematik för implementering av 4e generationens system.

Som en egen del i projektet uppmärksammas den diskussion som förs i branschen kring möjligheten att dra nytta av billig el, främst under perioder då det blåser mycket och det blir ett överskott av el i elnätet. I studien analyseras möjligheten att inte använda en konventionell pelletspanna som tilläggsvärmekälla utan en eldriven panna. Resultaten visar att med dagens styrning genom skatter och avgifter så är det inte möjligt att dra nytta av att det förekommer perioder med mycket lågt elpris. Rådande regelverk stödjer istället installationer såsom pelletspannor.

List of content

1 Background

Swedish district heating companies are challenged by increasing competition, lower heat demand and new customer needs. The Swedish district heating industry has successfully phased out fossil fuels and currently biofuels and waste are the most prevalent heat sources. The transition from fossil fuels is, however, not sufficient to create future competitiveness. It is likely that biomass resources will have other offsets than as fuels for incineration and heat production in the future and that the volumes of waste for incineration will decrease. In such a future, it is increasingly important to develop heat production and the district heating business to remain competitive. One possibility is to increase the usage of excess heat sources from both industrial processes and from low temperature heat sources (from waste water, infrastructure and cooling processes). Such transformation necessitates business models allowing for multiple, small heat sources delivering heat into the distribution network (prosumers), central heat storage and alternative usage for heat (by, for example, transforming it to cooling).

At Halmstad University, researchers have shown how enhanced design of the district heating network can lower the annual average return temperatures in the district heating networks. The innovative design consists of three improvements to avoid system embedded temperature errors. These improvements are three-pipe distribution networks, apartment substations and increased thermal lengths in heat exchangers (Averfalk & Werner, 2018b). By introduction of a third (small) recirculation pipe, apartment substations, and heat exchangers with increased length the return temperature on an annual basis is lowered. Lower return temperatures are obtained by (i) avoiding temperature contamination between supply and return flow, (ii) elimination of domestic hot water circulation in multi-family houses, and (iii) lower temperature difference between inlet and outlet flow rates in a heat exchanger. Simulations of the new design show that it is possible to reach an annual average return temperature of 20 °C. 4th generation district heating technology reduces distribution losses and facilitates usage of low temperature heat sources. It allows efficiency increases and reduced environmental impact. There is great interest in low temperature district heating solutions in Europe, especially in new construction. Pilot projects have been performed where the temperatures in the distribution networks are lower than in conventional, 3rd generation district heating networks. Known areas in Sweden where pilot projects have been undertaken are Ellös, Falkenberg, Göteborg, Halmstad, Kungsbacka, Linköping and Västerås (Lygnerud, 2017).

Sweden has a long tradition in district heating and has become a forerunner of the 3rd generation technology. To remain a competitive district heating provider, it is important to also be a forerunner in the development of the future district heating technology. To engage in implementation of the new technology, data are needed that point to a cost-efficient solution. Unless the new technology can be proven to result in an efficient business its possibility for large scale implementation is low. Pre-studies that can quantify the potential of the technology are needed.

In this project 4 questions are addressed. These are:

(1) How do costs differ between 3GDH and 4GDH installations?
(2) Distribution losses and system temperatures; what is the difference between 3GDH and 4GDH?
(3) Is it cost efficient to use electricity as additional heat source in district heating?
(4) Is the environmental impact between 3GDH and 4GDH heating installations different?

In the text 4GDHWA-3P and 4GDH are used.4GDH-3P is district heating with 4th generation temperature levels (50/20 °C) and with triple pipe distribution system configured according to Werner and Averfalk (2018b).4GDH intends low temperature systems but that are not configured according to the Werner Averfalk model. 3GDH is district heating with 3rd generation temperature levels, most systems in Sweden could be considered as 3GDH-2P systems. The average temperature levels for Swedish DH systems are 86°C (for supply) and 47°C (for return). (Werner & Fredriksen)

2 Purpose and goal

Existing district heating technology needs to be modernized to meet the requirements of new and energy efficient buildings. One option for modernization is to switch from large, central production units to take advantage of several, smaller and local heat sources. Such development allows energy systems that can make use of the energy flows generated in cities from people living in them. One important element of the modernization is that the distribution networks can manage lower temperatures than what is currently common.

The purpose of the project is to explore how 4th generation technology compares to 3rd generation technology.

The project has two goals;

(i) compare a 3GDH-2P system with a 4GDH-3P system in a secondary system in a new development area

(ii) identify at what price level an electricity operated additional boiler is more cost efficient than an additional pellets boiler[1]

[1] In addition to the main target, the project entails an analysis of the potential to use electric boilers as additional heat source in DH systems. The analysis will provide an understanding of if it is possible for DH companies to benefit from low electricity prices in periods with high electrical production from windpower. The analysis stems from the original application of the project where the new built area had a connection to storing solar heat making the potential to use cheap electricity very interesting. The analysis has been kept in the project since it was deemed to be interesting to new construction areas even if there is no solar heat storage.

3 Study

3.1 PROJECT PARTNERS

There are four partners in the project. These are Halmstad University, EKSTA, BG Dalman AB and IVL. The partners have complementary competencies. Halmstad University is one of the innovators for the novel heat distribution technology and perform simulations to compare the application of 4GDH-3P to 3GDH-2P. EKSTA is interested in implementing the new technology. EKSTA is a company that both owns houses and local district heating production and distribution. It is a company that is striving towards maximum usage of renewable energy in its building stock. Therefore, the company has invested extensively in solar heating. Low temperature district heating is efficient in systems that are operated with solar heating. When 3rd and 4th generation district heating technology are compared in the context of solar heating it has been shown that 4th generation technology reduces costs five times over 3rd generation technology (Averfalk & Werner, 2018a). BG Dalman has experience from technical solutions in district heating after more than 35 years in the district heating industry. IVL considers the environmental impact of the technology and coordinates the project.

3.2 THE AREA OF NEW CONSTRUCTION (NYA SÄRÖ)

EKSTA finds that there is a large potential to combined 4th generation technology with solar heating. Initially, an area with a solar heating park was foreseen for the pre-study. 2017-12-19, in the tender process another entrepreneur was designated the role of area developer. Hence, the initial area was substituted by another area where new construction is already underway. The new area consists of mixed housing with multi-family houses and public premises. The name of the area is "Nya Särö" and it is located south of Göteborg. The difference between using 3GDH-2P and 4GDHAW-3P in a secondary system is tested in this project, in Nya Särö.

Särö is a small city situated south of Göteborg (25 k). In the 1850ies the city was a vacation venue for wealthy citizens of Göteborg. The center of the city is now being modernized and both small houses, chain houses and apartments are being built. It is a state of the art project where Mjöbäcks, Järngrinden and AB Hundra collaborate. The residents are sustainable, and focus is on (i) energy savings, (ii) indoor climate, (iii) efficient sound levels, (iv) damp protection and (v) recycling of waste.

Below is an illustration of the area.

Figure 1, Illustration of the area New Särö

EKSTA has been given the task to design and install an energy efficient 3GDH solution. EKSTA is interested in installing the best technology available from the point of view of energy savings and would have been interested in the 4GDH technology if there were more results from actual implementations. To learn more,

Nya Särö has served as pilot to compare what characteristics the district heating system might have had if the proposed 4th generation technology had been applied.

An outline of the distribution network of Nya Särö is provided below. The area is considered to be connected as a secondary system from the point marked by a black circle. An adjacent district heating network exits the around the studied case area and the area is prolonged in three additional directions, this is not indicated by the figure and excluded from the analysis. The reference case 3rd generation 2 pipe-system (3GDH-2P) utilise 11 district heating substations, one for each building. The simulation case 4th generation 3 pipe-system (4GDH-3P) utilise 115 district heating substations (106, one for each residence and 9 for public areas such as stairwell with the exception of building F and E where no common substation is required).

Figure 2 Overview of Nya Särö

The distribution of piping in the area is outlined in 1. The piping shown in Figure 1 entail only piping in the ground according to 1 (DN32-50), for the DN25 within buildings an average of 5 m pipe per apartment is assumed, since no further data has been available during the project. Design for piping in ground is already established since the area is being constructed, for the purpose of the analysis equal pipe dimensions are utilised for piping in ground.

The energy performance in the buildings is in line with the Swedish building regulations (Swedish National Board of Housing, 2011), corresponding to 76.5 kWh/m²a.

Table 1 Distribution outline of pipe dimensions and lengths.

	In buildings	In ground			
Pipe dimension	DN25	DN 25	DN32	DN40	DN50
Length [m]	531	64	173	229	107
Total length 3rd	573				
Total length 4th	1104				

3.3 STUDIED QUESTIONS

In the project, four different questions are examined. Each question and the method applied for answering it are outlined, in turn, below.

Question 1: Distribution losses and system temperatures; what is the difference between 3GDH and 4GDH?

The distribution losses and system temperatures differ in 3GDH and 4GDH. What the differences are is not yet known from implementations. In the project, 3rd and 4th generation distribution pipes are analyzed through simulation to find what the differences in distribution losses and system temperatures

Halmstad University have developed a simulation model to determine temperature drop along each intersection of a network, both supply and return, based on predetermined activities in substations of the limited area being observed. In order to, obtain information of volume flow rates and temperatures for the system. However, the main purpose of the model is to establish a method to compute the necessary primary recirculation flow rates that occur in the network when no heat load is present (summer), in order to visualise the necessity for implementation of a strategy to avoid this supply to return pipe circulation (especially as the thermal envelope of buildings increases). Utilising the suggested simulation model Averfalk and Werner (2018b), characteristics of Nya Särö has been established both for 3GDH-2P and 4GDH-3P. A minimum recirculation flow from the service pipes from each district heating substation has been modelled during a year. In order to establish the potential of reduced primary return temperatures during summer utilising a third primary recirculation pipe. The function in the distribution network is simulated based on profiles for outdoor temperatures and estimated, annual energy demands. The flow volumes through heat exchangers to meet the heat demand and volumes for primary recirculation have been estimated by applying the methodology described in Averfalk and Werner (2018b). Thus, information from the area regarding distribution losses and system return temperatures have been obtained.

Question 2: How do costs differ between 3GDH and 4GDH installations?

To answer question 2, the cost for apartment-based district heating substations has been compared with conventional substations. In addition, cost differences per meter of 3rd generation pipes compared with 4th generation pipes have been identified as have the costs of eliminating the need for hot water circulation.

It should be noted that there are other cost saving potentials that have not been quantified in this study. There are, for example, possible savings from no hot water circulation installation and no technical rooms for district heating substations. Other possible savings stem from the usage of low temperature heat sources. New research from Germany has made an attempt to simulate all costs for a 3GDH-2P system and to compare them to a low temperature system. It is concluded that low temperature systems do not have disadvantages compared to a 3GDH system (Best et al. 2018).

Cost analyses have been made based on experiences from the industry (BG Dalman, EKSTA and 4th generation pipe supplier Thermaflex).

Question 3: Is the environmental impact between 3GDH and 4GDH heating installations different?

The environmental impact between the two technologies is estimated by using LCA analysis.

IVL has compared the environmental impact using an LCA that has investigated the same functional unit and systems of both the 3rd and 4th generation pipes. Specific data from two pipe manufacturers have been collected and the impact over the entire life cycle has been calculated. The results visualize results both per functional unit and for the entire system in Särö.

Question 4: Is it cost efficient to use electricity as additional heat source in district heating?

In the future, periods of much wind will lower the price of electricity. The fourth question addresses if it is cost efficient to use electricity as additional heat sources in such circumstances.

EKSTA has a vested interest in solar heating. Solar heating necessitate both central storage[2] and additional production units in order to be efficient. The most common addition to solar heat production today is biomass pellets boilers. Periods with very cheap electricity have been proven in Denmark. Assuming that this is the future development in Sweden, the possibility to use electricity instead of pellets- for additional production- has been explored.

BG Dalman AB has made the analysis of electricity as additional heat source. Denmark is the country in the world that has most wind power. The electricity price development in Denmark has been taken as a proxy for the future electricity price development in Sweden. Danish and Swedish wind statistics have been used to identify how many hours per year it can be assumed to have a low price of electricity. Based on the preconditions of Nya Särö, an estimation of how feasible it is to use electricity for additional electricity generation has been made.

3.4 VALIDATION OF RESULTS

During the study, the results have been discussed and related to real circumstances encountered by EKSTA. The project partners have met for two, three-hour meetings, where the results have been discussed in detail. At one occasion, the project partners met the engineers of EKSTA to understand/learn more about differences between 3rd and 4th generation implementation. The results have also been presented and discussed two times, with the steering group of the project (appointed by Energiforsk).

[2] Utilisation of local secondary heat storages in district heating substations is a common practice in certain countries. The issue with local storages is that is a potential Legionella hazard, therefore local storages is regulated, for instance in the Swedish house of boarding where it is stated that the temperature in heat storages should not be lower than 50 °C. This operation is no issue with high temperature level but with low temperature operation, it becomes an issue (Swedish National Board of Housing, 2011). In addition, the CEN document states that no temperature requirement is in place when no domestic hot water circulation nor local heat storages is in use (CEN, 2012).

4 Results

4.1 RESULTS ON DISTRIBUTION LOSSES AND SYSTEM TEMPERATURES

In section 4.1, questions that arise when 4GDH is to be installed are listed and the discussions and delimitations made in regard to the questions are provided. *These questions were identified when talking to EKSTA before the simulations were made. They reflect questions that arise in a DH company before implementation of 4GDH technology. In the project only questions within the focus of the project are answered but it is important to understand the span of the questions that arise with the technological shift.* The questions are broader than the four questions of this study but are very important since they reflect the palette of questions that arises before a DH provider is ready to implement 4GDH. The purpose of section 4.1.1 is to provide input to some of the many technologies that arise around the 4GDH new technology. The questions arose from discussions with EKSTA. In section 4.2, answers to the 4 questions of research are presented based on the simulations made at Halmstad University.

4.1.1 Distribution losses and system temperatures- questions that arise

Heat installations in Swedish multi-family houses are traditionally based on central substation in the building. From the central location, space heating and domestic hot water is distributed through piping in the building. The Swedish regulations for housing, demands comfortable temperature levels and sufficient temperatures to avoid Legionella bacteria, 50 °C or more in case of domestic hot water recirculation (Swedish National Board of Housing, 2011). To meet the requirements two pipes are needed for domestic hot water distribution (fresh water line excluded since it is required in both cases); one for distribution and one for circulation. For space heating, one flow line and one return line is required. Hence, buildings are populated with at least four pipes for internal heat distribution of domestic hot water. In addition, multiple risers for space heating can be part of the overall internal heat distribution in a building.

In the simulation case with 4GHD-3P individual district heating exchangers are applied in comparison with one single central. A total of 115 district heating apartment substations are required for the 4GDH-3P case, compared to 11 for the 3GDH-2P. Utilisation of apartment substations yields a technical solution where the need of hot water circulation in buildings is eliminated. If viable, policies regarding temperature requirements due to Legionella in the Swedish building regulations for domestic hot water preparation should be revised according to the technical recommendations in (CEN, 2012), where the absence of hot water circulation and local heat storages yield not temperature requirements due to Legionella.

The 4GDH-3P case consists of a solution with three-pipes to avoid increased return temperatures when circulation is required, when supply temperature drop due to low heat demands. Today, in 3GDH-2P systems, this is counteracted by leaking water through district heating substations, as displayed by (Crane, 2016). The introduction of the third pipe makes it possible to separate required recirculation in to a third pipe and thus, avoid an increase in return temperature. The third pipe is only used when there is a need to circulate water. Introducing district heating substations at the apartment level change the interface boundaries of the district heating system and thus, the boundaries of responsibility. With an interface where primary water is distributed further in to the building a new level of responsibility that requires consideration appears. Issues regarding the new interface are listed below.

1. Heat losses from hot water circulation in buildings are no longer a heat delivery from the district heating company to the owner of the building. Instead, the loss becomes the responsibility of the heat supplier and must be carried by the heat supplier

The loss is transferred from the house owner to the heat supplier. This can generate goodwill in the dialogue with customers by identifying and managing the loss. New model to share the cost for the loss must be developed.

In new buildings with low energy demands delivery of hot water circulation losses might constitute a significant part of heat sales. Business models that consider this change is required.

2. What are the preconditions to bring a flexible, pre-insulated pipe into a building and onto individual apartments?

Do pipe installations need to be done in a new way? Are the pipe installers ready for such changes? Are there barriers for pipe-installations? What can be learned from other countries? The Swedish model of evenly sharing heat costs between apartments is not common in Europe.

3. What impacts on space demand for piping is there with the 4th generation solution compared to 3rd generation solution?

The hypothesis is that the space needed for the 3rd generation and the 4th generation solution is identical. Hence, also cost levels between the two options are assumed to be in the same order of magnitude.

Is the hypothesis correct? New pipes necessitate more/less space? How is the saving of not needing technical rooms for the substations accounted for?

4. Is there a difference in heat loss from the 3rd generation solution for hot water compared to the 4th generation solution? The hypothesis is that: Heat losses for hot water circulation in buildings (3GDH-2P) are larger than the heat losses from a primary pipe inside of house (4GDH-3P).

Is the hypothesis correct? Unpublished results indicate that heat losses in 3GDH-2P compared to 4GDH-3P are more or less the same. The results of this study indicate that the domestic hot water circulation losses in buildings today are larger than the losses from the primary pipe that is required inside the buildings in a 4GDH-3P in the future.

5. District heating substations that do not mix supply water with return water are needed at the apartment level in the 4GDH solution.

Currently, supply water is mixed with return water during summer to maintain correct supply temperature. Since, heat demands are low during summer so is actual flow rate of *primary side water, which cause temperature drop due to stagnation (temperature degradation).*

6. Typically, today the legal responsibilities in case of a water leak are limited with regard to the heat supplier, since their activity ends at the pipes entering the building. However, when primary water is led up through the building the legal responsibilities of the heat supplier are extended. Thus, with apartment substations there may be a greater demand for failsafe mechanisms and proper option to drain water through a building.

The pipe installations need to be equipped with a water failure switch that is immediately shut in case of a leak.

7. When planning the construction of a building it is of interest to place the district heating substations easily accessible from the outside of an apartment. That way the intrusion of the personal sphere is minimized when service and maintenance is needed.

Placing the district heating substation outside of the entry door of the apartment should be preferable. That way it is accessible from the outside of the apartment. Is such construction possible? Does it work with "heat cabinets" outside of the apartments?

8. When apartment substations are applied there is an open question on who should heat share areas.

The suggestion is a district heating substation managing the need for space heating of stairwells. However, shared spaces with a need for domestic hot water (few spaces) should be heated by electricity or a need for hot water circulation in buildings is created which is something to avoid.

9. The domestic hot water used in apartments is generated on demand in the district heating substations of the apartments. This minimises the risk for Legionella.

In Germany, the risk for Legionella in smaller tap-water installations is regulated by keeping the volume of the pipe-installations (secondary side of apartment central) below 3 liters. This is referred to as the "3 liter rule" (DVGW, 2004). (CEN, 2012), the European standards organization, find that tap water installations with no hot water circulation in buildings and local heat storages do not need any temperature requirements. In essence the Swedish regulations (Swedish National Board of Housing, 2011) has organised the domestic hot water regulation around a one size fits all model, where every residential unit is considered to operate hot water circulation systems hence, requiring a minimum of 50 degrees for all domestic hot water applications. The Swedish regulation should be revised to facilitate lower temperatures in installations that do not have such strict temperature requirements (i.e. no local heat storages or hot water circulation), in order to account for 4th generation district heating technology.

4.1.2 Distribution losses and system temperatures- Assumptions and results from simulation

A number of assumptions have been made for the simulation and they are provided first. The results from simulations are provided in *italics*. In , parameters from the simulation (input/output) are summarized.

1. The needed space for building internal systems for 4GDH-3P and 3GDH-2P are expected to be in the same order of magnitude

2. The costs of building internal heat distribution for 4GDH-3P and 3GDH-2P are assumed to be on the same order of magnitude

3. Specific heat losses for 4GDH-3P and 3GDH-2P piping are expected to be in the same order of magnitude, since the recirculation pipe is in the same pipe as the supply and return pipe

4. Heat demand in shared spaces in multi-family houses is met by a district heating substation but domestic hot water in these spaces is met by local electricity solutions

5. Each apartment is allocated 5 meters of service pipe within the building in the 4GDH-3P case.

This impacts the length of piping. In the 4GDH-3P solution, 595 meters of additional piping is required. The additional 595 meters substitute the hot water circulation pipes in buildings and pipes for radiator-systems to each apartment. The increased pipe length impacts the linear heat density of the area (from 1.56 MWh/meter in 3GDH-2P to 0.70 MWh/meter in 4GDH-3P).

6. Supply temperature has been chosen as a constant over the year[3], with emphasis on the temperatures that might be expected during summer conditions, since this condition establishes the need for hot water circulation in buildings, which is the major attribute of interest.

Simulating the 4GDH-3P case for Nya Särö, the third pipe separates flow and return water lowering the system temperatures. In the simulation, the supply temperature was 52 and the return temperature 20 degrees Celsius. Simulating the 3GDH-2P case for Nya Särö, an annual average temperature would be impacted by hot water being circulated into the return pipe. In the simulation the flow temperature was 70 degrees and the return temperature was 53 degrees Celsius.

7. Domestic hot water circulation losses in buildings in 3GDH -2P has been estimated to be 1MWh/apartment and year.

The estimation is based on the following information: Örebrobostäder measured hot water circulation loss and report 11.5 kWh per m² and year (Åslund, 2016). This corresponds to 1035 kWh per apartment and year for the case area studied in this report. Another source is identified in a master thesis evaluating hot water

[3] In practice, the supply temperature would increase at lower outdoor temperature intervals.

circulation losses by studying two buildings (Paulsson & Svensson, 2016). For the two buildings, the corresponding indicator is 734 and 743 kWh per apartment and year. In a Danish report, (Bøhm, Schrøder, & Bergsøe, 2009) data for 13 multi-family houses is provided. The indicator varies between 302-2327 kWh/apartment and year. An average of 1013 kWh/apartment and year is established. Hence, it seems reasonable to assume an average indicator for hot water circulation losses to be 1 MWh/ apartment and year.

In this study, the hot water circulation losses from the (4GDH-3P) pipes inside the buildings are estimated to be 16MWh. This corresponds to a loss per apartment of 151 kWh/ year compared to an average indicator of 1MWh/ apartment and year in 3GDH-2P. Thus, heat losses in buildings are assumed to be lower in 4GDH-3P compared to 3GDH-2P since, domestic hot water circulation is presumed to cause large heat losses.

8. The heat losses in ground have been assumed to be in the same order of magnitude for both 4GDH-3P and 3GDH-2P.

Simulation output indicate that the distribution losses from pipes in the ground is 40 MWh per year for the 3GDH-2P case, whereas, heat losses from pipes in the ground for the 4GDH-3P case is 26 MWh per year. The decrease is achieved through lower operating temperatures.

However, in the case of 4GDH-3P, additional heat losses occur from the piping within the buildings; these losses add up to 16 MWh per year.
Thus, the total losses for the 4GDH-3P case is 26 plus 16 equalling 42 MWh/year. Hence, the losses of 4GDH-3P in this simulation is slightly higher than compared to the 3GDH-2P case, due to additional losses from primary piping within buildings.

Table 2 Simulation parameters for the 3GDH-2P and 4GDH-3P case.

		3GDH-2P	4GDH-3P
Supply temperature[°C]	Input	70	52
Return temperature [°C]	Output	53	20
Hot water circulation temperature [°C]	Output	-	50
Network length [m]	Input	509	1104
Line density[MWh/m]	Output	1,56	0.70
Number of district heating exchangers	Input	11	115
Heat demand [MWh]	Output	770	772
Heat losses [MWh]	Output	40	26 (+16, loss in building) = 42
Relative loss [%]	Output	5,2	3,4

In Figure 3 and Figure 4 the system temperatures are visualised for the two scenarios. In Figure 3, the temperature related simulation results are provided for 3GDH-2P. The flow temperature of 70 °C has been applied. This temperature level provides input on the necessary dimension of hot water circulation in buildings. In practice, the flow temperature would increase at lower outdoor temperatures. For outdoor temperature intervals of -10 to +10 °C a return temperature in the DH system at a temperature level of 30-35 °C would be attained. When the outdoor temperature is higher the return temperatures would increase because of the temperature contamination that occurs when the heat demand is low.

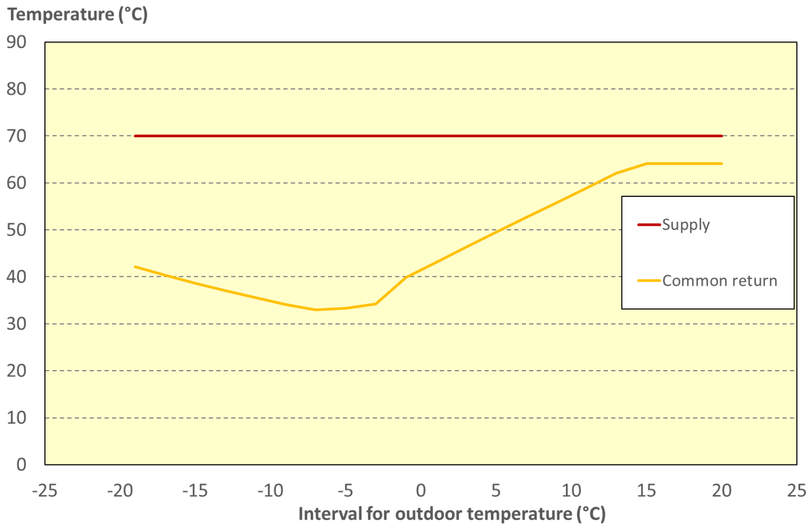

Figure 3 Results on system temperatures 3GDH-2P.

In Figure 3 the simulation results for 4GDH-3P are provided. The flow temperature of 52 °C has been applied, it reflects the vision of a flow temperature of 50 °C for 4GDH accounting for 50 °C at the customer's district heating exchanger (to account for comfort requirements).

There is an avoidance of temperature contamination during summer. In case there is zero flow, the hot water circulation temperature in buildings is the same as the surrounding temperature.

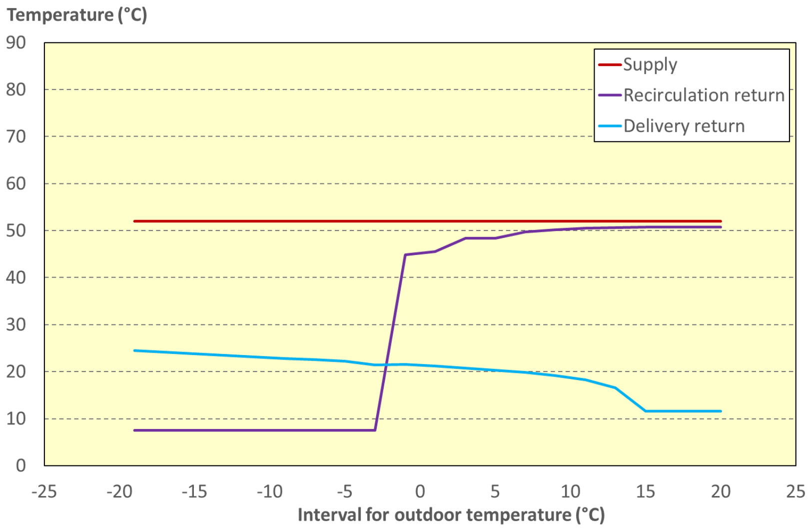

Figure 4 Results on system temperatures 4GDH-3P.

4.2 RESULTS ON COSTS

The second part of the analysis in this study addresses costs. The cost for apartment based district heating substations has been compared with conventional substations. In addition, cost differences per meter of 3rd generation pipes compared with 4th generation pipes have been identified. 4th generation pipes cost less per meter, but more meters are needed compared to the 3rd generation solution. An estimate of the potential cost savings due to the avoided hot water circulation in buildings has also been made.

Cost reductions from the hot water circulation installation being omitted, technical rooms for district heating substations not being necessary, savings from operational costs and the usage of low temperature heat sources are not accounted for in the study. To gain a full understanding of the costs it is necessary to identify differences in cost from installations and operation in buildings. Note that the project results only partially cover the costs for 4GDHWA-3P installations.

Three aspects of costs have been analysed. The first aspect is linked to the usage of apartment based district heating substations compared to central installations per house. The second aspect addresses the cost for the piping. The third aspect is an estimate of the hot water circulation savings in buildings. The results are summarised in Table 3.

Regarding the district heating substations, there would have been a need for 11 central substations in the 3GDH-2P scenario and for 115 units in the 4GDH-3P scenario. Based on information from EKSTA the cost for apartment district heating substation (installed, with circulation pump, meetering and automatic control engineering) is 19 000 SEK. EKSTA is paying 125 000 SEK per district heating substation in a multi-family house of 12 apartments, this excludes automatic control engineering. It is assumed that the cost of automatic control engineering for a substation is 10% of the total substation cost, hence the cost including automated control is: 125 000 SEK*1.1= 137 500 SEK. The cost for district heating substation in the 3GDH-2P case is: 11*137 500 SEK (1 512 500 SEK) compared to 115*19 000SEK (2 185 000 SEK) in the 4GDH-3P case. It is important to be aware that the more apartments in a building, the larger the investment cost is for the 4th generation solution. When discussing the results in the project group it was distinguished that, apartment buildings of between 10-15 apartments are still cost competitive compared to the 3GDH-2P solution. It should be noted that with the 4GDH solution space will be saved since no technical rooms for the substations are needed. This cost saving is not estimated in the cost analysis.

Building 4GDH-3P necessitates additional meters of piping compared to the 3GDH-2P solution. For Nya Särö, the difference in pipe length is 531 meters. In the 4GDH-3P case a 5 meter service pipe is foreseen from the central pipe in the building to each apartment rendering 1104 meters of pipeline. In the 3GDH-2P scenario, the needed metering of pipeline is 573 meters. The pipe provider of the 4GDH-3P pipes resorted to for this analysis is Thermaflex. Thermaflex is a company based in the Netherlands and they are forerunners in trying to establish 4GDH implementations across Europe. There is still no large scale production of the pipes, but they are being installed per demosite. There is, for example, an installation within the ongoing EU project TEMPO. According to Thermaflex flexible plastic pipes used for 4GDH are 15-20% lower in cost (total installation cost) for the same pipe diameter as 3GDH-2P pipes. It must, however, be noted that cost will depend on diameter, ground conditions, network layout and other. There are also more or less cost efficient alternatives for 3GDH installations. The 3GDH-2P for Särö is cost efficient and, as far as EKSTA is aware, best available 3GDH-2P technology. The cost per meter of the pipes used in Nya Särö are 580 SEK/ meter (including welding and muffling VAT and land works), and the used diameter is 40 centimetres. Assuming identical diameters of pipes for the two scenarios (40 centimetres), the cost for the 3GDH-2P scenario in Nya Särö is 332 340 SEK and for the 4GDH-3P scenario it is -15 to 20%. For the building installations there are no cost estimates from Thermaflex, hence no cost estimate has been made for the pipes in the buildings.

The difference of dimensions of the different kinds of pipes is minimal. The width and depth of the shafts as well as the space needed for indoor piping will be the same in both 3rd and 4th generation. There is no difference in the number of branch pipes, valves etc. which leads to the assumption that we have the same cost for 3rd and 4th generation installations.

Hot water circulation savings in buildings are possible in the 4GDH-3P solution. Experiences have shown that in the 3GDH-2P solution, the domestic hot water circulation loss in buildings is 1 MWh/ apartment and year. This loss can be cut completely with the 4GDH-3P solution. In Nya Särö there are 106 apartments and 9 shared spaces, it has been estimated that the heat needed for the hot water circulation in these areas is 115 MWh/year. The cost per MWh is in September 2018, 700 SEK for EKSTA. This means that 80 500 SEK can be saved with the 4GDH solution. EKSTA is unconventional in the sense that they sometimes both own the buildings and are heating providers to them. Hence, the heat delivery for hot water circulation is not a source of additional income to them in their own buildings. Indeed, one of the largest gains of 4GDH to EKSTA is the removal of the need for hot water circulation in buildings.

With 3GDH the distribution of heat is made by the installation of risers between floors. In apartments with walls in two outdoor facades there is often risers in both facades. From the risers the heat is distributed to the radiators by apartment piping. In the case of 4GDH distribution of heat goes from one centrally located apartment central. From this central there is a need of piping to the radiators and the costs of these pipes are assumed to be the same as the costs of the risers. The pipes between radiators are assumed to have the same cost in both 3GDh and 4GDH.

Conducting the study the project group identified that the boundary conditions of the district heating business changes with 4GDH. It is no longer the building owner that carries the heat losses occurred inside of the house. In wintertime the loss is a gain since it heats the building but in summertime it is a loss. The estimated loss in the area of Nya Särö was 16 MWh/ year. Discussing with EKSTA engineers and executive it was identified that the fact that the loss is identified and communicated to a customer increases the credibility of the heat provider. Through a transparent price model it should be possible to split the cost for the loss between the heat provider and the owner of the building. The switching boundary of the heat delivery is, however, a challenge to overcome since the heat delivery in a conventional business model 3GDH ends at the wall of the house. Since EKSTA sometimes both own the buildings and are heating providers to them the switching boundary condition is not a challenge.

Regarding the operational costs, they increase for the district heating provider in the 4GDH solution as a consequence of more substations, longer network and more meeters. The owner of the building reduces the operational cost since no installation of a VVC system with pipes, vaults, pumps and automatic control engineering is needed. Also, risks for legionella and risk of malfunctioning system is shifted from the building owner to the district heating company. So, accounting for the total operational costs it is uncertain if they increase or decrease with the 4GDH. To determine the total operational cost in more depth was not within the scope of the work here but would be an interesting area for future research.

Table 3 Results on costs 3GDH-2P and 4GDH-3P Nya Särö.

	3GDH	4GDH
Cost for district heating exchangers [SEK]	1 512 500	2 185000
Piping [SEK]	332 340	-15-20%
Costs for providing hot water circulation in building [115 MWh/year at a cost of 700 SEK/ MWh]	80 500	0

4.3 RESULTS ON THE ENVIRONMENTAL IMPACT

The environmental impact is important to the future design of district heating systems. By means of a LifeCycleAnalysis (LCA) it is possible to estimate the differences in environmental impacts of the 3rd and 4th generation district heating systems. Focus is on understanding the environmental impact of the pipes (3rd generation with two pipes and 4th generation with 3 pipes). However, since the heat exchanger is an important component, an estimate has also been made of its impact on the system. Last, the impact on the environment of the energy used for both systems is addressed.

LCAs facilitates calculations of products' or systems' impact on the environment. The environmental impact will be important for building district heating systems in the future. In this pre-study, an LCA is performed to compare 4GDH-3P and 3GDH-2P systems. The difference of production and energy use of the two piping systems are included in the analysis. The analysis provides input on the impact on climate change of the 4GDH-3P and 3GDH-2P solutions. Input data has come from Swedish manufacturers of 3GDH-2P and from an internationally progressive 4GDH-3P manufacturer.

4.3.1 The impact of the pipes

The analysis in this pre-study is made per meter pipe. The environmental impact for 3GDH-2P is more than three times higher per meter pipe than for 4GDH-3P. The results per meter pipe are provided in figure 5.

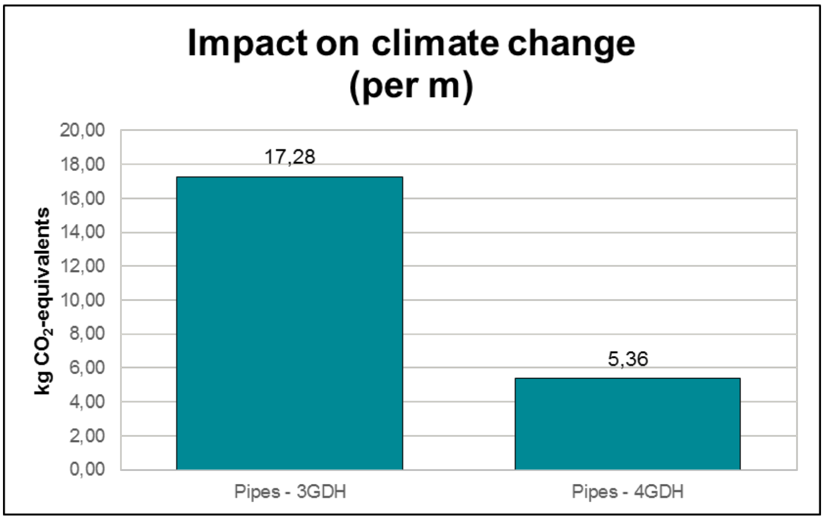

Figure 5 Environmental impact per meter pipe 3GDH-2P compared to 4GDH-2P.

The main reason for the difference in the environmental performance of the two pipes is the amount of material needed per meter pipe. 3GDH-2P pipes have a core steel and therefore a more than three times higher weight per meter than pipes based on plastics. The environmental impact per kg pipe does not differ significantly, with the 3GDH-2P pipe having a five percent lower environmental impact per kilogram pipe than the 4GDH-3P pipe.

The distribution of the environmental impact per kg pipe for the included parts is presented in Figure 6 and Figure 7.

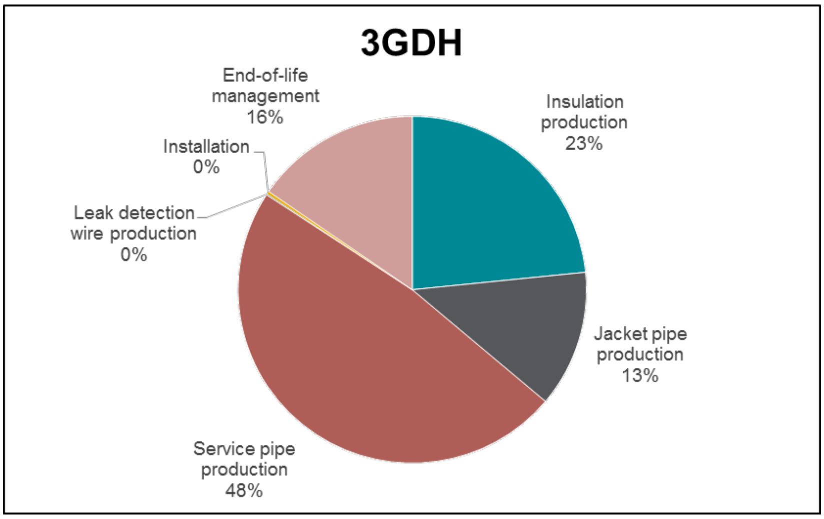

Figure 6 **Distribution of the environmental impact per kg pipe for 3GDH-2P system.**

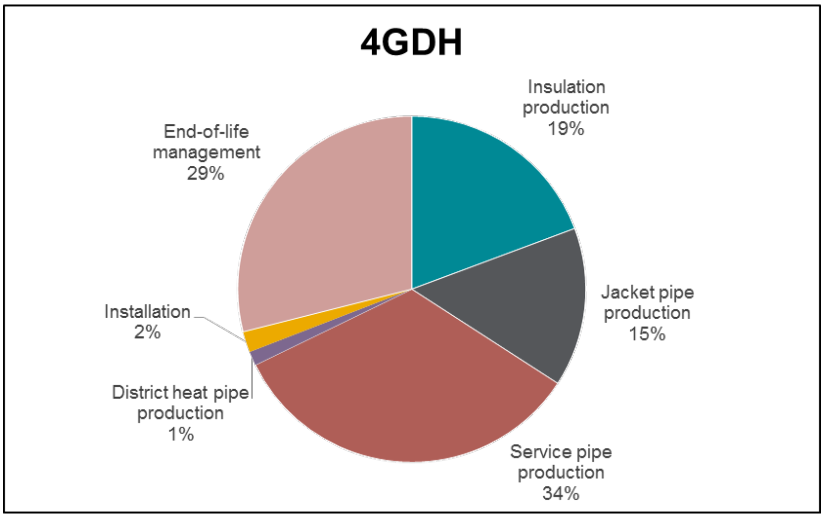

Figure 7 Distribution of the environmental impact per kg pipe for 4GDH-3P system.

More than double the metering of pipes for the 4GDH solution is needed compared to the 3GDH solution. Even so, the environmental impact of the 4GDH-3P solution (1 104 meters) is lower than the 3GDH-2P solution (573 meters).

For the assessment of the climate impact of the entire system, estimates of the lifetime of the different systems are required. Two scenarios are used for the estimation of the lifetime: industry estimate (3rd generation: 75 years, 4th generation: 40 years) and manufacturers' estimate (3rd generation: 30 years; 4th generation: 100 year). Both estimates were included to reflect the viewpoints of both industry and pipe manufacturer. Which estimate is the most realistic is not known since there are no 4GDH-3P that have been in use for 40 or 100 years to date. The estimates provide a range of operational life of 3GDH-2P of 30-75 years and of 4GDH-3P of 40-100 years. Figure 8 presents the results for the environmental impact for the system when used 30 or 100 years.

If the system is used for 30 years, the pipes do not have to be replaced during their timespan. The results of the environmental impact are shown in the left pillars in figure 8. The 4GDH-3P has lower impact than the 3GDH-2P solution. The results for the use of the system for 100 years show that estimations for the lifetime have a significant impact on the total results.

First, applying the lifetime estimate of the *industry*: 3GDH-2P (75 years) and 4GDH-3P (40 years). It means that the 3GDH-2P needs to be replaced once and the 4GDH-3P needs to be replaced twice in 100 years. The environmental impact of both technologies is identical accounting for this replacement rate of the pipes. Second, applying the lifetime estimate of the *manufacturers* 3GDH-2P (30 years) and 4GDH-3P (100 years) the 3GDH-2P need to be replaced three times while the 4GDH-3P do not need to be replaced in 100 years. The environmental impact of the 3GDH-2P solution is in this case much larger than for the 4GDH-3P solution.

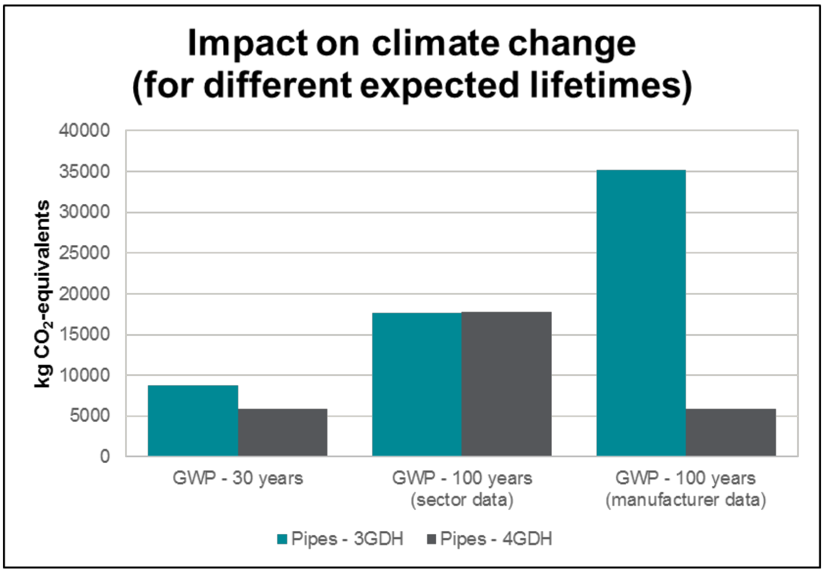

Figure 8 **Environmental impact of systems for different lifetime estimations.**

4.3.2 The impact of energy delivery

The corresponding environmental impact from the energy delivery for the two systems is presented in Figure 9. The results show that the impact from the energy delivery is significantly higher than the impact from the production of the pipes: which confirms that the production of the pipes has a very small environmental impact compared to the energy they use whilst in operation. It is therefore very important to have efficient energy usage that is as renewable as possible in order to leave as low a carbon footprint as possible, independently of district heating technology generation.

LCI data for thermal energy production from solid biomass in Sweden is used for the approximation of the environmental impact of the energy delivery (Thinkstep, 2018). The energy delivery is foreseen for 30 year operational life of system and for 100 year operational life of system. The differences amongst the 3GDH and 4GDH solution are minimal, having an approximately two percent lower environmental impact for the 4GDH solution.

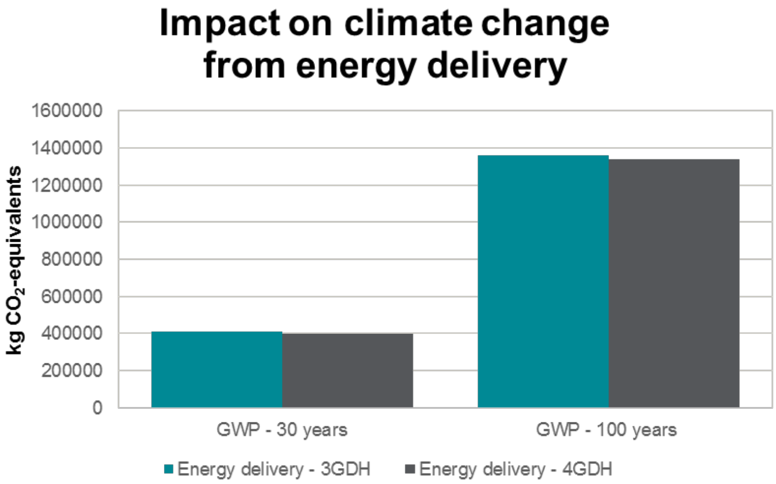

Figure 9 **Environmental impact of systems from energy delivery.**

4.3.3 The impact of district heating substations

The environmental impact of the district heating substations is different in the two systems since the 4GDH-3P solution necessitates a larger number of substations that then 3GDH-2P solution. The environmental impact in the two systems is calculated by using the installed total capacity in heat exchangers. Generic data are used to calculate the environmental impact of the substations. The data contains information of the environmental impact of the production and disposal of substations per kW installed capacity and are taken from a generic database entailing data on district heating substations in district heating systems (Thinkstep, 2018). Installed capacity differs in the studied systems since more substations are needed for the 4th generation (115) than for the 3rd generation (11). For the 3rd generation systems a capacity per substation is assumed of 62.4 kW (used by EKSTA in Särö) which is higher than for the 4th generation systems (38kW).

The lifetime of the substations, both in 4GDH and in 3GDH is expected to be 30 years. 10 shows the results for the environmental impact of the installed substations for both systems.

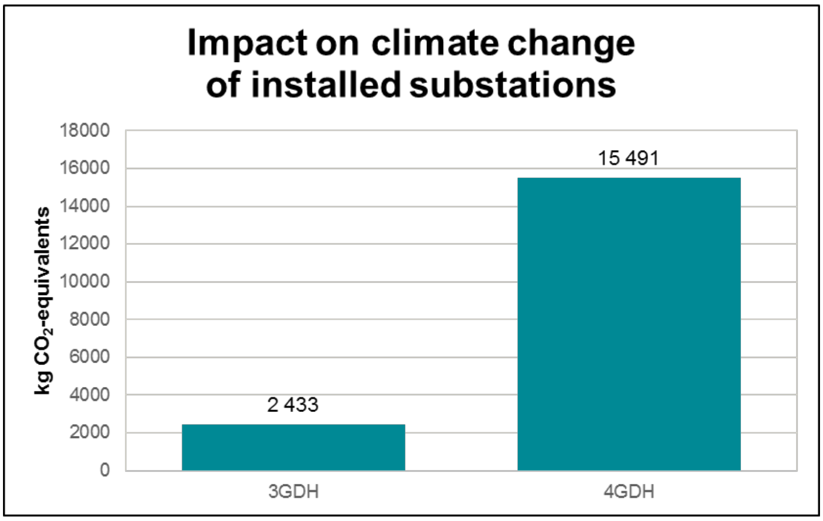

Figure 10 Environmental impact of installed substations in 3GDH compared to 4GDH

4.3.4 Comparing the impact of the pipes with the impact of the substations

The distribution of the environmental impact per system for the included components in this study is presented in Figure 11. The figures show that the environmental impact of the substation is higher than the impact of the pipes for the 3rd generation. The impact of the substation for the 4th generation is higher than the impact of the pipes for 4th generation district heating installations. In both systems, energy delivery has the largest environmental impact.

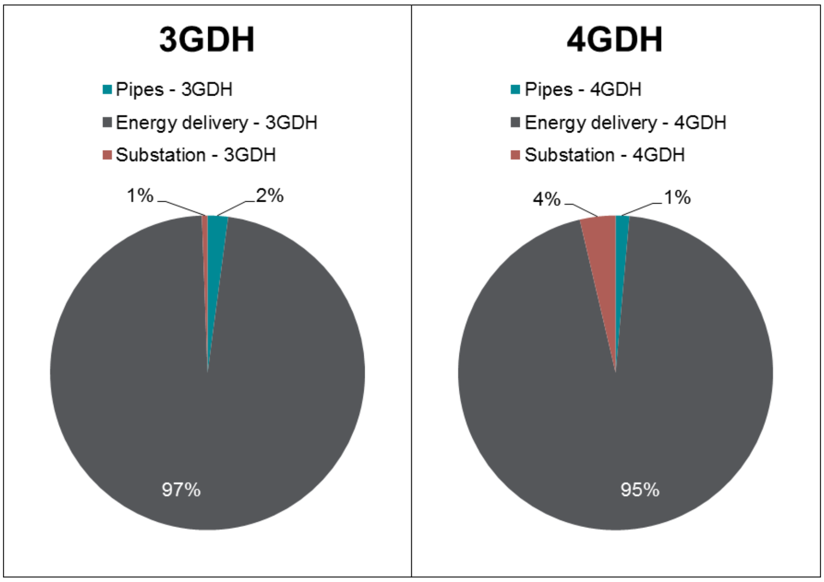

Figure 11 Distribution of the environmental impact per system for the studied components

4.4 SUMMARY OF THE MOST IMPORTANT RESULTS

In the project some results were identified that are of greater relevance for implementation than other. These results are summarized in table 4. Regarding temperature and distribution losses it is concluded that the return temperatures of 4GDH are lower than 3GDH. The monetary savings from the reduced temperature level have not been quantified in the study but should be important. When it comes to distribution losses the fact that additional piping is needed inside of the buildings increases the distribution loss of 4GDH and makes it slightly higher than the distribution losses in 3GDH network.

Concerning costs, the study has focused on understanding the cost of substations, pipelines and VVC losses. One saving with 4GDH that is not quantified is the omission of technical rooms for substations. Another saving is the cost of installing VVC, it can be excluded in the 4GDH case.

When it comes to environmental impact, the 3GDH steel component triggers higher negative environment impact than 4GDH per meter. Even though the 4GDH pipes are needed in larger lengths (inside buildings) and their operational life is shorter than the 3GDH pipes they have a smaller environmental impact than 4GDH pipes.

Studied parameters	3GDH	4GDH	Comment
Return temperatures	Higher	Lower	Unknown how large the cost saving is in 4GDH compared to 3GDH
Distribution losses	Lower	Higher	The 4GDH distribution losses in ground are smaller than in the 3GDH. The additional losses in the pipes inside of buildings generate additional loss to the 3GDH solution.
Cost - **substation**	Lower total cost for Särö with the large substations	Higher total cost for Särö with apartment substations	The gain of not having to install technical rooms for the substations is unknown. It is a saving in the 4GDH case

-piping	Higher cost per meter 3GDH pipe	Lower cost per meter 4GDH pipe	compared to the 3GDH case. Since additional piping has been assumed to be installed in the buildings the number of meters of 4GDH is extensively increased which drives cost.
-VVC	The annual loss is 115 MWh (80 500)	0, no VVC is needed	There is a cost of VVC installation in 3GDH. The savings from not needing VVC in 4GDH are not known.
Environment	Higher environmental impact per meter	Lower environmental impact	The life of the 4GDH pipes is unknown, assuming that the assessment of the industry of 40 years for plastic pipes and 75 years for steel pipes the 4GDH solution needs to be substituted twice in a timespan of 100 years. This increased the environmental impact of 4GDH, but it is still at pair with the 3GDH.

Other important conclusions are drawn by EKSTA. Based on the results and the increased understanding of the 4GDH technology there is no doubt that the technology can be managed. The more difficult part is to understand how the changes impact the district heating business as a whole. The boundary conditions between the customer and the energy provider will change and the conventional district heating business must be revisited. The result of 4GDH will be lower losses for the building owner and more losses and responsibility for the district heating company. In a future of passive houses the heat volumes will be lower and the need for a transparent and trusting relationship between building owners and district heating companies needs to be established. In such a scenario, the consequences of the new technology on the district heating business can generate a competitive advantage.

EKSTA is interested in taking the next step and implementing the 4GDH in a physical demosite. Meeting the challenges of 4GDH installations will enrich the way that district heating business is conducted which is imperative in the increasingly competitive Swedish heat market.

4.5 RESULTS ON ELECTRICITY AS ADDITIONAL HEAT SOURCE

The fourth part of this study is linked to the development of electricity price in Denmark. It shows periods of cheap electricity due to extensive wind power generation. In this study, the possibility to have electricity driven additional production unit has been explored.

With 4GDH-3P the temperature levels in heat distribution will be significantly lower than in 3GDH-2P. Lower supply temperatures make it possible to use more heat from solar collectors since heat from the sun can be distributed even if the supply temperature is 50 degrees Celsius (compared to the conventional 86 degrees in 3GDH-2P). The return temperatures in the distribution networks will also be lower (20 degrees compared to the conventional 47 degrees). Lower temperatures reduce the need for storage as it is possible to reduce/lower the storage to a lower temperature level in 4GDH-3P compared to 3GDH-2P. In total, lower temperatures and smaller storage units make solar heating relevant in the 4GDH-3P context.

In this pre-study, we have assumed that Nya Särö would be using 4GDH-3P and that solar heat would cover 75% of the heat demand of the area. This means that an additional heat source is needed, in this case it is foreseen to be electricity to profit from periods of low electricity price resulting from ample wind power (or other intermittent renewable production?) in the future energy system. To meet targets on climate change, renewable alternatives are needed. Across Europe, solar and wind power are areas where heavy investments are taking place. As a result the energy system is challenged in that the provision of electricity becomes intermittent, resulting in volatile price (e.g. lower prices when it is windy). Studies show that there is a link between substantial wind and electricity price (Sköldberg, Unger, & Holmström, 2015), (OECD/IEA, 2016).Long time spans with low prices makes it increasingly interesting to make use of the low electricity prices.

The conventional additional heat source is a pellets boiler. In this study, we simulate the difference between an additional heat sources operated by electricity or by pellets. The additional heat source of this study is needed during the winter period (November 1-April 30). This means that in the summer period, heat can be stored for later usage. In September, the storage is fully charged and in October, a discharge of 30MWh is assumed allowing for a recharge of the storage when the price of electricity is low. The assumptions for the calculations below are provided as appendix 1.

4.5.1 Conceptual design

One precondition for the sun collector solution is that the heat availability is high (a complete list of the assumptions made for the simulation is provided in Table 3 below). For Nya Särö 1900 m^2 solar collectors and a water based heat storage of 7500m^3 (only volume that can be charged and uncharged) would be necessary for the 75% coverage. Allocated at the apartment level it means that 18m^2 of sun catchers and 70m^3 are needed. The large water volume is needed to generate flexibility and the option to add heat from an additional heat source of electricity when the price of electricity is low. If the additional heat source is operated on a continuous basis, November 1-April 30, it needs an effect of 57kW. To have a sufficient margin for unavailability of the solar collectors or fewer solar hours than average it is assumed that an effect of 100 kW is suitable for an area with the size of Nya Särö.

The conceptual layout of the installation is provided in Figure 8. Solar collectors primarily deliver heat to the low tempered district heating network. If the water temperature from the heat collectors is higher than desired return water from the distribution network is pumped to the supply line resulting in the desired supply temperature of 52 ° C. When the sun collectors are generating more heat than the heat demand the excess heat is stored at the temperature level of 85 ° C. This is to avoid reaching the maximum temperature of water based storage (95 degrees Celsius). At 95 ° C the excess heat is chilled through air chillers to avoid the risk of the water turning into steam. The additional heat source is connected in parallel with the sun collectors and feeds, when needed, hot water to the storage at 85 ° C. That way the solar collectors and the additional heat source primarily provide heat to the distribution network.

70 degrees Celsius in the supply temperature makes the losses lower than at 85 degrees Celsius. The supply temperature curve is lower at all outdoor temperatures during heating season. Thereby, it becomes a more robust system to operate when the temperature level from the solar collectors or heat storage do not hold the temperature necessitated by the network. This, in turn, means that the system can reach a higher level of solar energy.

The additional heat source is started up on November 1st and the effect of the heat source is determined by calculating the heat volumes required from the storage at a certain point in time (to manage the heat demand until April 30th in the following year). When the heat from the sun collectors is not sufficient to meet the heat demand, heat is taken from the storage at 85 ° C.

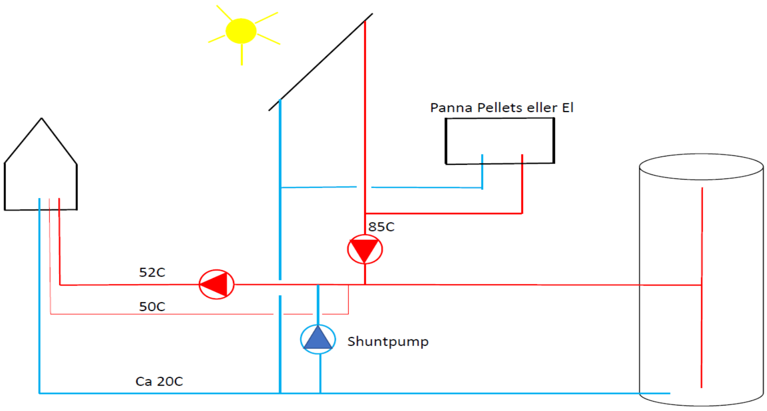

Figure 12 Conceptual layout of the installation.

4.6 IS THERE A BENEFIT FROM LOW ELECTRICITY PRICE?

The current electricity taxation and the effect charge (made by owners of the distribution networks) impact the potential to use electricity as additional heat source. This is accounted for in the simulation.

It is assumed that low electricity prices will occur during night time (21-06) and during weekends since the electricity demand from industry is low in those periods.

We have resorted to the Danish experience (DK1) and assume that the situation in Denmark reflects the future energy system in Sweden. In Denmark, wind power is more frequently installed than anywhere else.

Reviewing statistics for the time period of 2013-2017 the results show that on average the electricity price is lower than 200 SEK/MWh for 898 hours annually. The average electricity price was, during these hours, 108 SEK/MWh. Three scenarios have been made at price levels 200 SEK/MWh, 100 SEK/MWh or 0 SEK/MWh. In the scenarios the usage of low price electricity is set at 800 hours.

We have also developed statistics correlated to wind speeds in 2008-2017 South Sweden by collecting data from Vinga lighthouse outside of Göteborg. According Söder (2017) ,future wind turbines will have maximum power generation at wind speeds above 10m / s. The results show that on average over the studied period, it blows more than 10 m/s for 703 h/year. This validates that 800h is a reasonable assumption of the number of low price electricity hours.

The annual cost and heat production price per kWh for a pellets boiler is 173 kSEK and 0.7 kSEK/MWh, respectively. This value constant regardless of electricity price.

Simulation: 800 hours of low electricity price

A simulation has been made where 800 hours of low electricity price is used at different costs per MWh (200 SEK, 100 SEK and 0 SEK). The results of the simulation are summarized in table 5 and show that the annual cost for the electricity boiler goes from 1.3kSEK/MWh to 1.1 kSEK/MWh. Not until the tax and effect charge is removed the electricity boiler becomes more cost efficient than the pellets boiler.

From the simulation it is concluded that regardless of the price level of electricity, the current system of taxes and charges on electricity make the usage of electricity boilers inefficient as additional heat sources.

To make low priced electricity a competitive alternative, to pellets, for additional heat production the current taxation and effect charge need to be removed.

Table 5 The consequences of removing electricity taxation and effect charge.

Electricity price kSEK/MWh	Annual cost taxes and effect charges included (heat price kSEK/MWh)	Annual cost no taxes	Annual cost no effect charges	Annual cost no taxes or effect charges
0.2	319 (1.3)	232 (0.9)	239 (1.0)	152 (0.6)
0.1	292 (1.2)	206 (0.8)	213 (0.9)	127 (0.5)
0.0	267 (1.1)	182 (0.7)	188 (0.8)	102 (0.4)

The current taxation and charges incentivize the usage of biofuels to low price electricity. Biofuels is a limited, future, resource that can become scarce making the current tax and charge structure on electricity undesirable. In addition, making use of electricity during night time and over weekends creates a better balance in the electricity system, especially when it is windy.

5 Conclusions and recommendations

4th generation solution increases overall energy efficiency in buildings. The key driver is that the need for heating for hot water circulation in buildings is removed. Considering the pipes only the distribution losses are also lower compared to the 3rd generation solution.

The 4th generation solution necessitates more meters of pipeline since it goes into the building, into the apartment themselves. This introduces new boundary conditions for the district heating provider. In the conventional solution, district heat is switched to the customer at the wall of the building. The switch in the 4th generation solutions takes place at the apartment level. This means that the heat losses inside of buildings are not carried by the owners of the buildings but by the district heating provider. In the customer dialogue, this can create good will from the view of the consumer since there is complete transparency on heat losses. With a contractual arrangement allowing for a split of the heat loss in the building, both the owner of building and the heating provider can benefit.

With the apartment switch, the risk for Legionella is removed. A solution removing the risk of Legionella completely is out of scope or the recommendations in current policy documents on Legionella (Boverkets Byggregler) and a dialogue with the policy maker is needed to facilitate the 4th generation implementation.

The apartment switch necessitates additional investment compared to the conventional solution with a heat exchanger in the ground floor/ basement of a building. This means that there is a limitation to the cost efficiency of the 4th generation solution making it apt in buildings with up to 10-15 apartments in each. This situation can change in the future if apartment switches become standard, and hence cost efficient.

Considering the environmental impact, the steel core of the 3rd generation pipes has a negative impact. I the 4th generation solution the environmental impact per meter of piping is significantly lower than in the 3rd generation solution. Even taking the extra metering needed in Nya Särö into account, the environmental impact of the 4th generation solution is lower. The operational life of the 4GDH-3P is not yet proven. If it is long, as suggested by the manufacturers (100 years) or shorter as suggested by the industry (40 years) greatly impacts the environmental gain of 4GDH-3P.

For solar heating, the 4th generation technology is very apt reducing the cost gradient significantly. In a solar context, storage for making use of cheap electricity would be relevant. From our simulation we find that with the current policy framework (effect costs, taxes etc.). it is not possible to make use of cheap electricity. This implies that current policy creates an inefficient usage of low cost electricity in times of low demand (nighttime).

The project group concludes that the potential for 4th generation solutions is large. One step for increased implementation is to provide practitioners with answers to the questions they have. The technology is new to the district heating companies, to their customers and to the actors installing it.

The results in this report provide some answers but also raise additional questions. The 4th generation solution needs to be implemented in physical demosites. Demonstration projects in different kinds of buildings (single family, multi family, commercial) is needed. Designing the business model for the demo sites should include comparisons with the current business model (the logic of the 3rd generation). Modernization of the district heating industry is needed if it will remain as a backbone of future cities. Further exploration of 4th generation is necessary in this quest.

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7 Appendix

Appendix 1. Assumptions for calculations

Assumptions		
Pellet fuel boiler 100kW		
Investment	825 000	SEK
Capital cost per year (annuity), 25years, 6% interest	0,078	
Fuel (pellets)	275	SEK/MWh
Efficiency	90	%
Operation and maintenance (fixed)	136	SEK/kW,år
Operation and maintenance (flexible)	68	SEK/MWh
Electricity boiler 310KW		
Investment		
Boiler	175000	SEK
Connections	500000	SEK
Capital cost per year, annuity, 25years,6% interest	0,078	
Operation and maintenance	0,5	% of investment
Electricity network		

Fixed cost	2850	SEK/year
Flexible effect	43	SEK/kWmonth
Flexible energy	5,27	SEK/MWh
Electricity taxes	349	SEK/MWh

ANALYSIS OF 4TH GENERATION DISTRICT HEATING TECHNOLOGY COMPARED TO 3RD GENERATION

Swedish district heating companies are challenged by increasing competition, lower heat demand and new customer needs. The industry has successfully phased out fossil fuels and currently biofuels and waste are the most prevalent heat sources. However, this is not sufficient to create future competitiveness.

In the future, it is increasingly important to develop heat production and the district heating business to remain competitive. One possibility is to increase the usage of excess heat sources from both industrial processes and from low temperature heat sources, from waste water, infrastructure and cooling processes for example. Such transformation necessitates business models allowing for multiple, small heat sources delivering heat into the distribution network, central heat storage and alternative usage for heat, for example by transforming it to cooling.

To engage in implementation of the new technology, data are needed that point to a cost-efficient solution. Unless the new technology can be proven to result in an efficient business its possibility for large scale implementation is low. Pre-studies that can quantify the potential of the technology are needed. This is one of them.

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