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.

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Authors: Emanuele Zilio, Maja G. Minzari, Peter B. Reisler, Reto M. Hummelshøj, Robert A. Sederberg-Olsen (COWI Denmark A/S)
Anders Jirdén, Markus Falkvall (Kraftringen Energi AB)
Uffe Schleiss (Høje Taastrup Fjernvarme AMBA)

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Dissemination level:		
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Scope of deliverable

The report aims to present the design process as well as the requirements adopted in low-temperature district heating network. New technical solutions, such as pipe dimension and pressure losses, are evaluated in order to optimise the design of the network. Lastly, the investigation results of two real cases are presented to show the improvements that can be obtained in a LTDH network.

Context of deliverable

The reduction of the supply temperature in district heating networks is related to the aim of reducing heat loss in the distribution network and including low-temperature energy sources in the heat production. In particular, this report focuses on the characteristics that low-temperature district heating networks should have and the factors that influence its performance. The report shows the design process and the results of two low-temperature district heating networks. The first one is located in Denmark in the city of Høje-Taastrup, where a part of an existing district heating network is going to be replaced with a low-temperature district heating network that will use surplus heat from a shopping mall as heat source. The existing buildings connected to the existing network will be upgraded to be ready for the low-temperature supply.

The second case is located in Sweden in the city of Lund. In the Brunnshög area, a completely new area is going to be built, which will include research facilities, offices and residential buildings. A new low-temperature district heating network will be implemented in the area, which will utilise the surplus heat from the world's strongest synchrotron microscope (MAX IV) located in the area.

Perspective of deliverable

The report provides information about the design process of a low-temperature district heating network, highlighting the design factors that lead to the reduction of the heat losses in the distribution pipes and consequently can optimise the network. Furthermore, the results of two real-scale demonstration projects are shown in order to present the achievements of the implementation of the low-temperature district heating technology.

Involved partners

COWI A/S (COWI-DK), Kraftringen Energi AB (UTIL-SE) and Høje Taastrup Fjernvarme AMBA (UTIL-DK).

Prepared by: Emanuele Zilio et. al (COWI-DK)

Checked by: Maja G. Minzari, Reto M. Hummelshøj (COWI-DK) and Markus Falkvall (UTIL-SE)

Approved by: Reto M. Hummelshøj (COWI-DK)

Summary

The design phase of a district heating system defines the technical aspects of the network, and this phase has a particularly high influence on the heat losses. A traditional system is usually oversized to guarantee a safety margin for the operations. However, this choice affects the heat losses negatively.

In traditional networks, the heat losses account for around 17% in high energy density areas but can be up to 35% in low energy density areas. Around half of the heat loss is in the connection lines (service pipes) of the consumers. In contrast, the energy used for pumping is around 2% of the supplied heat. Therefore, through a hydraulic optimisation of the network it is possible to increase the pumping losses and reduce heat losses, which have a high impact on operation costs.

The purpose of this report is to explain the design process that can lead to the reduction of the heat losses in a district heating system as well as to present the main factors that affect the heat losses. In particular, the factors considered are: improved pipe insulation, use of twin pipes, reduced pipe size, reduced pipe length and the distribution principle in between the buildings.

The level of insulation of the pipes can affect the performance of the network greatly. From the pipes catalogue, it is possible to see that the heat loss from double pipes with the highest level of insulation can be around 50% lower than a single pipe with the lowest insulation level.

The diameter of the pipes can also affect the heat losses in the network. A smaller diameter can guarantee a reduction of the losses. However, smaller diameters lead to higher pressure gradients in the pipes and the increase of the pumping requirements. The first phase of the optimisation of Østerby's district heating network showed a reduction of heat losses by 45% thanks to a hydraulic optimisation and implementation of double pipes with the highest insulation instead of low insulated single pipes.

The optimisation of the network's length is another important factor that can lead to a relevant reduction of the heat losses. The length optimisation can be performed reducing the length of the service pipes. For example, the optimisation of the network's length in Østerby district led to the reduction of 1 km of service pipes, out of 3.7 km, and a reduction of the heat losses by about 23%. The percentage of heat losses in relation to the supplied energy was about 10.8%.

The district heating network located in Brunnshög was optimised applying the same process where the network was hydraulically optimised in order to reduce the losses. Since the area is under development, the initial design and optimisation of the network had to consider the possibility of being expanded in the future. It was evaluated that in the initial phase, the heat losses are around the 9% of the total delivered energy due to the low heat demand. They will be lower percentwise once the network runs at full load, accounting for around 3% of the total delivered energy.

COOL DH
COOL DISTRICT HEATING

Contents

1 Introduction

COOL DH is a research project founded by Horizon 2020, the biggest EU research and innovation programme. The acronym 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". The purpose of the project is to investigate new technical solutions that can be applied to low-temperature district heating (LTDH) networks in order to guarantee the comfort of the users as well as increase the share of renewable energy. An interesting part of the project is the creation of two real-scale demonstration projects where the technical solutions investigated and developed in the research can be implemented. The first test case will be conducted in the city of Høje-Taastrup in Denmark where a renovation plan will be applied to existing buildings as well as to the district heating (DH) network, which will be upgraded to achieve a LTDH. The second case is located in the city of Lund in Sweden where a new district is under development and construction. In the area, new residential buildings, research facilities, offices and other types of buildings are going to be built and connected to the new LTDH network.

2 Background

The aim of the European Union (EU) is to reduce the CO_2 emissions related to human activities and in order to define the targets that have to be reached, a detailed plan was developed. It was established that the greenhouse gases (GHG) emissions have to be reduced by about 20% by 2020, by 40% by 2030 and by 80% by 2050, where the reduction percentage is in relation to the GHG emissions measured in 1990, which is used as reference year (1).

The building sector has a relevant impact on the energy demand in the EU; the energy consumption for heating and cooling in building and industry accounts for 50% of the EU's annual energy consumption (2). Regarding the energy demand for heating and cooling in households, it accounts for the 80% of the total energy use. Therefore, improving the energy performance of the building sector by focusing on the construction and the design of efficient systems can lead to a relevant reduction of the energy consumption (3).

2.1 District heating networks development in history

The development of the DH networks led to significant improvements in the heating supply and a gradual reduction of the heat losses in the distribution network, related in particular to the reduction of the supply temperature.

The first DH networks generation was introduced in the USA between 1880 and 1890 and it used steam as heat carrier. The technology was expanded in the USA as well as in Europe until 1930. The systems were highly inefficient due to the high heat losses and the risk of accidents was high due to the high pressure of the steam. Concrete ducts were used in the distribution network, however, for other components corrosion was a relevant problem, which also affected the efficiency of the systems (4).

In the second generation, steam was replaced with pressurized water as heat carrier with supply temperatures that were normally above 100°C. This type of system was developed around 1930 and was used until the 1970s. The systems consisted of distribution concrete pipes and other heavy and large components. The primary reason for the development of such systems was to save fuel and increase comfort (4).

The third generation of systems was introduced in the 1970s with a larger expansion in the 1980s and after. The systems still used pressurized water as heat carrier, but the supply temperature was usually lower than

100°C. In these systems, new prefabricated and pre-insulated pipes were used for the distribution system. A large part of the existing DH networks belongs to this generation, even though a renovation process has already been initiated in order to improve the performance of the systems. The trend is towards the new DH systems generation with a remarkable reduction of supply temperatures, widespread use of assembly-oriented components and use of more flexible pipes (4).

Nowadays, standard (and existing) district heating networks are over-dimensioned in order to ensure a safe margin of the heating supply capacity. However, this solution leads to high heat losses in the distribution network, which are typically around 17%, but can reach peaks of around 35% when the energy density is low. The heat losses are defined in the design phase and therefore, with an optimisation of the network design, they can be substantially reduced.

The role of the new DH systems generation (fourth generation) is becoming increasingly relevant, mainly in relation to the targets imposed by the European Union's roadmap towards a sustainable energy system and reduction of GHG emissions. The building sector has a relevant role in the integration of renewable energy sources in the energy market. Due to the building renovation plans and the low energy requirements in newly constructed buildings, the energy demand in the building sector is decreasing. This leads to the possibility of implementing low-temperature systems in buildings, which can be connected to LTDH networks.

The reduction of the supply temperature in the DH network leads to lower distribution losses and integration of sustainable heat sources, such as waste heat recovery, geothermal energy, solar energy etc.

3 Purpose

The purpose of this report is to present and explain the design process that has to be undertaken during the design of a LTDH network. As mentioned in Chapter 2.1, the heat losses, and consequently the efficiency of the entire system, are defined in the early design stage. Therefore, a precise and systematic design process can improve the performance and optimise the network.

In order to optimise the system, the investigation has to consider, firstly, the estimation of the users' energy demand and its development in the future. Afterwards, focus is on the design of the network, with the choice of the supply temperature and the use of specific pipes that can reduce the heat losses and optimise the network. The high percentage of heat loss in the network has a large impact on operation costs. On the other hand, the pumping losses are considerably lower. Therefore, one way to reduce the total operation costs is to increase the pressure losses by a certain percentage, which can be achieved by reducing the pipes' diameter. This solution leads to a remarkable reduction in heat losses, reducing the operation costs of the system significantly.

The purpose of this report is to show the optimisation process undertaken in two different real-case projects. As mentioned in Chapter 1, the first demo site is located in Denmark in the city of Høje-Taastrup, where a LTDH network is going to be implemented in a residential area that was renovated. The second case concerns a new area located in Sweden in the city of Lund where research facilities, commercial and residential buildings are going to be built.

4 Design process of a LTDH network

This chapter introduces the design process for the optimisation of a LTDH.

4.1 Heat demand forecast/energy planning

The first step of the LTDH network optimisation process is energy planning and mapping of different areas to evaluate the feasibility of a new LTDH network.

Once an area is defined as suitable for LTDH, it is necessary to assess the development plan of the area, so that it is possible to estimate the future requirements of the network. In particular, it is important to forecast the future heat demand, considering both space heating (SH) and domestic hot water (DHW). The condition/age of the building stock is evaluated, so that the heat demand can be more accurately estimated.

It is necessary to know the potential renovation actions in the buildings as well as any new constructions planned in the area. Furthermore, the aim of the mapping and energy planning is to identify the potential energy sources that can be used for the energy production. Nowadays, in LTDH networks, it is relevant to take advantage of the decentralised sustainable energy sources.

A LTDH network is suitable both for new and existing areas, even though the implementation process is slightly different. In new areas, where all the buildings are new, the low energy demand and the low-temperature space heating systems make the low-temperature supply particularly suitable. On the other hand, in existing DH areas, a renovation process can be carried out to make them suitable for LTDH connection. It is important that the heat demand estimation for a LTDH network is made after a potential renovation of the buildings; otherwise, in case of later renovations, the network will not be optimised.

4.1.1 Optimisation of an existing area

As mentioned above, LTDH can be implemented in existing networks. In order to facilitate the transition to low- temperature supply, an existing DH area can be divided into sub-areas, which are managed and upgraded separately.

Due to the renovation of the building stock connected to a traditional DH network, the supply temperature used in the design phase of the network can be too high with consequent high heat losses in the distribution pipes. Therefore, it can be convenient to lower the supply temperature, initially by around 5-10°C. This first step is called Flow Temperature Optimisation (FTO). The FTO ensures optimal setpoints for inlet temperatures at the users and minimises the heat losses in the network with a saving in the range of 2-5%. If necessary, a first check of the network is carried out, since old installations can lead to problems with this first optimisation.

The second step of the transition to a lower supply temperature is to check the return temperature at the users. In particular, a Return Temperature Optimisation (RTO) is implemented. The users that present a high return temperature are checked to optimise their use of the heat supply. Usually, improvements/updates of the heating systems at the consumers are required. Optimisation of the return temperature ensures lower heat losses in the distribution network and consequently to a lower return temperature. The aim of the RTO is to keep the same temperature difference between the supply and the return temperature.

However, for old DH networks with short remaining life, it may be inexpedient to keeping existing installations may not be worth the efforts due to too high maintenance costs, a non-optimised network and high heat losses. Therefore, in these cases, replacing the DH network and implementing a new optimised LTDH network may be a better solution.

4.2 Network factors

The following sections introduce the factors that influence the optimisation of a LTDH network. By acting on these factors, it is possible to reduce heat losses and therefore achieve a reduction in operation costs, while fulfilling the comfort requirements of the consumers. Table 1 presents the factors that can influence the DH network optimisation.

Table 1. Factors that influence the DH network optimisation

Factor	Description
Pipe insulation	The available pipes have different level of insulation. Furthermore, the pipes are divided into single pipes and double pipes (twin pipes).
Pipe size	The diameter of the pipes influences the pressure losses and the heat losses of the network.
Pipe length	The pipe length has a high influence on the heat losses. The length of the networks should always be minimised.
Distribution principle in the buildings	At the building level, the supply pipes can be designed in different ways, influencing the heat losses.

4.2.1 Pipe insulation

The first factor considered for the optimisation of the LTDH network is the insulation of the network's distribution pipes. It has a relevant role in limiting the heat losses in the distribution network. There are different levels of insulation available on the market. They are indicated with a number from one to three. In particular, the pipes with thinner insulation are indicated with "Series 1", while the thickest insulation is indicated with "Series 3". Furthermore, as shown in Figure 1, the supply and return pipes can have separate insulation (on the left) or joint insulation (on the right) where the two pipes are pre-insulated together in a joint insulation. The second type of pipes is usually called "double pipes" or "twin pipes" and they guarantee a reduction of heat losses by up to 30 % compared to single pre-insulated pipes.

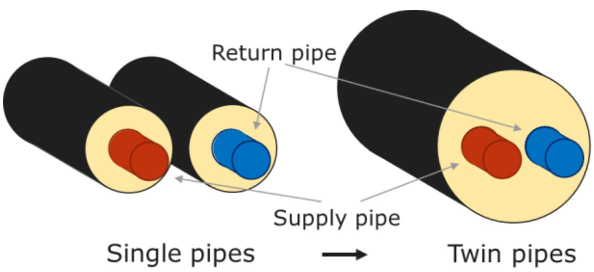

Figure 1. The heat losses can be reduced using twin pipes instead of single pipes

In order to reduce the heat losses of the DH network, twin pipes characterised by the thickest insulation level seem to be the ideal solution; however, in the design phase, the higher investment cost has to be considered.

4.2.2 Pipe size

The second factor considered in the LTDH network optimisation is the pipe size since the diameter influences the pressure losses as well as the heat losses. A larger diameter reduces the pressure drop and consequently the pumping costs, but it increases the heat losses. In contrast, smaller diameters lead to higher pressure drops, but decrease the heat losses. The heat losses in a standard DH network are normally around 17% when the energy density is high but can reach values of around 35% in low-density energy areas. In comparison, the pumping losses are usually around 2%. Therefore, it can be relevant to increase the pressure drop in the network to reduce the heat losses.

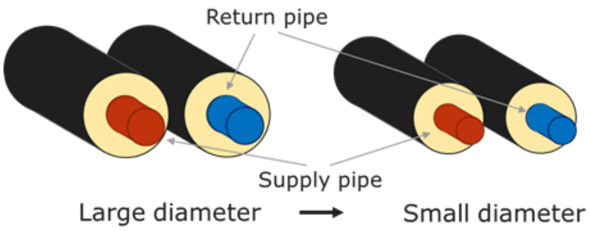

Figure 2. The heat losses can be reduced reducing the diameter of the pipes

As shown in Figure 2, the pipes' diameter can be reduced. However, the increase of pumping costs will lead to a higher reduction of the operation cost due to the heat losses. The maximum allowable pressure drop in flat calculations is increased from 100-200 Pa/m to 500 Pa/m.

4.2.3 Pipe length

The third factor that influences the optimisation of the DH network and can reduce the heat losses is the length of the network's distribution pipes. Therefore, if it is possible, the length of the distribution pipes must always be minimised, considering the shortest path between the production point and the consumers. As shown in Figure 3, one way to optimise the length of the pipes is to minimise the number of pipes between the main distribution pipe and the consumers.

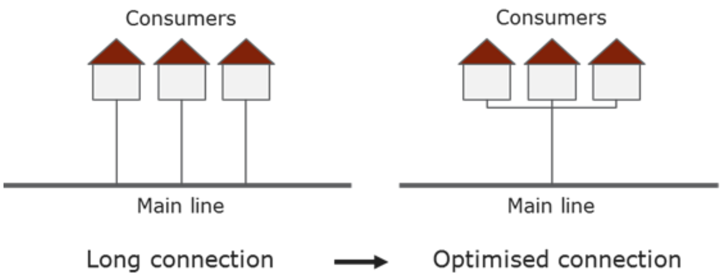

Figure 3. The length of the network has to be optimised in order to reduce the heat losses

4.2.4 Distribution principle in the buildings

The fourth factor that can influence the optimisation of the network is the distribution principle in the connected buildings. In particular, in multi-storey buildings, the distribution pipes can be divided into different shafts as shown in the left-hand image in Figure 4. In each shaft, a set of pipes is placed, which supplies a column of apartments. As opposed to this, as shown in the right-hand image in Figure 4, a single shaft can be designed where a single set of pipes is located; for example it can be located next to the central staircase and it supplies all the apartments.

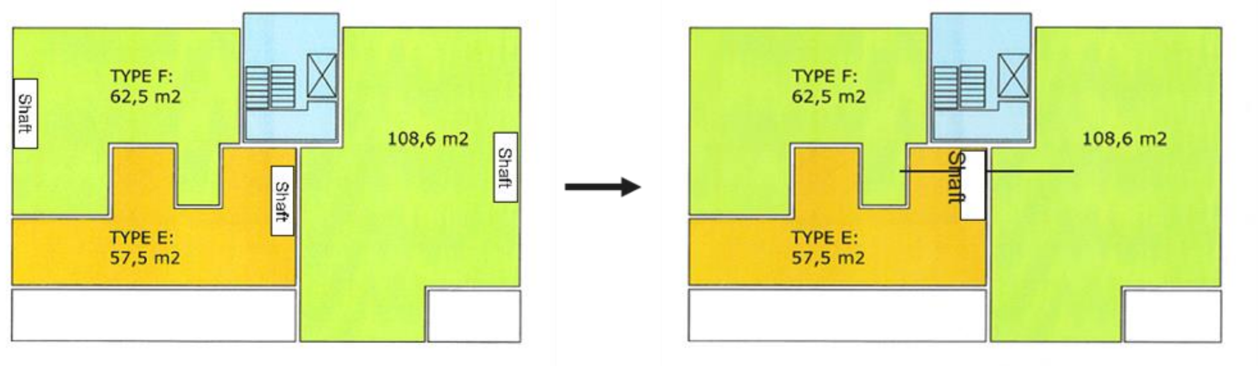

Figure 4. The heat losses can be reduced with the optimisation of the pipe distribution and the location of the technical service shafts in the buildings

5 Prerequisites

5.1 Domestic hot water production and DH supply temperatures

The temperature requirements in a LTDH network are related to the need of ensuring the heat demand for DHW production. The requirements for DHW systems are stricter due to the risk of legionella contamination. In respect of storage tank design, in particular in Denmark, it must be possible to heat up the water to 60°C in case of legionella contamination. However, it is not required to keep this temperature for a long period, as that may result in calcification problems. Another requirement is to keep the water at 55°C in the circulation circuit so that it is possible to have a water temperature of 50°C at the tap. By comparison, less restrictions can be found when micro heat exchangers are used at the consumers where the limited water volume in the system allows for reduction of the water temperature, which can be supplied at 55°C.

The DH network has to guarantee the temperature at the users, therefore, due to the requirements and the heat losses in the distribution network, the supply temperature at the production plant in an LTDH network is usually set around 70°C.

On the consumer side, when a water tank is implemented in the systems, the supply temperature should be kept at 62°C (at the furthest consumer) in order to ensure a water temperature of 60°C in the water tank. On the other hand, if a DH-unit (micro heat exchanger) is implemented, the water has to be supplied at a temperature of 55°C (at the furthest user) in order to ensure a temperature of 50°C at the tap. Lastly, the heat producer has to be able to raise the temperature for short periods, in case of low outdoor temperatures.

However, it is possible to use other technologies to boost the temperature of the DHW (i.e. booster heat pump, electric heater etc.). In this way, the DH supply temperature can be lowered even below the requirements for the DHW production.

5.2 Plastic pipes

The use of plastic pipes in LTDH networks is related to the interesting features that the material guarantees. In particular, plastic pipes require lower maintenance due fewer problems with corrosion compared to steel pipes. On the other hand, they are more sensitive to the water temperature and pressure. High temperatures can cause the plastic to deteriorate faster and consequently shorten the life of the pipes. The deterioration of the plastic reduces the ability of the pipes to withstand high pressure and consequently they can be damaged faster. However, the most recent products ensure a long life also in case of pressure about 10 bar and with a water temperature of up to 80°C, which make them particularly interesting and suitable for LTDH applications. They can be even used with higher pressure (e.g. 13-16 bar) at a lower service temperature.

6 Investigation cases

The aim of the COOL DH project is to investigate and demonstrate new technical solutions for LTDH applications. As mentioned above, two real-scale demonstration cases are going to be built. The first one is located in Høje-Taastrup, Denmark, where, in the Østerby district, a new LTDH network will be implemented to replace part of an existing network. The second project is located in the city of Lund, Sweden, where, in the Brunnshög area, a new residential research and commercial district will be developed. In this area, the world's strongest synchrotron microscope (MAX IV) and the European Spallation Source (ESS) will be built.

6.1 Østerby

Østerby's DH network, owned by Høje Taastrup District Heating Company, had a limited remaining life and presented high heat losses after the renovation of some of the connected buildings. Therefore, the DH network became over-dimensioned in relation to the new heat demand. The maximum size of the pipes was DN150, which was previously designed for a DH network with supply and return temperatures at 85/50°C. However, even when the temperatures were reduced to 65/48°C, the heat losses turned out to be very high in any case. In December 2017, a temperature drop of 7°C was measured in the supply flow temperature over a length of 200 m.

In the area, different housing associations owned the different buildings and, consequently, different technical installations could be found in the buildings. For example, some buildings had a dedicated energy meter for each user, while others had only one energy meter for the entire block. As shown in Figure 5, the area was supplied by a centralised heat exchanger located at the end of the main distribution network (red line) in the middle of the figure. From this point, an internal DH network guaranteed the direct connection of the SH system for all the consumers, while different types of units were implemented in each building for the DHW production. The distribution pipes of the existing DH network were placed under the buildings. Since it is not possible to adopt the same solution in the new LTDH network, the distribution pipes of the new network will be longer than the existing one.

Figure 5. Existing DH network in the Østerby district (Red Line: Høje Taastrup District Heating company network. Green Line: internal DH network)

Østerby district appeared to be an ideal area for the transition to LTDH. Due to the lower heat demand and the short remaining life of the network, the performance of the existing DH network was not optimal. In relation to the COOL DH project, Høje Taastrup District Heating Company proposed the replacement of the existing DH network. A LTDH network supplied by a sustainable heat source was considered as an alternative. In particular, the surplus heat from the cooling systems operating in the nearby shopping mall called "CITY2" is used as heat source. Furthermore, the surplus heat from the cooling systems of the server rooms at Danske Bank data centre as well as another nearby office and hotel is planned to be used as heat source. Heat pumps will be implemented to utilize the surplus heat, which will be supplied to the LTDH network. The cooling and heat pump systems of the shopping mall "CITY 2" will operate at cheap electricity thanks to a 16,300 m² PV plant with an installed capacity of 2.07 MW_p on the roof.

Østerby district is composed of 413 users distributed in different type of dwellings. In the first part of the optimisation process of the new LTDH network, all the buildings were supposed to be supplied by the network. However, during the negotiation process to implement the new network, part of the housing associations decided not to continue with the replacement process. Therefore, the users going to be supplied from the new network are 159 for a total area of 12,692 m², while the remaining 254 users are not going to be connected to the new LTDH network in the first phase. As part of the implementation of the LTDH network, individual DH-units will be installed in each consumer's dwelling.

6.1.1 TERMIS simulation/optimisation

The optimisation process of the new LTDH in the Østerby district was performed using TERMIS, the simulation software provided by Schneider Electric/COWI. It makes it possible to obtain a hydraulic model of the network and simulate the behaviour of flow directions, pressure and thermal conditions in the distribution network.

The first step of the optimisation started with the mapping process of the heat demand in the dwellings and placing of the existing heat exchangers. Since the buildings are managed by different housing companies, different accounting systems are adopted. Consequently, it was difficult to obtain an overview of the heating consumption in the different dwellings. Some of the buildings had a general heat meter, which could not give the consumption of the single users. Therefore, it was necessary to estimate the heat demand based on the surrounding building stock and relate it to the heated area of each apartment.

Following the data collection phase, a representative district heating pipe network was drawn up in CAD and imported to TERMIS. In TERMIS, the various restrictions and boundary conditions were inserted. Some of the parameters to incorporate in the simulation software included allowable pressure loss at the consumer, maximum pressure gradient through the given pipe sections and/or types and maximum supply velocity through the different pipes in the distribution network. With these inputs and considering the expected supply temperature at 55°C and the return temperature at 30°C, TERMIS simulated a static scenario of how to supply the network. The results included the relevant smallest possible pipes that still fulfil the restrictions set beforehand, the flow, pressure gradient and heat loss of the various pipe sections and the network as a whole.

6.1.2 Østerby's DH network optimisation process and results

The first step of the optimisation process was the choice of the pipes for the new distribution network. Table 2 shows the comparison of two types of pipes available on the market. The existing network adopted single pipes from the Series 1, which were characterised by the lowest insulation level, and, consequently, by high heat losses. Therefore, in order to reduce the heat losses of the new LTDH network, double (twin) pipes from the Series 3 will be used. Table 2 shows the comparison between the heat losses obtained with a single pipe from the Series 1 and a double pipe from the Series 3, measured in case of standard conditions. The data are from current steel pipes catalogues (7) (8). As it may be noted, the implementation of double pipes characterised by the highest insulation level leads to a reduction of heat losses of around 50% on average.

Table 2. Heat losses comparison between single pipes and double pipes

Pipe type	**Single pipes - Series 1 (*) (**)**	**Double pipe (Twin) - Series 3 (*)**	**Heat losses reduction using both twin pipes and higher insulation**
	W/m	**W/m**	**%**
DN20	13	7.1	45%
DN25	14.7	7.0	52%
DN32	15	7.8	48%
DN40	17.1	8.9	48%
DN50	18.9	8.6	54%
DN65	22.2	9.8	56%

DN80	22.8	10.3	55%
DN100	24.4	11.1	55%
DN125	28	10.7	62%
DN150	32.7	12.0	63%

***** *Based on new standard catalogue Isoplus pipes (7) (8).*

****** *The reference pipes in Østerby are more than 30 years old, and they certainly have greater heat losses.*

Once the type of pipes was decided, the hydraulic model of the network was implemented in the simulation program. However, to optimise the network, the constraints had to be defined. Table 3 shows the data set in the first simulation model. The criteria were used to simulate the reference scenario (Step 0), which is the new designed network where single pipes are implemented. Furthermore, the same criteria were used with the first optimisation step, called "Step 1", where double pipes were implemented in the network. In the two cases, it was decided to perform a traditional optimisation, without minimising the pipe diameter. The maximum velocity was set to 1.2 m/s and the maximum design pressure gradient was set equal to 100 Pa/m.

Table 3. Design criteria for the reference scenario (Step 0) and the first optimisation step (Step 1)

Design criteria: **Step 0 - Reference scenario** **Step 1 - Pipe optimisation**
Temperature set: 55°C supply / 30°C return Temperature set: 65°C supply / 40°C return (only for Step 0)
Pressure level expected = 10-13 bar
Expected thermal power = approx. 1.2-1.4 MW_{th} (*)
The consumer's DH-unit is connected directly to the supply pipes
No requirement for maximum pipe dimension
Maximum design velocity = 1.2 m/s
Maximum design pressure gradient = 100 Pa/m

(*) with all the consumers connected (entire Østerby district)

Contrary to this, Table 4 shows the data set for the second step of the optimisation, called "Step 2", where it was decided to perform a hydraulic optimisation of the network and therefore limit the maximum pipe diameter to DN80. The maximum allowable pressure gradient in flat calculations was increased from 100 Pa/m to 500 Pa/m and the maximum design speed allowed in the DN 80 pipes was set to 2.3 m/s, even though it was not expected to reach this value.

Table 4. Design criteria for the second optimisation step (Step 2)

Design criteria: **Step 2 - Hydraulic optimisation**
Temperature set: 55°C supply / 30°C return
Pressure level expected = 10-13 bar
Expected thermal power = approx. 1.2-1.4 MW_{th} (*)
The consumer's installation is connected directly to the supply pipes
Pressure difference at the user installation ΔP = 0.5 bar
Requirements for the maximum pipe dimensions set to DN80
Maximum design pressure gradient = 500 Pa/m
Maximum design velocity = 1.5 m/s but it is allowed up to 2.3 m/s in DN80 pipes

(*) with all the consumers connected (the entire Østerby district)

Based on the simulation model, it is possible to obtain the characteristics of pipes that should be used in the network to fulfil the requirements defined in Table 4. Table 5 shows the pipe length for each pipe diameter as well as the length of the network obtained in the three different scenarios. The lengths reported in the table refer only to the distribution pipes, whereas the length of the service pipes is not considered. Furthermore, the table reports the length of the distribution pipes for the entire Østerby district, since initially all the consumers were supposed to be connected. However, as mentioned above, only 159 consumers will be supplied by the new LTDH network.

In detail, the second column of Table 5 (Step 0 - Reference scenario) shows the pipes of the new DH network consisting of single pipes with the lowest insulation level (Series 1), as it was used in the existing network. The system is not optimised since it leads to high heat losses. The third column (Step 1) shows the network's pipes when twin pipes with the highest insulation level (Series 3) are implemented. In this case, a traditional pressure gradient in the pipe was considered so that the pipes' diameters were not limited. Lastly, the fourth column (Step 2) shows the results for the optimised network where the pressure gradient was set higher and the maximum pipe diameter was set to DN80.

Table 5. Pipes lengths for three DH network scenarios: reference scenario, reference scenario optimised and optimised scenario

	Step 0 **Reference scenario**	**Step 1** **Pipe optimisation *(*)***	**Step 2** **Hydraulic optimisation *(*)***
Pipe Type	***Single pipes - Series 1 (**)***	***Double pipe - Series 3 (**)***	***Double pipe - Series 3 (**)***
DN20	0 m	0 m	**1294 m**
DN25	53 m	0 m	**511 m**

DN32	773 m	435 m	**370 m**
DN40	438 m	514 m	**312 m**
DN50	633 m	951 m	**248 m**
DN65	168 m	614 m	**48 m**
DN80	657 m	44 m	**211 m**
DN100	150 m	195 m	0 m
DN125	83 m	275 m	0 m
DN150	17 m	0 m	0 m
SUM	**2971 m**	**2994 m**	**2994 m**

***** *Additional to the previous optimisation step*
****** *Based on new standard catalogue Isoplus pipes*

As shown in Table 5, the "Step 2" scenario guarantees the use of pipes with smaller diameters, which ensure lower heat losses. Figure 6 shows the layout of the DH network for the entire Østerby district after the first phase of the optimisation process. As shown, in this phase, only the distribution pipes were designed in the simulation program and the service pipes had not been designed yet.

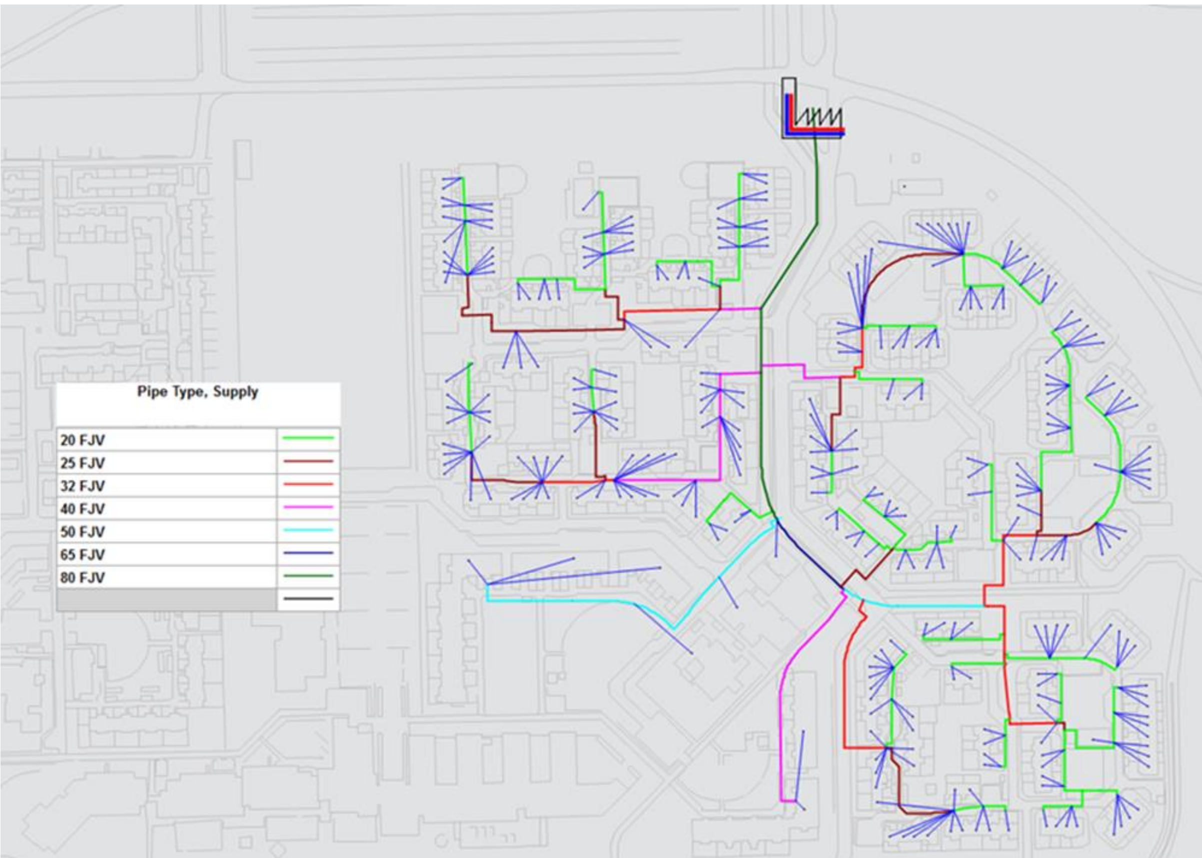

Figure 6. Overview of Østerby DH network for Step 2 scenario (the service pipes are not shown in detail)

Table 6 shows an evaluation of the heat loss reduction in the DH network shown in Figure 6 thanks to the reduction of the operation temperature as well as the optimisation of the network's pipes. The reference network is composed of single pipes as in the existing network, and the supply/return temperatures are set to 85/50°C. The standard third generation refers to the heat losses in case the supply/return temperatures are set as in a traditional third generation DH network equal to 80/40°C. The fourth row shows the heat losses for the reference network (Step 0) with reduced temperatures, where the supply/return are set to 65/48°C. Lastly, the optimised network (from Step 2 scenario) refers to the network, where the temperatures are reduced to 55/30°C and the single pipes are replaced with double pipes characterized by a smaller diameter.

Table 6. Heat losses comparison of different scenarios

Scenario	Supply temp. [°C]	Return temp. [°C]	Heat losses [kW]	Improvements
Reference network	85	50	82	-
Standard 3rd generation	80	40	72	*Lower temperature*
Reference network with reduced temperature - Step 0	65	48	67	*Lower temperature*
Step 2	55	30	37	*Lower temperature + new twin pipes + hydraulic*

Based on the Step 2 scenario, the heat loss reduction in the main distribution network is estimated to be around 45% compared to the reference network with reduced temperature. Particularly noteworthy, the heat loss in the reference network with reduced temperature is around 67 kW, whereas after the optimisation the loss is 37 kW. In the optimised network, the loss corresponds to 11% of the total delivered energy by the network.

The last step of the optimisation process considered the optimisation of the pipe length. Initially, the DH network was designed based on a traditional method. Normally, the distribution pipes are buried under the nearest road and then the users are connected with long service pipes to the distribution network as shown in Figure 7. Figure 7 also shows the 159 users that are going to be connected to the new LTDH as well as the users that are not going to be connected. In detail, the black lines indicate the part of the network that is not going to be implemented.

Figure 7. Overview of the LTDH network in the Østerby district before length optimisation

Using the traditional method, the length of the network did not become optimum. Since the length of the DH network is one of the main factors that influences the heat losses, its optimisation can lead to a relevant reduction of the heat losses. Therefore, in the Østerby district, it was decided to bury the distribution pipes closer to the users' buildings (approx. 1 meter from the external wall) so that the length of the service pipes was reduced. In this optimisation phase, it was also decided to replace the steel pipes with new plastic pipes since one of the aims of the project was to implement this type of pipe.

Table 7 shows the criteria used during the length optimisation process.

Table 7. Design criteria for the length optimisation and the hydraulic optimisation

Design criteria: **Step 3 - Pipe optimisation** **Step 4 - Length optimisation** **Step 5 - Hydraulic optimisation**
Temperature set: 55°C supply / 30°C return
User installation ΔP = 0.5 bar Main transmission line ΔP = 0.8 bar Shunt station ΔP = 0.6 bar Network pipes ΔP = 2.8 bar Total pressure supply/return = 10 bar/2.5-3 bar
Expected thermal power = approx. 1.2-1.4 MW_{th} (*)
The consumer's DH-unit is connected directly to the supply pipes
Maximum design velocity = 1.5 m/s (actual maximum 1.2 m/s)
Maximum design pressure gradient = 500 Pa/m (actual maximum 430 Pa/m)

(*) with all the consumers connected (entire Østerby district)

Table 8 shows the length of the DH network's pipes, sorted by the pipes' diameters, as well as the total length of the network when the new plastic pipes were implemented. The second column (Step 3) shows the pipe information before the length optimisation but with the introduction of plastic pipes. The third column (Step 4) indicated the pipe characteristics when PE-RT20 (internal diameter 14.4 cm) pipes were implemented as service pipes. In the fourth column, called "Step 5", the diameter of the service pipes was reduced as PE-RT16 (internal diameter 12 cm) pipes were implemented. The lengths shown in Table 8 consider both distribution and service pipes. As a result of the optimisation, the length of the network was reduced by about 2 km. However, to achieve that, the length of the distribution pipes was slightly increased. The network length was reduced by a total of about 26.4 %. In "Step 5", the network was also hydraulically optimised. The use of smaller service pipes (PE-RT16) makes it possible to reduce the waiting time at the user's tap after a period of idle load because the water volume in the pipes is smaller. Furthermore, in a double pipe with a smaller diameter, the heat exchanged between the return and supply pipe is expected to be smaller.

Table 8. Length of the pipes in the Østerby LTDH network after the length optimisation

	Step 3 **Pipe optimisation *(*)***	**Step 4** **Length optimisation *(*)***	**Step 5** **Hydraulic optimisation *(*)***
Pipe Type	***Plastic twin pipes - Series 3 (**)***	***Plastic twin pipes - Series 3 (**)***	***Plastic twin pipes - Series 3 (**)***
PE-RT16	0.0 m	0.0 m	966.7 m
PE-RT20	2325.7 m	1412.5 m	445.8 m

PE-RT25	212.7 m	240.9 m	240.9 m
PE-RT32	410.6 m	390.3 m	390.3 m
PE-RT40	119.6 m	122.1 m	122.1 m
PE-RT50	326.2 m	246.0 m	246.0 m
PE-RT63	222.5 m	222.5 m	222.5 m
PE-RT75	106.6 m	106.6 m	106.6 m
PE-RT90	0.0 m	0.0 m	0.0 m
PE-RT110	0.0 m	0.0 m	0.0 m
SUM	**3723.9 m**	**2740.9 m**	**2740.9 m**

***** *Additional to the previous optimisation step*
****** *Based on plastic pipes catalogue from Logstor.*

Figure 8 shows the final layout of the DH network after the length optimisation of the service and distribution pipes. In particular, the figure shows the different pipes' diameters in the network. It must be mentioned that in Figure 8, the pipe length seems to be optimised only in part of the network since on the right side of the figure the service pipes have the same length as in the network before the optimisation. However, in the TERMIS simulations, the pipes were reduced by half without having to update the drawing of the network.

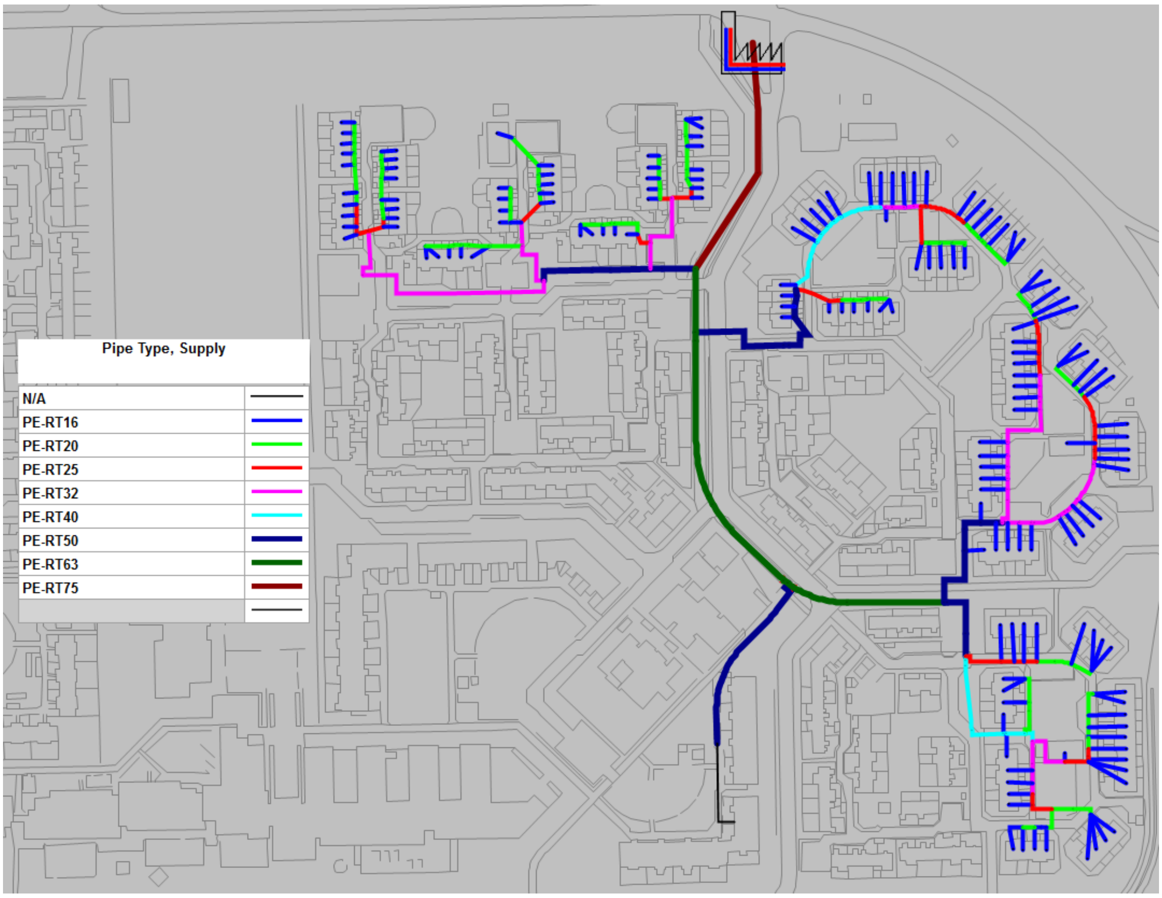

Figure 8. Overview of the LTDH network in Østerby after the length optimisation

Lastly, the temperature distribution of the optimised networks was checked. Figure 9 shows the temperature distribution in the DH network when plastic pipes PE-RT16 are implemented as service pipes. The temperature distribution shows that the water is supplied at a temperature higher than 50°C in the entire network, which ensures fulfilment of the users' requirements. If PE-RT20 service pipes were implemented in the network, the temperature distribution was the same as that shown in Figure 9 obtained using PE-RT16 service pipes. Figure 9 shows also the connection to the kindergarten in the middle of the area.

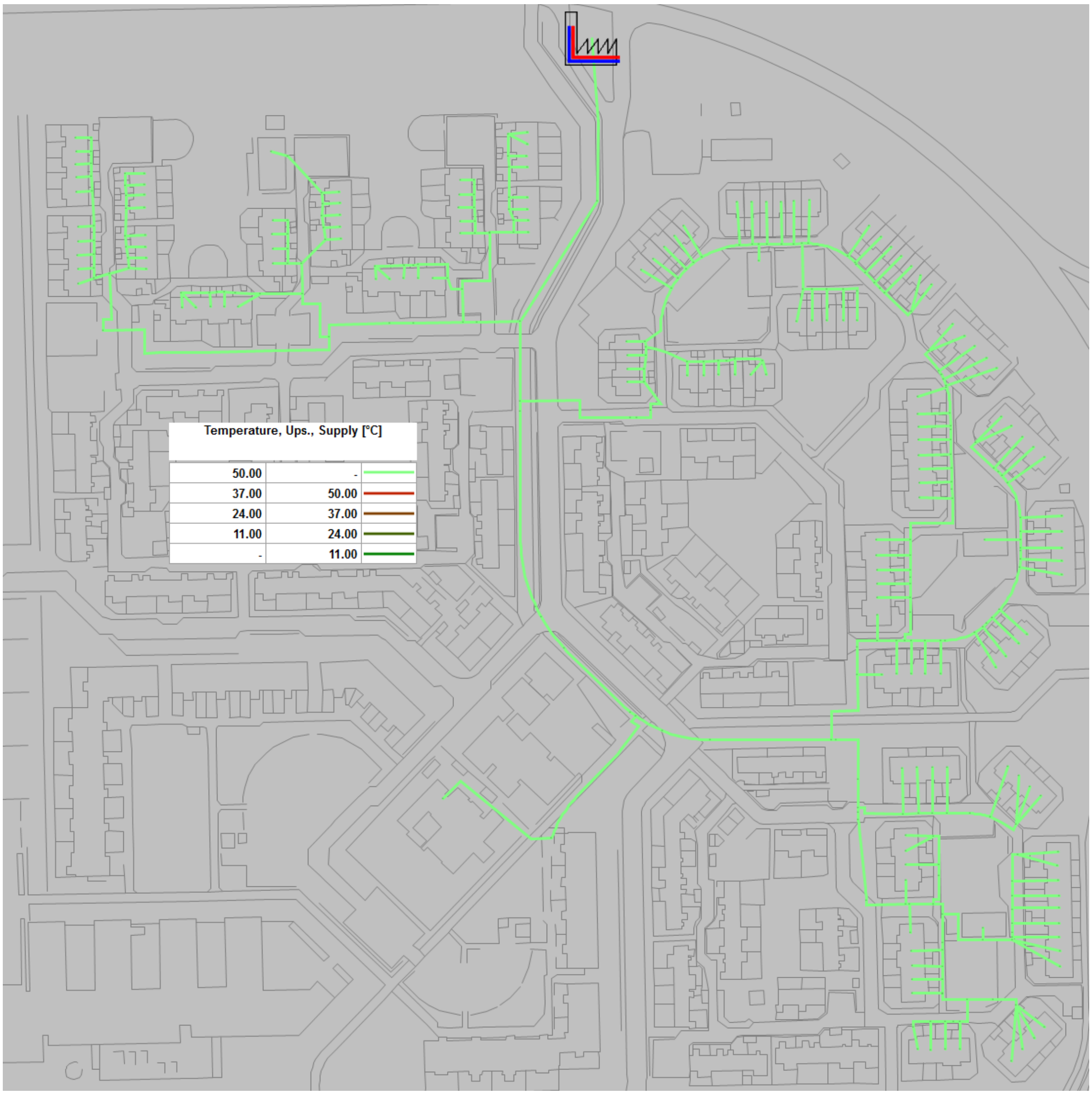

Figure 9. Temperature distribution in the network's supply pipes with service pipes PE-RT16/PE-RT20

Looking at the heat losses of the optimised network presented in

Table 9, it may be noted that the reduction length optimisation of the network led to a heat loss reduction from 17.2 kW to 13.2 kW, which corresponds to around 23%. On the other hand, the reduction of the service pipes' diameter did not lead to a relevant reduction of the heat loss, which is 13.2 kW. The heat losses in the optimised network was 10.8% of the total delivered energy.

Table 9. Heat losses in the Østerby network after the length optimisation

Scenario	Supply temp. [°C]	Return temp. [°C]	Heat losses [kW]	Improvements
Step 3	55	30	17.2	*New plastic twin pipes*
Step 4	55	30	13.2	*Optimised length*
Step 5	55	30	13.2	*Hydraulic optimisation*

6.2 Brunnshög

Lund is a city that aims to reduce its environmental and climate impact in line with the trend proposed by the European Union's roadmap to achieve a sustainable future. The city wants to improve this transition and reach a nearly zero GHG emission by year 2050.

In the new district of Brunnshög, the world's largest low-temperature district network based on fossil-free heat sources will be created. The area will host the research facilities MAX IV (synchrotron light) and the European Spallation Source (ESS particle accelerator). The aim of the LTDH network is to take advantage of the surplus heat from these facilities and use it as a sustainable heat source. The new LTDH will supply the new buildings in the area. It is expected that the district will have 40,000 inhabitants and employees in total before 2050. The area will therefore be a high-density area, with primarily multi-storey buildings. Therefore, the heat losses in the distribution network will have a higher impact on the total supplied energy.

A LTDH network is particularly suitable in this area as there will be the possibility to utilise a relevant amount of surplus heat, which can be used to meet the heat demand of the new buildings. Furthermore, since new buildings will be built in the area, they can be equipped with low-temperature SH systems, which guarantee a higher efficiency of the LTDH. The area will be an example of design optimisation of all parts of a LTDH network. The LTDH network, which is part of the demonstration project of COOL DH, will be supplied with the surplus heat coming from MAX V's facilities.

6.2.1 NetSim simulation/optimisation

The optimisation of the LTDH in Brunnshög was performed using the network simulation software NetSim provided by Vitec. The first step of the optimisation was to evaluate the heat demand that has to be fulfilled by the network as well as identify the location of the consumers. However, since the area is still under development, it may become challenging to define the consumers' heat demand accurately and their location. Since only a small area of the Brunnshög district is already planned, in the first period (3-5 years) the network will largely be over-dimensioned. In particular, the main distribution pipes were initially designed with a large diameter in order to be able to supply the future heat demand when the area will be fully developed. However, it was possible to obtain a better optimisation of the network in the distribution pipes close to the consumers because the heat loads were already defined.

When the heat loads are defined or estimated, the layout of the LTDH network can be designed and implemented in the simulation software. NetSim gives suggestions on how the network has to be optimised. In the design procedure a certain safety margin was considered to allow the future development of the network. In particular, the main lines were designed with a larger margin, the medium distribution lines were designed with a medium safety-margin, while the small connections (service pipes) were designed with a low margin. The margin ensures the network's operation also in case of special conditions (i.e. the power coming from one direction) and for the future heat loads that are going to be connected.

6.2.2 Brunnshög optimisation process and results

Table 10 shows the design requirements of the LTDH network in the first phase of the optimisation process. The network is dimensioned for a supply temperature of 55°C with the possibility of supplying a temperature of up to 65°C and the return temperature is set at 30°C and 35°C during peak periods. In the first phase of the design procedure, the maximum pressure allowed in the system was set to 6 bar due to the limit of the available pipe technology. However, further developments of the pipe technology were expected, which could allow a higher-pressure limit in the network. The maximum pressure in the network can set a limit in the long term, since it can limit the future expansion of the network. In Table 10, the expected consumption represents the heat demand that was forecasted once the area is fully developed.

Table 10. Design criteria for the LTDH network in Brunnshög

Design criteria - Brunnshög
Temperature set: 55°C supply (peak 65°C) / 30°C return
Maximum pressure level expected = 6 bar (aim at 10 bar)
Minimum pressure level expected = 1 bar
Pressure difference at the user's installation ΔP = 0.8 bar
Expected production/consumption = 14.6 MW
Estimated losses in the main pipe system= 0.090 MW

Figure 10 shows the layout of the network after the first phase of the optimisation. Due to the low heat load in the network, the pressure is lower than expected.

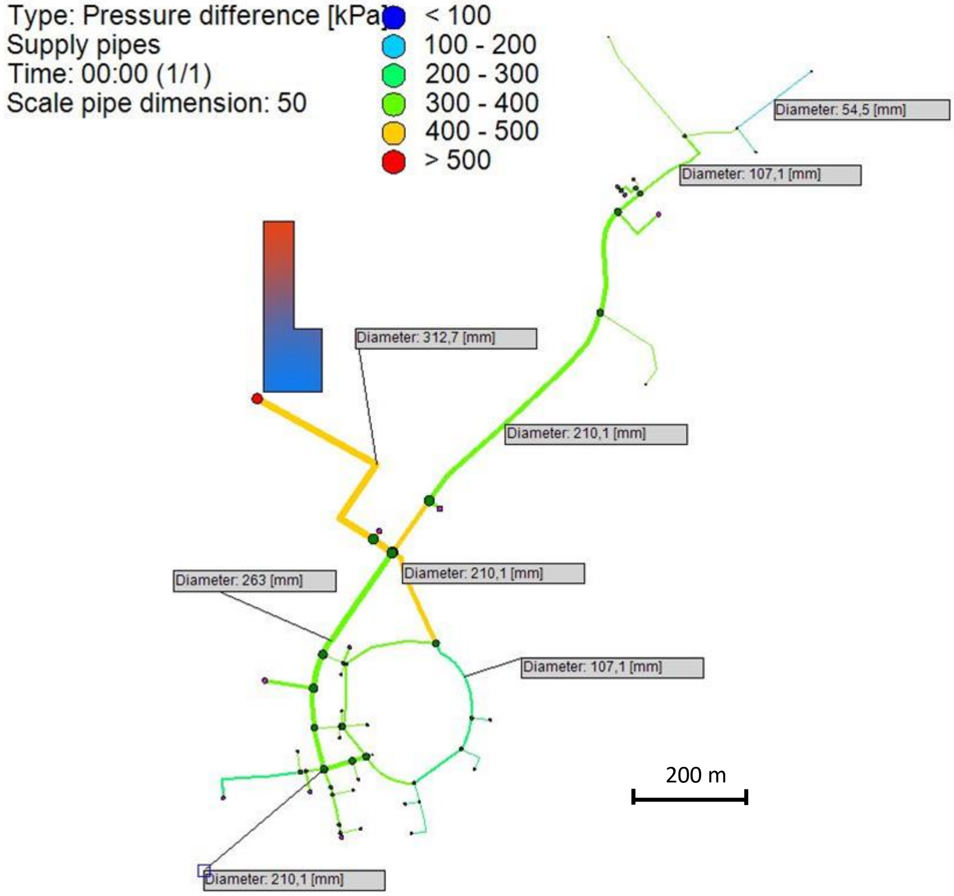

Figure 10. Network layout in the first design phase

Since the area has a high heat density due to the high number of buildings, the heat loss of the distribution network has a lower impact on the total energy supplied. As shown in Table 10, the heat loss in the main distribution network corresponds to 0.09 MW, which is about 0.6% of the full load capacity. However, considering the operation of the network for an entire year, full load is expected for 3000 hours and the heat loss in the main network is expected for the entire year (8760 hours). As shown in Table 11, the heat losses account for around 3% of the total energy supplied.

Table 11. Heat losses, percentage estimation in case of full load

	Power [MW]	Max load period [h]	Energy [MWh]	Percentage of heat loss in the main line	Percentage of heat loss in branches (estimated)	Percentage of total heat loss (estimated)
Main line heat load	15	3000	45000			
Heat loss main line	0.1	8760	876	2%	1%	3%

However, in the first phase of the project, the expected full load is lower. Therefore, the heat losses have a larger impact on the total supplied energy. As assumed for the case above, full load is expected for 3000 hours and heat losses for 8760 hours. Table 12 shows that the total heat losses account for 9% of the total supply energy.

Table 12. Heat losses, percentage estimation in case of reduced load

	Power [MW]	Max load period [h]	Energy [MWh]	Percentage of heat loss in the main line	Percentage of heat loss in branches (estimated)	Percentage of total heat loss (estimated)
Main line heat load	5	3000	15000			
Heat losses main line	0.1	8760	876	6%	3%	9%

Table 13 shows the design criteria of the optimised LTDH network in the second phase of the design process. With the new developed pipes, the maximum pressure level reached is 10 bar, which allows further expansion of the network. In this phase, the expected consumption is increased because the area of Southern Brunnshög is also going to be connected to the network.

Table 13. Design criteria for the optimised LTDH network in Brunnshög

Optimised design criteria - Brunnshög
Temperature set: 55°C supply (peak 65°C) / 30°C return
Maximum pressure level expected = 10 bar
Minimum pressure level expected = 1 bar
Pressure difference at the user's installation ΔP = 0.8 bar
Expected consumption = 17 MW
Estimated heat losses in the main pipe system = 0.134 MW

Figure 11 shows the model of the LTDH network optimised with NetSim. The different colours highlight the pressure difference in the different areas of the network. The main distribution pipes with a diameter larger than DN100 consist of steel pipes and for the DN80 and smaller dimensions, plastic pipes are used. Due to the optimisation of the network, the pressure is higher than in the previous scenario. Figure 11 shows also the new distribution line towards Southern Brunnshög. In this connection, due to space problems, it was necessary to reduce the insulation level of part of the network in order to be able to place the pipes. The area will consist in a local network composed by plastic pipes.

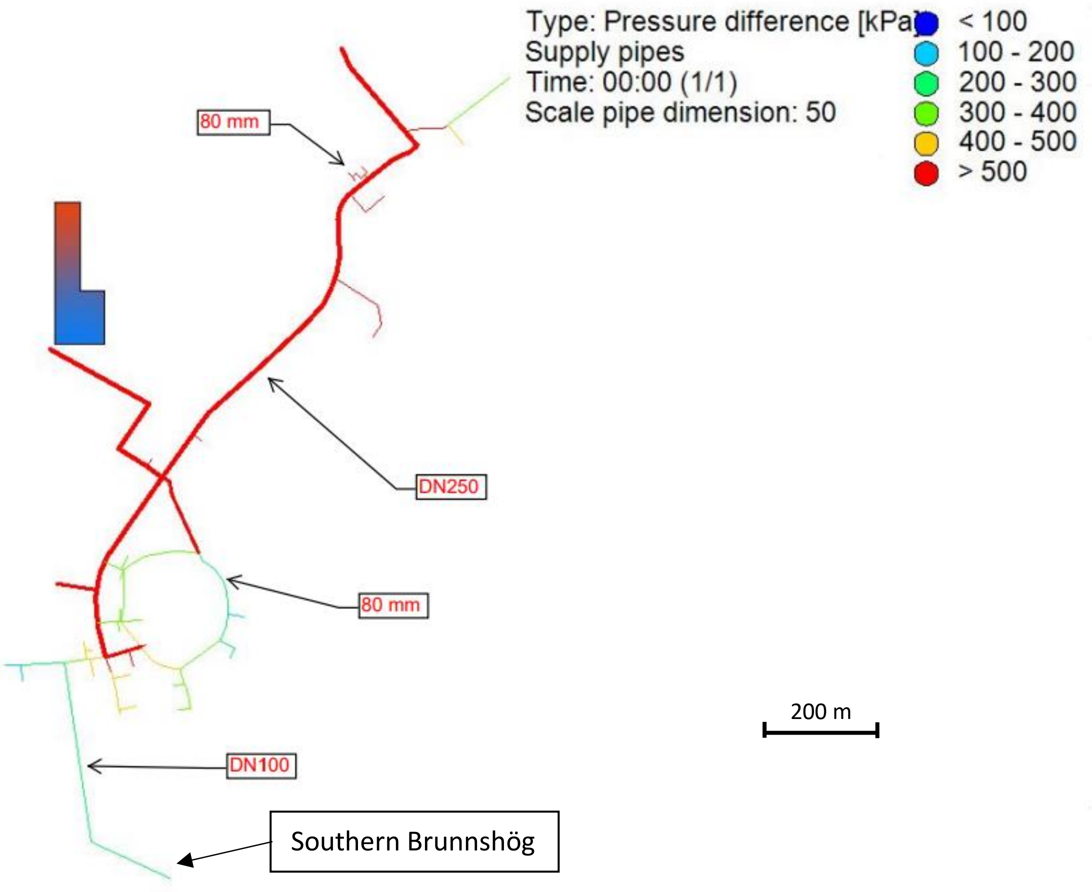

Figure 11. LTDH network implemented in the Brunnshög area connected to MAX V

As it was calculated in the previous case, the heat losses of the distribution network have been calculated. Table 13 shows the heat loss in the main distribution network equal to 0.134 MW, which results about 0.8% of the full load capacity. Considering the network operation during an entire year, 3000 hours of full load and 8760 hours for the heat losses in the main network, the heat losses account for 3.5% of the total energy supplied, as it is shown in Table 14.

Table 14. Heat losses in the optimized network, percentage estimation in case of full load

	Power [MW]	Max load period [h]	Energy [MWh]	Percentage of heat loss in the main line	Percentage of heat loss in branches (estimated)	Percentage of total heat loss (estimated)
Main line heat load	17	3000	51000			
Heat loss main line	0.134	8760	1176	2.3%	1.2%	3.5%

Table 15 shows the heat losses percentage in the first phase of the project, when the expected full load is lower. In this phase, the heat losses have a larger impact on the total supplied energy. As assumed for the case above, the full load is expected for 3000 hours and heat losses for 8760 hours. The total heat losses account for 9.9% of the total supply energy.

Table 15. Heat losses in the optimized network, percentage estimation in case of reduced load

	Power [MW]	Max load period [h]	Energy [MWh]	Percentage of heat loss in the main line	Percentage of heat loss in branches (estimated)	Percentage of total heat loss (estimated)
Main line heat load	6	3000	18000			
Heat loss main line	0.13	8760	1176	6.5%	3.3%	9.9%

7 Recommendations

This report can be used by DH companies willing to renovate an existing DH network or when a new DH network has to be designed. In the same way, consultant companies can use this report as guideline for DH networks design. Table 16 summarises the important characteristics that a LTDH should have and those that it should not have (5)(6).

Table 16. Dos and Don'ts for the design of a LTDH network

DO	DON'T
• The distribution network length should be minimised as much as possible to reduce heat losses. • The pipe diameter should be reduced in order to minimise heat losses with a consequent increase of the pressure losses. • Implementation of twin pipes with a high level of insulation should be considered to reduce heat losses. • In buildings, the technical installations should be organised in order to minimise the number of shafts and consequently the number of pipes. This solution leads to lower heat losses. • Optimisation of the DH network should begin with a thorough evaluation of the heat demand and development of the interested area.	• The design of longer distribution pipes leads to higher heat losses. • The pipes should not be oversized. • The use of pipes with a low level of insulation can increase heat losses remarkably. • In buildings, a dedicated set of distribution pipes for each apartment should be avoided. • New LTDH networks should not be implemented without considering the development plan of the area.

• The implementation of plastic pipes used at lower temperatures can lead to a longer life of the DH network, achieving a lower degree of maintenance. • The use of DH-units (micro heat exchangers) makes it possible to reduce the supply temperature compared to systems with domestic hot water preparation tanks. They also allow for implementation of individual metering of the consumers. • Consumers should be informed of the possibility of using low-temperature solutions for the space heating system. This could lead to optimisation of the LTDH network.	

8 Innovation requirements/further research

The aim of this report is to describe the concepts behind the optimisation of a LTDH network. However, further investigations can be undertaken in order to achieve additional improvements:

- The DH-units located in the consumer's dwelling can be further improved in order to find the optimal size of the heat exchanger that can lead to a better distribution of the heat.
- Test the possibility of lowering the supply temperature when DH-units (micro heat exchangers) are used at the consumers. However, the comfort limit has to be guaranteed, with the lowest DH supply temperature set at 48°C during the summer period (53°C in Sweden).
- The use of water tanks in apartment blocks can reduce heat losses in the distribution network by reducing the diameter of the pipes. However, it can be investigated whether it would be more advantageous to increase the losses in the buildings in order to lower the ones in the distribution network.

9 Video presentation

The results reported in this deliverable were presented at the COOL DH Innovation webinar arranged on the 12th of December 2018 at Kraftringen's office in Lund. The video presentation can be found by following the link attached underneath.

Video presentation:

https://lund.solidtango.com/video/cool-dh-innovation-webinar-12th-december-11-00-12-00--2#t=1862

10 References

(1) European Union, *Climate strategies & targets*. Available online at: https://ec.europa.eu/clima/policies/strategies_en (Retrieved on 13/09/2018)

(2) European Union, (2016), *Towards a smart, efficient and sustainable heating and cooling sector*. Available online at: http://europa.eu/rapid/press-release_MEMO-16-311_en.htm (Retrieved on 13/09/2018)

(3) European union, *Heating and cooling*. Available online at: https://ec.europa.eu/energy/en/topics/energy-efficiency/heating-and-cooling (Retrieved on 13/09/2018)

(4) Lund, H., Werner, S., Wiltshire, R., Svendsen, S., Thorsen, J.E., Hvelplund, F., Mathiesen, B.V. (2014), *4th Generation District Heating (4GDH) Integrating smart thermal grids into future sustainable energy systems*, Energy 68, 1-11.

(5) Kaarup Olsen, P., Christiansen, C.H., Hofmeister, M., Svendsen, S., Thorsen, J.E. (2014), *Guidelines for Low-Temperature District Heating. A deliverable in the project financially supported by the Danish Energy Agency in the R&D programme EUDP* (Energiteknologisk Udviklings- og Demonstration Program): "EUDP 2010-II: Full-Scale Demonstration of Low-Temperature District Heating in Existing Buildings".

(6) Christiansen, C.H., Paulsen, O., Bøhm, B., Thorsen, J.E., Larsen, C.T., Jepsen, B.K., Kaarup Olsen, P., Lambertsen, H., Hummelshøj, R., Svendsen, S., Fan, J., Furbo, S., Worm, J., Didriksen, J., (2009), *Udvikling Og Demonstration Af Lavenergifjernvarme Til Lavenergibyggeri*.

(7) Isoplus, Steel - pipes and components: *Single pipes - design - laying rules*. Available online at: http://www.isoplus.dk/_upload/27062017105856_250092075_0000.pdf. Retrieved on 22/10/2018

(8) Isoplus, Steel - pipes and components: *Double pipes - design*. Available online at: http://www.isoplus.dk/_upload/26112012145142_414208630_0000.pdf. Retrieved on 22/10/2018