COOL DH
COOL DISTRICT HEATING

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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Dissemination level		
PU	Public	X
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Scope of deliverable

The COOL DH Data management and monitoring plan is developed as a working plan for how to monitor the overall impact of the Low Temperature District Heating project with regards to energy use and performance of involved plants and buildings, the environmental and social studies of building and operating the included DH systems.

This monitoring report is a concluding document of the evaluations that have been carried out based on the monitored data collected. The report is focusing on monitoring of energy performance, environmental impacts, economic analysis as well as social studies of the demonstrations on the Danish side of COOL DH and evaluation of the following:

- New type of substations and energy consumption in LTDH network of Østerby area in Høje Taastrup
- Conversion of Østerby area from traditional DH network (85/50°C) to an LTDH network
- New main line with innovative heat recovery system
- Waste heat recovery by heat pump from cooling machine in local energy system at the shopping centre CITY2 in Høje Taastrup
- Integration of prosumers (Bank datacentre and CITY2) in Høje Taastrup

Context of deliverable

This monitoring report includes data monitoring and evaluation of the demonstrations on the Danish side of COOL DH in terms of energy flows, production sites, cost of DH network, customer installations, special innovations, and heat recovery pipes.

Perspective of deliverable

The monitoring report is presenting collected measurements and used for evaluation of the performance of the demonstrations on the Danish side of COOL DH. The deliverable intends to inspire utilities and building owners to replicate feasible solutions.

Involved partners

Lund University (UNI-SE) was lead responsible for compiling the report. In the process for developing this report, also representatives from UNI-SE (lead), Høje Taastrup Fjernvarme (UTIL-DK), Kingspan / Logstor (IND-DK) and COWI-DK were involved.

Summary

Several applications for low-temperature district heating have been demonstrated in the EU project COOL DH. This report reports results from demonstrations that have been made in a Danish context where a new low-temperature district heating system has been built and put into operation in Østerby area of Høje Taastrup on the outskirts of Copenhagen in Denmark. The low temperature system supplies terraced houses built in 1985-1986 with space heating and domestic hot water and has replaced the former secondary network for conventional district heating that existed in the area, a system that had high heat losses.

The new LTDH system includes several features. A new network has been built with elements of a new type of plastic pipe (PE-RT) that has been developed and tested within the project. The connected chain houses have been installed with a DH substation for each apartment, which allows immediate production of domestic hot water, individual metering and billing of space heating and hot water use, as well as better possibilities to regulate the heating system in the apartments. The LTDH system is connected to the nearby shopping centre CITY2, from where heat that is generated in the shopping centres' cooling machines is utilised for LTDH. A heat pump was implemented to cogenerate heating and cooling and supply heat for the LTDH network in Østerby. An i-grid mixing loop was installed to supply LTDH when the heat pump is not in operation. This unit mix output of the HP return water with supply heat from the conventional DH grid. In addition, a booster pump is installed to ensure sufficient differential pressure at the consumers. Further heat losses from the main pipe exiting from CITY2 towards Østerby District are recovered by a new innovative solution. A bank data centre is incorporated to the LTDH network as a prosumer to exchange heating from cooling with the network. This installation implies on importance of including data centres as well as the role of prosumers in DH systems.

The different installations have been monitored and evaluated in terms of energy performance, environmental impacts, economic costs, and user acceptance. In a general perspective, this part of the project showed the functionality and viability of using LTDH system in a real scale successfully and in a techno-economic way.

KPI's:

2021	HIU (159) substations In Østerby	Conversion to LTDH in Østerby 3119 m pipe	Heat loss recovery on DH twin pipe 350 m	Co-production at CITY2 1.34 MWheat & 0.99 MWcool	Prosumer installation at Bank 1.9 MW**	Total demo-case
Utilised low-grade heat (MWh/y)	*	*	*	(2,970)	7,971	10,941
Increased non-fossil supply (MWh/y)	*	*	(94)	(4,023)	11,162	15,279
Primary Energy savings (MWh/y)	*	*	(48)	(1,328)	3,057*1.2 = 3,668	5,044
CO_2 reduction (tonnes/y) ***	*	*	(1)	(157)	379*1.2 = 455	613
Simple pay-back period (years)	14	n.a.	8	(8-10)	(11-13)	~ 14
Investment excl. 25% VAT (€)	458,000	1,596,800	6,711	1,140,000	1,610,000	4,811,511

() Figures in brackets are estimated values

* Included in co-production from CITY2. ** Multiplied by 1.2 to get figures for a normal full year.

*** Based on CO2 eq emission factor of 42 kg/MWh for the district heating system in 2021

Abbreviations

ATES	Aquifer Thermal Energy Storage
CAPEX	Capital Expenses
COP	Coefficient of Performance
CW	Cold Water
DC	District Cooling
DCW	Domestic Cold Water
DH	District Heating
DHW	Domestic Hot Water
DOW	Description of Work
EU	European Union
HIU	Heat Interface Unit
HP	Heat Pump
IHS	Individual Heat Substation
KPI	Key Performance Index
LTDH	Low-Temperature District Heating
OPEX	Operational Expenses
PE	Primary Energy
PEF	Primary Energy Factor
PES	Primary Energy Saving
PE-RT	Poly-Ethylene Raised Temperature
PEX	Cross-linked polyethylene
PV	Photovoltaic
RES	Renewable Energy Source
SH	Space Heating
UNI-SE	Lund University
UTIL-DK	Høje Taastrup Fjernvarme a.m.b.a.
WP	Work Package

Table of Contents

1 Introduction

Work Package 5 (WP5) monitors the overall energy and carbon impact of the COOL DH project, and the energy performance of all COOL DH Demonstration Projects in Denmark and Sweden.

The aim of deliverable D5.3 is to report the results, findings and conclusions from the monitoring activities related to the COOL DH project in Høje Taastrup, presented in Figure 1.

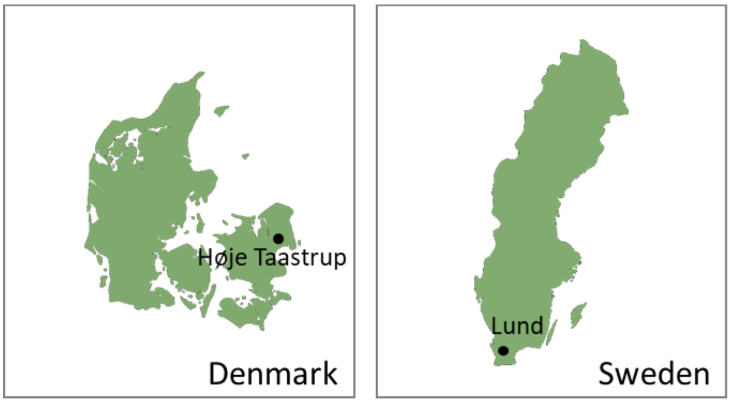


Figure 1. Map representing the two demonstration communities, Høje Taastrup in Denmark and Lund in Sweden

1.1 Data management and monitoring

The COOL DH Data monitoring is based on the Project Plan developed in the Grant Application (DOW Technical Annex 1). It identifies how progress should be monitored and how success will be evaluated in terms of energy performance, environmental impacts, and social studies. In Figure 2, a principal sketch is shown for monitoring and evaluation of the project. The project is to be evaluated from:

- Energy efficiency
- Environmental impacts
- Social studies

The different evaluations have been performed at different aggregation levels. To be able to make the evaluation, the performance must be compared to a reference case. The output from the evaluation can be described as different Key Performance Indicators (KPI's).

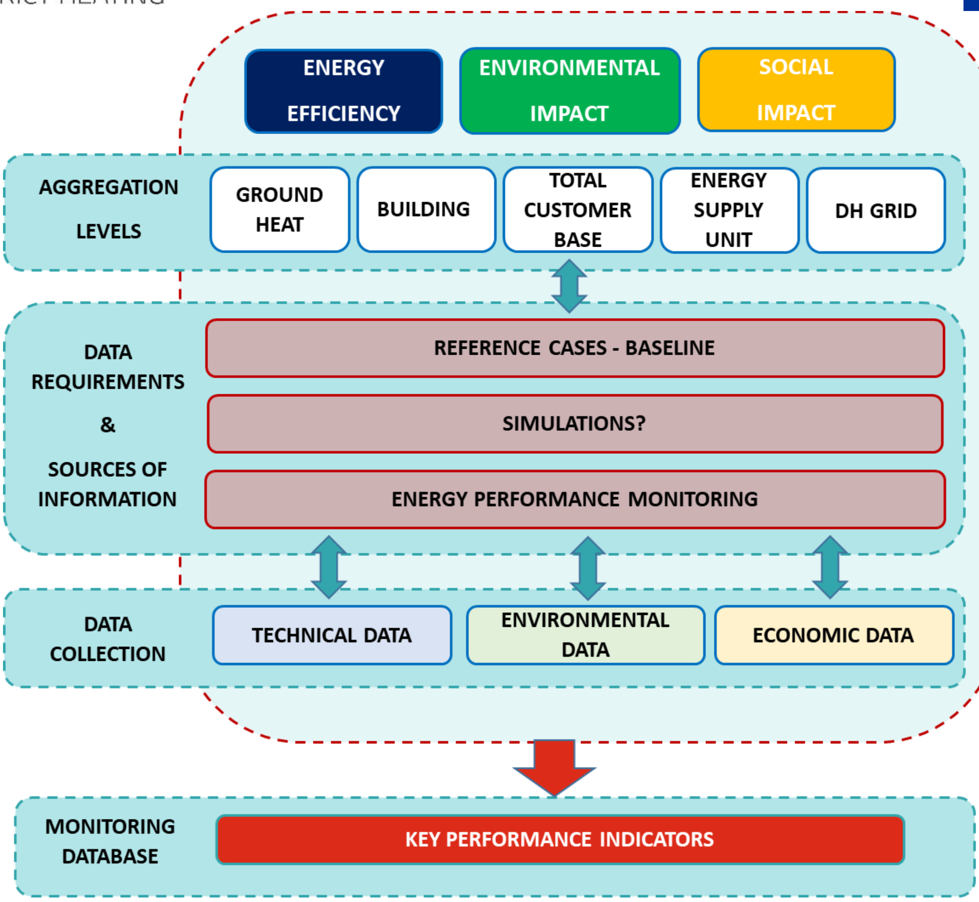


Figure 2. Principle sketch of project monitoring

1.2 Objectives

The COOL DH data management and monitoring is developed as a working plan to monitor the energy flow of the involved plants and buildings in the two low temperature district heating systems: Brunnshög in Lund, Sweden, and Østerby in Høje Taastrup, Denmark. The data monitoring works as a strategic document on how the systems should be evaluated in terms of energy use and performance, as well as the environmental and social studies.

This monitoring report is focusing on monitoring demonstrated and constructed installations in the Danish parts within the project in terms of energy performance, environmental impacts, economic analysis as well as social studies with the evaluation of:

- LTDH customer installations to monitor energy usage for each customer
- LTDH network in Høje Taastrup for monitoring of heat supply, heat demand and temperatures
- New innovative main pipeline with heat recovery to reduce heat losses
- LTDH production site at CITY-2 in Høje Taastrup to use cooling and surplus heat for the LTDH network
- Integration of prosumer to exchange heating and cooling

The specific measurements made can be seen in Table 1.

Table 1. Data collection of each site

Site	Heat delivered	Heat use	Heat losses	Cool delivered	T_{supply}	T_{return}	Electri-city	COP
New substations								
LTDH in Østerby								
Heat recovery line								
PV HP at CITY2								
Prosumer: Data Center								

Gray	N/A	Blue	Calculated data	Green	Measured data

1.3 Background of the Project and Organization

The monitoring and evaluation involve many partners within the project. In the process to develop the monitoring plan, the input from different participants in the project have been valuable. The discussions with the different partners have been both formal meetings and informal face to face meetings or meetings over telephone or Teams.

1.4 Høje Taastrup Demonstrations

The Danish side of COOL DH as seen in Figure 3 and 4 is concentrated in the Østerby area of Høje Taastrup city, west of Copenhagen. This part of the project includes several installations such as the converted LTDH network, heat recovery at CITY2 Mall, and connection of prosumers.

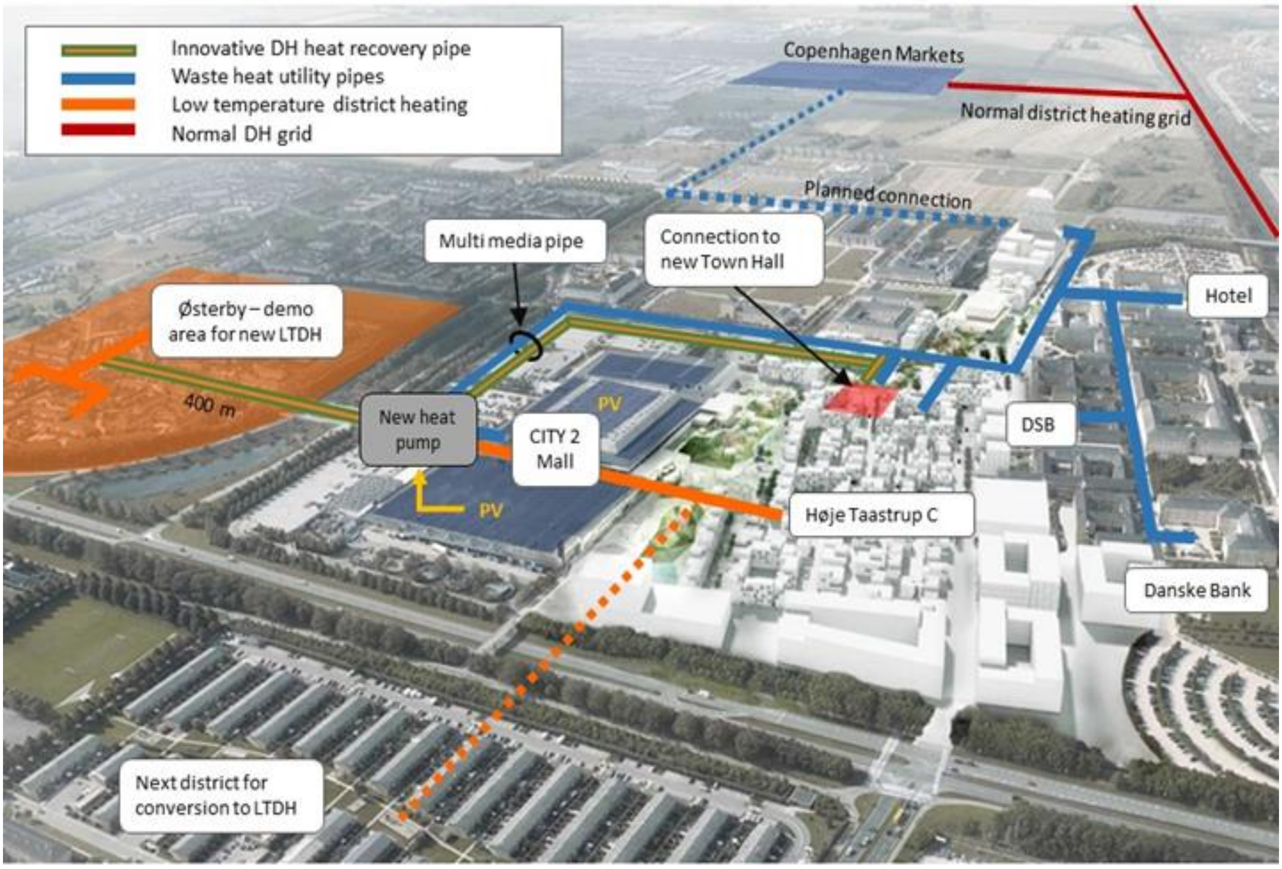


Figure 3. Demonstrations of the Danish side of COOL DH in Høje Taastrup [1]

Høje Taastrup Municipality has a population of more than 50,000 people located in Greater Copenhagen about 20 km west of the city Centre of Copenhagen [2]. The municipality has committed itself to the requirements by the Danish Society for Nature Conservation with a minimum of 2% reduction of CO_2 emissions per year on a continuous basis. Over the last ten years, the municipality has reduced its CO_2 emissions by more than 3% each year [3].

The initiative to reduce its emissions originated partly from the former EU supported ECO-Life project under the Concerto initiative. From 2010-2015 the Danish partners carried out more than 67 successful demonstrations, improving energy efficiency and the integration of RES. This led to a Danish project called Høje Taastrup Going Green, supported by the Danish Energy Authority, and laid the foundation for Høje Taastrup's participation in COOL DH.

During the project progress in Høje Taastrup, the share of renewable energy in the DH network has increased from 51% to about 85% for the served area in Østerby.

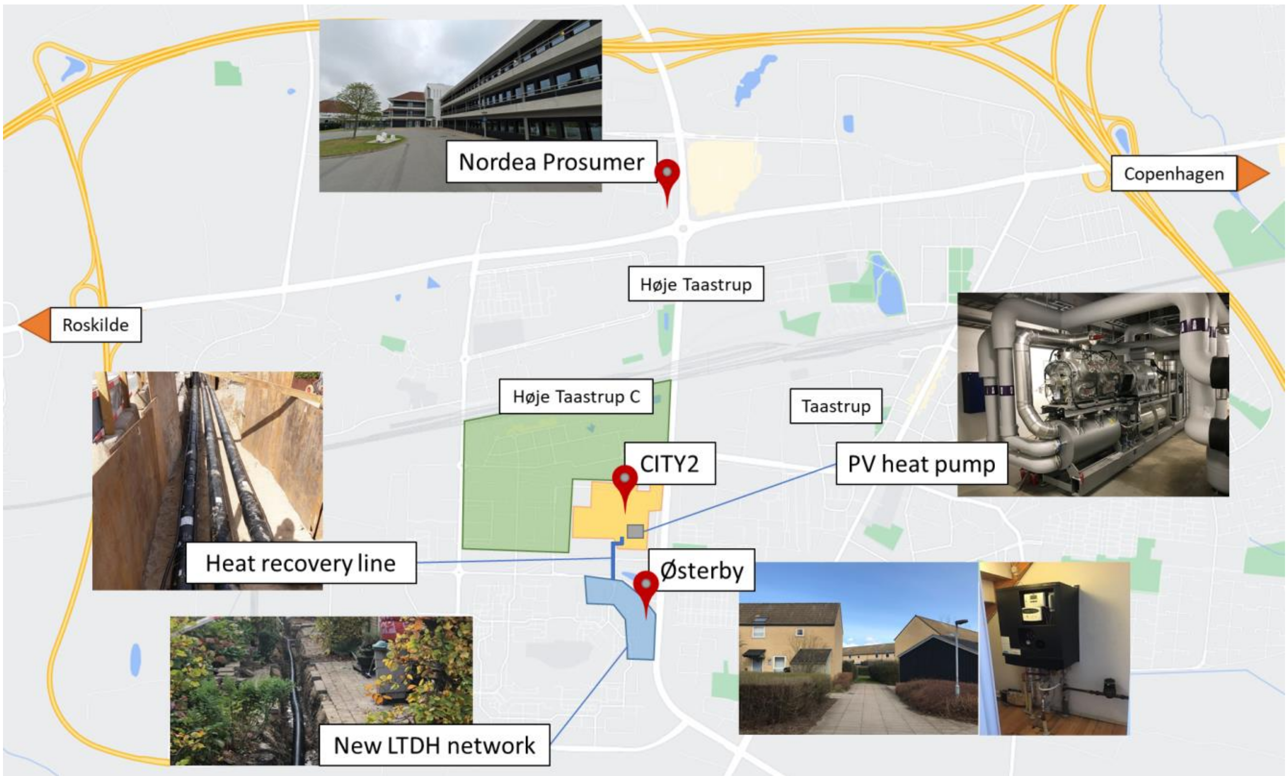


Figure 4. Overview of the demo site in Høje Taastrup

As it is presented in Figure 4, the demonstration site in Høje Taastrup consists of the following activities:

- **New type of substations:** New substations called Heat Interface Unit (HIU) are installed at each customer to be connected to the LTDH network, which provides domestic hot water (DHW) and space heating (SH). A total of 159 units are installed at the customers in the Østerby district.
- **Conversion of LTDH network in Østerby:** The existing DH network in Østerby is replaced with a new LTDH, aiming to reduce the heat losses in the network. The new network has a total length of 3,119 m and is made with a mix of traditional steel pipes and mainly new PE-RT plastic pipes developed within the COOL DH project. The network consists of a main pipe from the new heat pump installed in the shopping centre CITY2 to Østerby district, and a network in the district where 158 customers plus one kindergarten are supplied with low-temperature heat.
- **Heat recovery pipe:** The main pipe that distributes the heat from the shopping centre CITY2 to the Østerby district has been equipped with heat recovery collectors to recover heat losses from the main line. The recovery pipe is placed on the first part of the main pipe for a length of about 350 m. The total length of the recovery pipe is therefore around 700 m. The heat pump installed to recover heat is about 6.2 kW with frequency control. It supplies heat directly back to the LTDH network.
- **Production of LTDH with PV supplied heat pump:** A new PV powered cascade heat pump system is implemented at the shopping mall CITY2 to provide heat for the converted LTDH network using surplus heat of cooling machines. The heat pump has a heat capacity of 1.3 MW and a cooling capacity of 990 kW.

- **Prosumer Nordea:** A heat pump is installed in the server room of a bank in Høje-Taastrup, which uses the surplus heat from the servers to supply the DH network and at the same time provide cooling to the server room. The heat pump installation has a heat capacity of 1.9 MW incl. heat from pumps, and a cooling capacity of 1.5 MW.

1.5 Content of deliverable

The monitoring report is focusing on energy and economic data collection for the demonstrations that are already constructed and demonstrated in the Danish side of the COOL DH project. The report is structured as follows: At first, a brief introduction to the different parts of the project and monitoring is described in this chapter. Then, the methodology used to evaluate the project is explained in Chapter 2. The monitoring plan for the objects in focus within this report is presented in Chapters 3 through 7, where each main section is focusing on a main demonstration area:

- Chapter 3: Demonstration of new HIU substations with micro heat exchangers
- Chapter 4: Conversion from traditional DH network to new LTDH network in Østerby area
- Chapter 5: Demonstration of heat recovery pipe on main transmission pipeline
- Chapter 6: Co-production of heating and cooling using heat from cooling machine(s) to provide heat for LTDH network
- Chapter 7: Connection of a bank datacentre as a prosumer into LTDH network
- Chapter 8 Final conclusions

Appendix: Monitoring Fact sheet for the Danish side of COOL DH

2 Methodology

In this chapter, the evaluation methods are briefly explained as described in more details in D5.1: COOL DH Data management and monitoring plan.

2.1 Evaluation of Energy Performance

2.1.1 Heat losses

One of the most important parameters in each thermal system is the heat loss that can be calculated by the following Equation (1):

$$Q_{loss} = Q_{sup} - Q_{use} \qquad (1)$$

Where Q_{loss}, Q_{sup}, and Q_{use} are heat losses, heat supplied and heat usage of the system, respectively.

2.1.2 HP Performance

A heat pump performance in a DH system is measured by COP and calculated as:

$$COP_{HP} = \frac{Q_{del}}{P_{el}} = \frac{Q_{del}}{Q_{del} - Q_{rec}} \qquad (2)$$

Where Q_{del} is the energy delivered to the supply line, Q_{rec} is the energy recovered from the return pipe and P_{el} is the electricity used by HP. Consequently, a Primary Energy COP can be defined as:

$$COP_{PE} = \frac{Q_{del} \times 1}{P_{el} \times 2.1} = \frac{COP_{HP}}{2.1} \qquad (3)$$

Since PEF = 2.1 is used for electricity which corresponds to The Energy Efficiency Directive (2012/27/EU) with amending Directive ((EU) 2018/2002). In addition, PEF = 1.0 is considered for DH in this project.

2.2 Environmental evaluation

2.2.1 CO_2 Emissions

The evaluation of the environmental impact will be described in terms of CO_2-emission equivalent and fossil fuel dependency. The average monthly CO_2 intensity for electricity used to conduct the environmental evaluation can be found in Table 2. According to the environmental declaration for Høje Taastrup in 2021 [4], reference values for CO_2 equivalent emission factors are 40.9 kg/MWh for district heating and 81.0 kg/MWh for district cooling. Although, the reference value for CO_2 emission intensity for electricity in 2021 is given by 172.2 kg/MWh, the values of Table 2 were considered for the evaluation (181.5 kg/MWh in average).

Table 2. Average CO_2 values for electricity (in kg/MWh) in 2021 used for the environmental *evaluation [5]*

Month in 2021	Average CO_2eq emissions	Average CO_2 marginal emission	Average of emission production	Average carbon intensity import
January	242.0	106.5	299.4	184.3
February	251.1	96.9	279.7	222.6
March	218.6	100.6	299.0	122.2
April	193.3	99.5	265.5	90.5
May	183.0	95.4	274.9	79.7
June	177.9	100.0	240.2	117.2
July	145.7	100.0	191.0	128.9
August	128.2	91.8	153.2	118.1
September	126.9	105.6	189.8	77.0
October	144.0	97.8	206.5	63.7
November	174.8	104.1	247.1	85.1
December	197.0	101.5	257.4	138.0
Total	**181.5**	**100.0**	**241.7**	**118.4**

2.2.2 Primary Energy Saving (PES)

In this section, the primary energy saving is described. For a full primary energy analysis all energy flows, as well as a reference system, needs to be defined to describe the impact in terms of primary energy savings. Primary Energy Factors (PEF's) is based on the standard procedure and PEF for specific energy carriers such as electricity and in this project, it is defined as European standard values. As explained above, PEF = 2.1 is used for electricity and PEF = 1.0 is considered for DH in this project (however, in Denmark normally used primary energy factors are 0.85 for district heating and 1.8 for electricity). Therefore, PES in a system including electricity use and heating production in DH is calculated as below:

$$PES = (1.0 \times Q_P) - (2.1 \times P_{el}) \quad (4)$$

Where Q_P is the heat production of the system, and Pel is the associated electricity consumption used for powering heat pumps etc.

2.2.3 Evaluation of Costs

To provide a basis for operators who are interested in establishing the LTDH system, an evaluation of the system has been made. For investors, authorities, and energy companies, it is of interest to gain insight into investment costs to build a LTDH network, as well as understanding how the lower system temperatures, lower heat losses, and the possibility of using more low-grade surplus heat is affecting the operational costs.

2.3 Social evaluations

The social evaluations made in this monitoring report includes an evaluation of comfort, user satisfaction, and experiences of involved partners within COOL DH. The evaluations are based on the following studies:

- A survey study with households in Høje Taastrup. A questionnaire in Danish was sent out in September 2021. The data was analysed in the tool SPSS, most analyses included descriptive data of distribution of responses on an ordinal scale level (Likert scale).

- Interviews with key persons in COOL DH were carried out in May 2022 where the demonstrations in the project were discussed. Information about success factors and obstacles on the way was gathered. Group interviews or personal interviews were used.

3 New Type of Substation

In this part of the report, the installation of new individual units (HIUs) in the Østerby district in Høje Taastrup Municipality, is presented. The old DH network in Østerby was replaced with a new LTDH network, which supplies heat to 159 users for a total heated area of 12,604 m² including flats in chain houses and a kindergarten. The LTDH network utilize surplus heat from the cooling system that operates in the nearby shopping mall CITY2. The temperatures of the LTDH network are dimensioned to be 55°C on the supply side and 30°C on the return side, as a starting point. However, currently the network is operating with 70/38°C supply/return temperatures on average.

The HIU is a technology that implements a decentralized heating system, where heat exchangers are used for the instantaneous production of DHW and SH. The water coming through the heat source passes through the heat exchanger and heats up the water on the cold side, which is then delivered to the consumers tap. The implementation of a HIU ensures a minimal risk of Legionella contamination since there is nearly no water in the system and it operates as a plug flow system. A principal sketch of the type of HIU implemented in the Østerby district can be found in Figure 5.

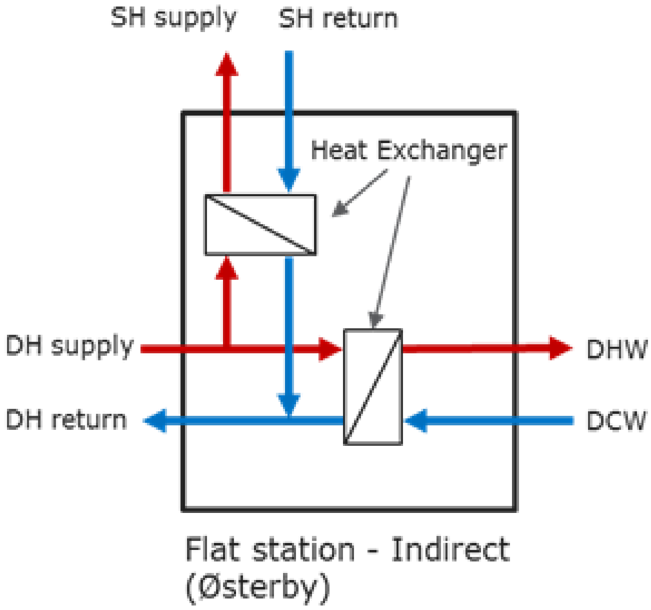


Figure 5. Simplified representation of the HIU technology implemented in the Østerby district

The HIU installed in the dwellings is a Germina Termix unit. The connection of the unit to the district heating pipes was optimised by keeping the pipes as short as possible to reduce the heat losses. The HIU installed in one of the dwellings can be seen in Figure 6. An energy meter is installed above the control panel, which allows for individual measurements of the heat consumption in each flat.

Figure 6. Installation of a DH unit (HIU) at a customer's dwelling in Østerby

The Østerby area is divided into three neighbourhoods: Cederlunden with 51 customers, Olivenlunden with 72 customers and Palmelunden with 35. All customers have the new type of substation installed in their flats.

3.1 Energy performance

The energy performance evaluation for converting to HIUs in the Østerby area was investigated for Cederlunden, Olivenlunden, and Palmelunden. The monitored parameters in this part of the report can be found in Table 1 in the introduction. The heat consumption was measured in each flat.

The measured monthly heat delivered to Østerby, and the corresponding heat losses calculated based on the consumer consumption (as described in previous sections) can be found in Figure 7. The monitoring started on the 1st of January 2021.

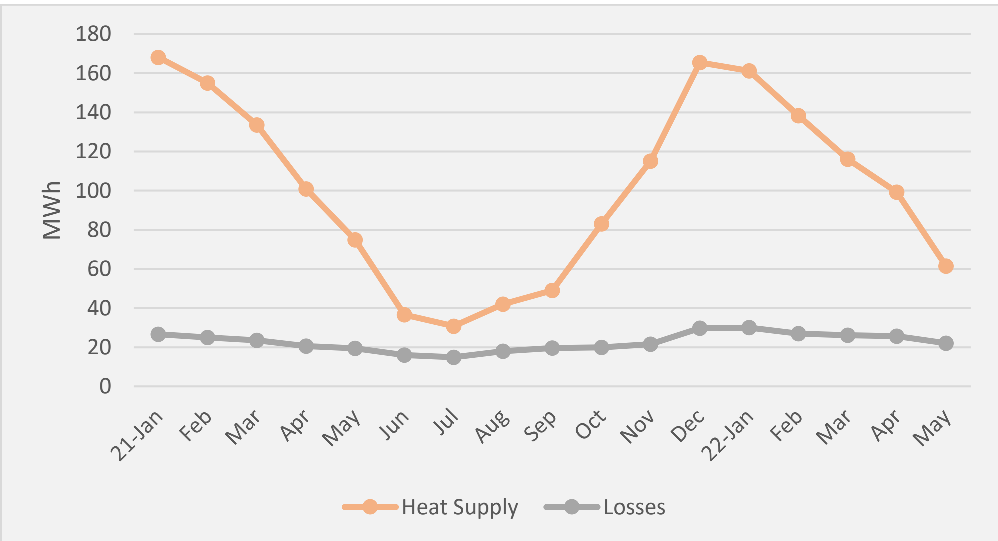


Figure 7. Total heat supply and heat losses in the Østerby district

The total heat delivered to the Østerby network was 1,154 MWh in 2021. The heat consumption by the customers was 899 MWh in 2021 corresponding to 68.8 kWh/m^2 per year in average, with Cederlunden being the highest at 72.5 kWh/m^2 per year. The highest heat delivery to the network was 168 MWh in January 2021 and the lowest was 31 MWh during July. The total heat loss in 2021 was 255 MWh (equal to 22% compared to 35% before network renovation) corresponding to 19.5 kWh/m^2 per year (Cederlunden 17.9 kWh/m^2 per year). The heat loss relates to off-set higher temperature operation conditions during commissioning.

Generally, the delivered heat is significantly higher during the winter months compared to the summer months, which is expected because of the colder weather during winter which results in a higher space heating demand. Higher heat losses (real values, not in percentage), also occur during the winter months, due to the higher temperature of heat delivered.

Figures 8, and 9 show the total heat supply and heat losses within the network in different districts of Høje Taastrup. Data from Olivenlunden and Palmelunden are shown combined since there is no separate heat meter in these areas while Cederlunden has its own heat meter. The areas have similar heat profiles.

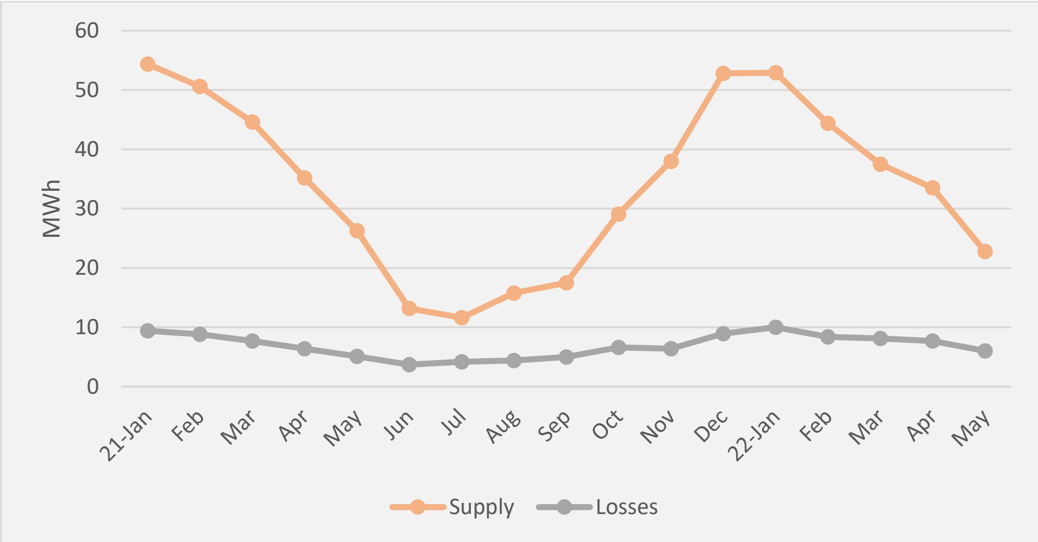


Figure 8. Total heat supply and heat losses in Cederlunden

Figure 9. Total heat supply and heat losses in Olivenlunden and Palmelunden combined

As seen in both graphs, the trend for both the areas are the same. Due to colder weather in the winter months, the demand for heating is higher, which increases the heat losses as well.

The heat supply and heat consumption in each neighbourhood in Østerby can be found in Figures 10 and 11 respectively.

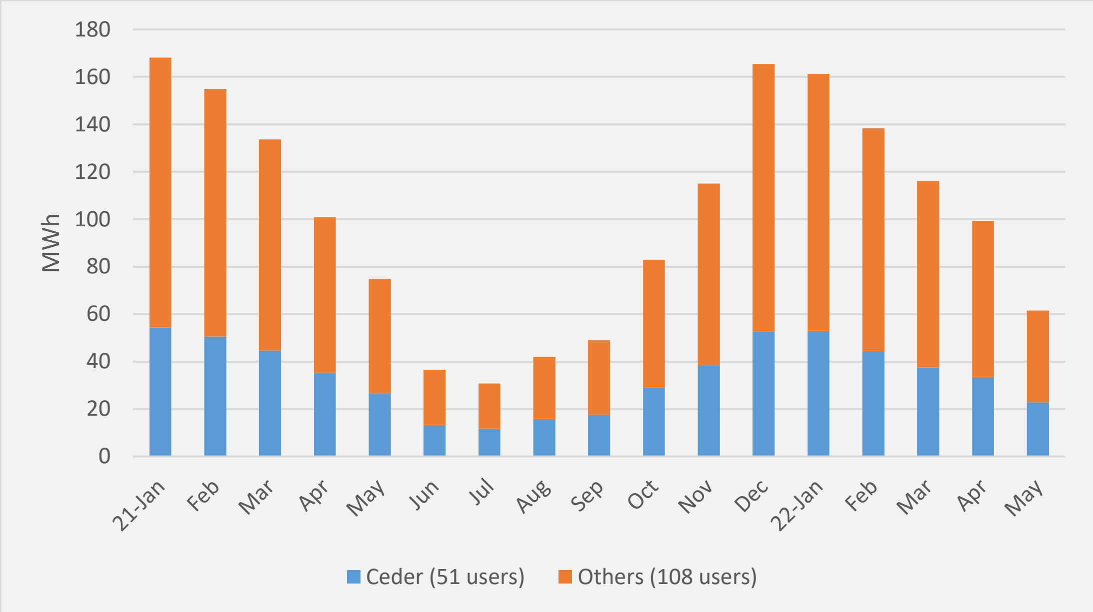


Figure 10. Total heat supply in Cederlunden, and other neighbourhoods

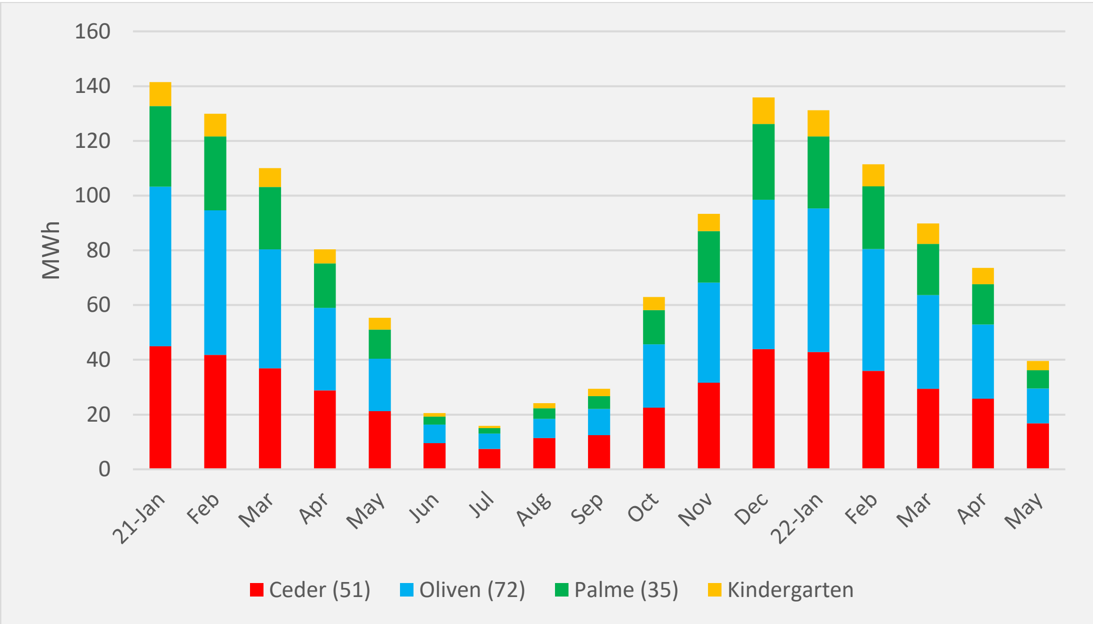


*Figure 11. Total heat **use** in Cederlunden, Olivenlunden, Palmelunden and the Kindergarten*

As seen in Figure 11, the area consuming the most heat is Olivenlunden, followed by Cederlunden. This was to be expected since Olivenlunden has the highest number of dwellings connected to the new LTDH network. The heat supply in Figure 10 corresponds well with the number of dwellings connected.

In Figure 12 the total heat distributed in the new LTDH network in Østerby is showed for 2021. The heat use is divided into the three previously mentioned areas and the kindergarten. The figure also includes the heat losses in the network. All values are in MWh.

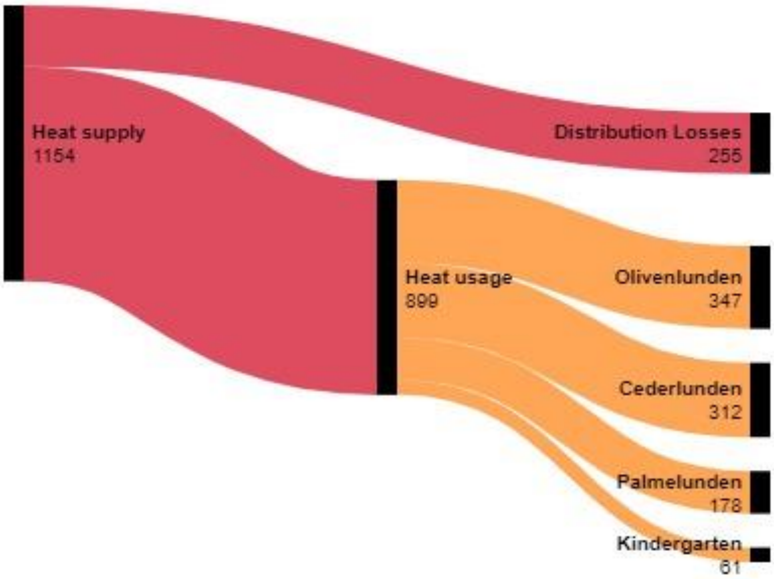


Figure 12. Heat distribution in Østerby in 2021 [MWh]

The average monthly supply and return temperatures in the HIUs were calculated for the total number of dwellings in each district (Cederlunden, Olivenlunden, and Palmelunden). The results can be seen in Figure 13.

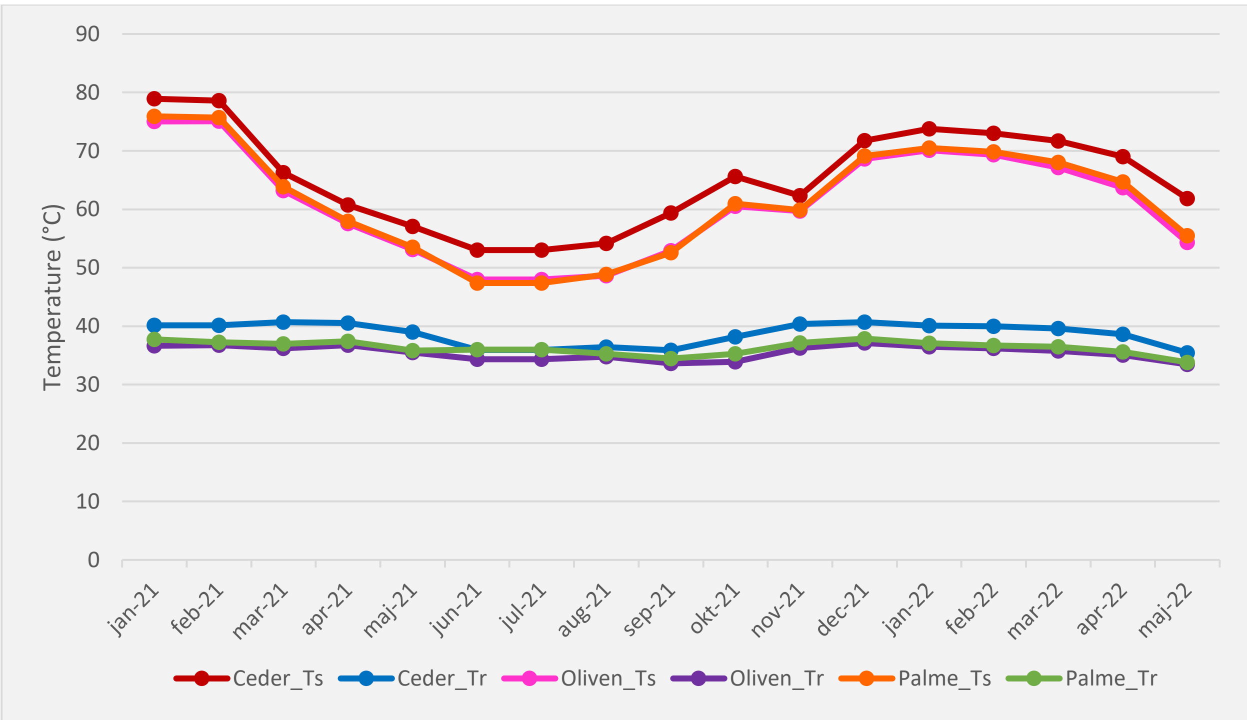


Figure 13. Average monthly supply and return temperatures in Cederlunden, Olivenlunden, Palmelunden

Cederlunden dwellings had the highest supply and return temperatures during the monitored period. This is due to Cederlunden being closest to CITY2, thereby lowering the pipe distance and the heat losses, also seen in previous figures. The dwellings in Olivenlunden had the lowest supply and return temperatures. This is due both to the high pipe length, which can be seen in Chapter 4, Table 6, and the high number of dwellings. These factors increase the heat losses and reduces the temperature delivered. The supply temperature was raised to be significantly higher during the winter months around 60-75°C (as an intermediate solution), whereas it was shortly down to non-intended 45-50°C during the summer months. The design value at the consumer is 55°C in DH supply temperature which will be achieved when the booster pump is installed. The return temperature in the LTDH network is relatively constant around 35-40°C, close to the dimensioned value of 30°C. The temperature was slightly higher but it can be reduced by adjusted thermostatic bypasses.

The low supply temperatures in the summer months lead to lower domestic hot water temperatures at the tap points in the flats, lower supply temperatures than the rules for domestic hot water installations prescribe, therefore the temperature was raised to avoid lead to problems with Legionella bacteria. Legionella bacteria lives in all free watercourses and the cold water can thus contain legionella bacteria. If the water is not heated to more than 45°C, the bacteria will most likely not be killed by the heating. However, since the hot water is produced directly in the heat exchanger and there are very short pipe lengths to the tap points, there is very little time for the legionella bacteria to grow in the system. The district heating utility monitors the supply temperatures to their customers closely. However, in this case, the utility is waiting for the booster pump to be able to provide the most far away consumers with correct differential pressure which will enable lowering of the supply temperature during winter. The average supply and return temperatures in 2021 were calculated and is shown in Table 3. Note that the values are averages of every individual measurement at each dwelling during the monitored period.

Table 3. Average measured supply and return temperatures

	Cederlunden	Olivenlunden	Palmelunden
Average T_{supply} [°C]	63.4	59.2	59.4
Average T_{return} [°C]	38.7	35.5	36.4

Again, Olivenlunden seems to experience both the lowest supply and the lowest return temperatures.

A comparison between heat use in the converted LTDH network and a previous conventional network, as per available historical data, is shown in Figure 14. Average specific heat demand for houses in Østerby in 2021 was 66.5 kWh/m^2.

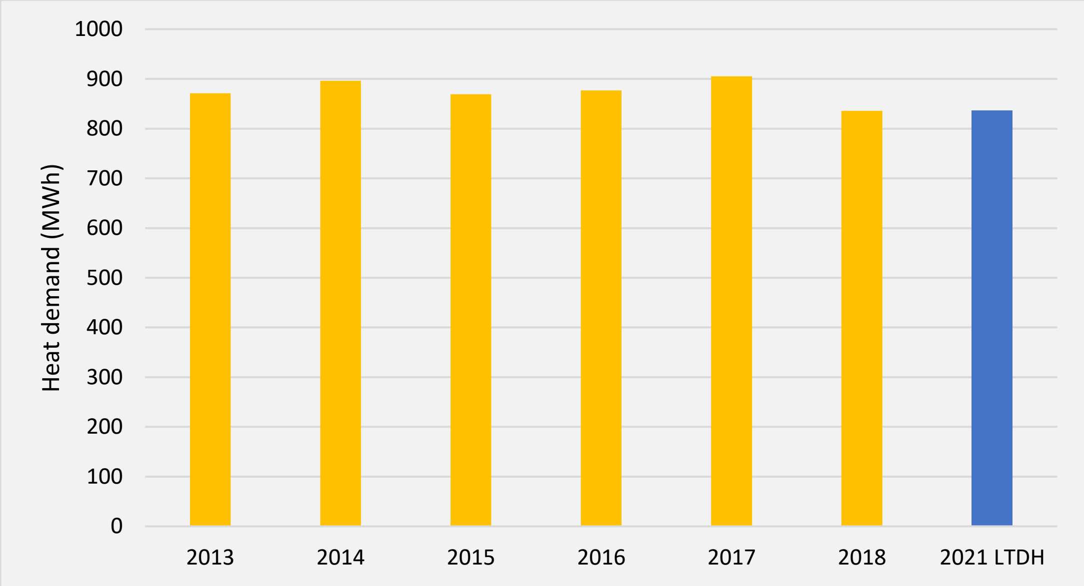


Figure 14. Heat use before and after running converted LTDH network (year 2017 was about 4% milder than 2021 in degree-days and 2021 was interim operated at average DH temperatures of 70/38°C)

In addition, degree-days in 2021 is compared to a degree-days reference (Average 1980-2020) in Figure 15. It shows that 2021 is relatively in accordance with the reference year.

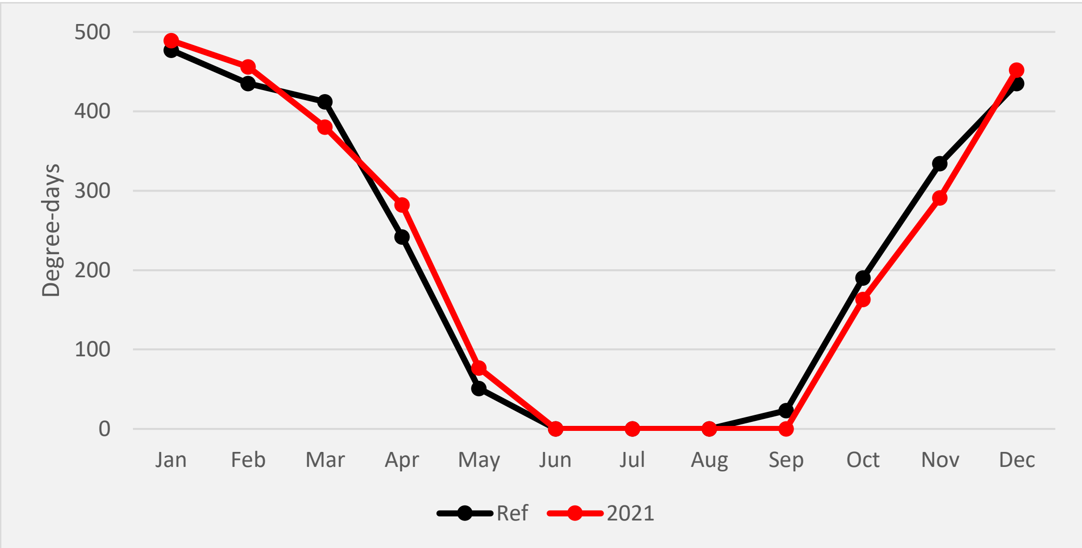


Figure 15. Comparison of Degree-days between 2021 and the reference year

3.1.1 Energy Signature

The energy signature is a method for presenting a buildings energy use and it is based on heat supply and heat use being correlated to climatic data over the cold season. This method provides useful information about the energy performance, the heat loss coefficient, and the balance temperature of a building. The method can be utilized on a large scale (e.g., buildings in a neighborhood/district) of the building by plotting the average heating versus the average outdoor temperature [6, 7]. According to this method, the most influential parameter on the heat use is the outdoor temperature, and the indoor temperature is considered constant. The monthly heat supply in Østerby is plotted versus the average outdoor temperature and degree-days for the heating season as shown in Figures 16 and 17.

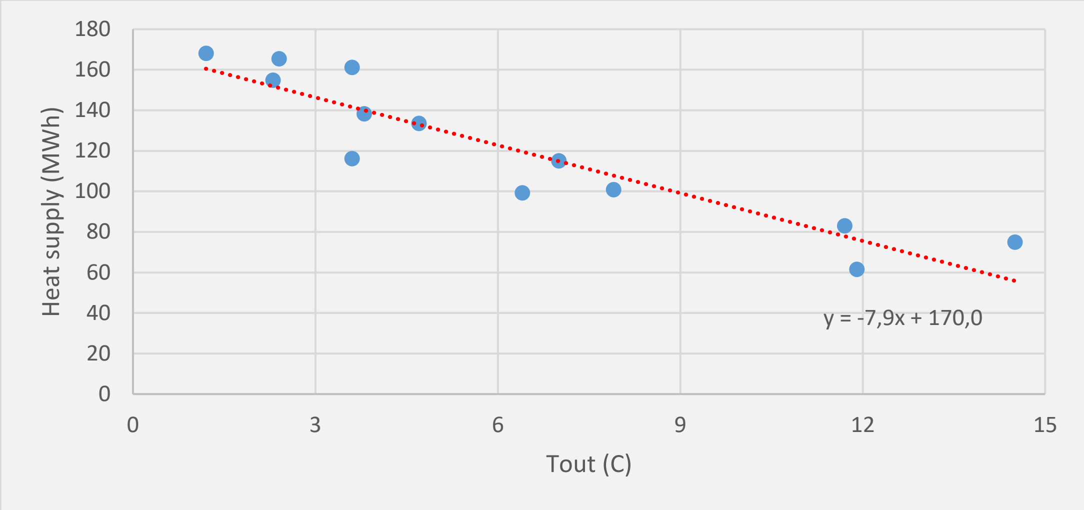


Figure 16. Monthly heat signature

The red trendline in Figure 16 intersects the Y-axis at y = 170 and it implies that if the average outdoor temperature is 0 °C, approximately 170 MWh heat would be used in a month. The slope of this line is proportional to the average heat transfer coefficient of the buildings and in this case, it is 7.9 MWh/°C. This means that a reduction of 1°C in outdoor temperature results in a heat use increase of 7.9 MWh on average.

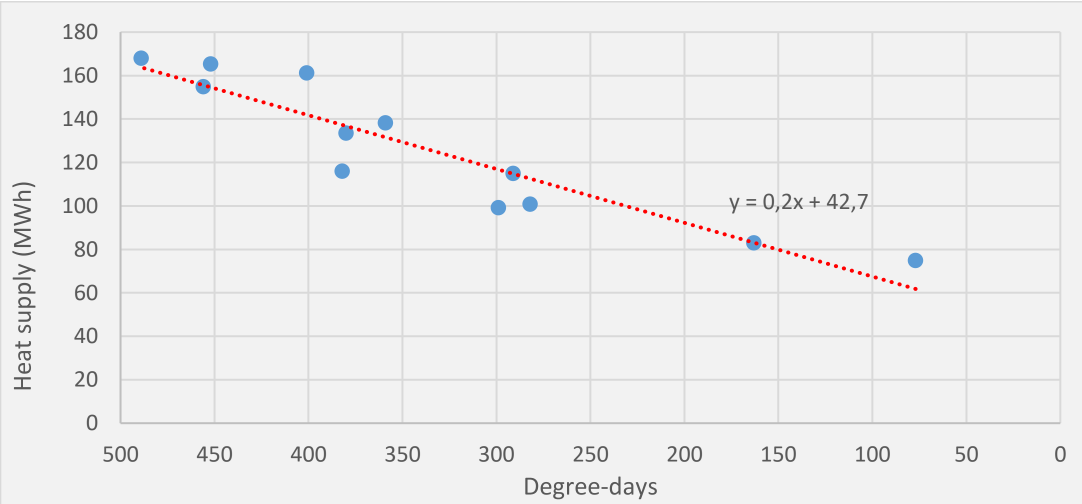


Figure 17. Heat supply vs. degree-days

The red trendline in Figure 17 intersects the real Y-axis (x=Degree-days = 0) at y = 42.7. This is the base heat supply, and it can approximate the sum of DHW and the losses within the network in the warm season when the degree-days in a whole month is zero.

3.1.2 Indoor climate with new HIU and LTDH

As was mentioned before, an evaluation of the indoor temperatures was conducted, before and after installing the new LTDH network. The evaluation was based on temperature measurements taken in eleven (11) dwellings in Østerby, and includes indoor temperature, DHW consumption, and cold-water consumption. As it can be seen in Table 4, there are not any significant difference in indoor temperatures for the mentioned dwellings in high and low DH temperature supply modes. The minimum indoor temperature is 20°C in December 2021 in a near high temperature mode. This proves that a LTDH system can meet comfort temperature needs for the inhabitants just the same as a conventional DH system.

Table 4. Indoor temperatures (°C) for the selected dwellings in high (orange) and low (yellow) temperature modes

Tsup (°C)	Month	1	2	3	4	5	6	7	8	9	10	11
86	Nov-20	22,3	23,7	-	21,5	23,5	20,5	21,6	20,9	22	21,2	23,8
86	Dec-20	21,9	23,2	22,2	21,5	23	20,5	21,5	20,6	21,8	20,4	23,4
86	Jan-21	22,4	23,1	22,9	21,4	23,1	20,1	22,3	20,6	21,5	21,3	23,1
86	Feb-21	21,9	22,9	23,1	21,6	23,6	20,2	22	21,5	21,7	21,8	23,8
71	Mar-21	22,5	23,3	23,5	22,1	23,5	21,7	22,4	21	22	21,7	23,8
65	Apr-21	22,8	23,7	23	23,2	24,2	20,7	22,3	20,4	22,3	22	24,4
61	May-21	23,1	24,4	23	24,2	24,3	-	22,4	20,9	22,9	22,9	24,5
62	Jun-21	25,6	25,3	25,3	27,7	26,3	-	24,7	24,8	24,5	25,2	25,6
63	Jul-21	25,6	25,4	26,2	27,7	26,5	-	25,1	25,4	24,8	25,5	26,1
61	Aug-21	24,3	24,8	24,1	25,2	24,9	-	24,1	25,5	23,8	24,3	24,7
69	Sep-21	23,4	25	24,3	24,4	24,4	-	23,4	23,6	23,6	23,5	24,2
74	Oct-21	22,4	24,4	23,9	21,9	23,3	-	22,4	21,9	23,1	21,7	23,5
68	Nov-21	22,4	23,5	23,3	21,9	22,8	20,5	22,3	21,1	22,7	21,4	23,7
77	Dec-21	22,1	23,3	23	21,6	22,3	21,9	21,9	21	22,3	**20**	23,4
80	Jan-22	22	23,4	23,1	22	22,4	22,2	22,2	21,3	22,4	20,9	23,3
79	Feb-22	21,2	23,4	23	21,4	22,6	21,3	22,3	20,1	21,9	21,5	23,5
79	Mar-22	21,7	23,3	23,8	22,2	23,9	21,3	22,6	23,5	22,5	21,6	24,2
77	Apr-22	21,9	23,9	23,9	-	24,3	22,3	22,3	23,1	22,3	21,4	24,6
72	May-22	23,2	25	24,5	-	24,6	22,8	22,6	24,1	23,2	22,8	25,5

3.2 Economic analyses

Approximate expenses to install and operate HIU units can be seen in Table 5.

Table 5. Expenses for DH units

Expenses	
HIUs (159 units)	€ 270,000
Total (Units incl. installing, building works etc.)	€ 458,000
Total incl. VAT	€ 547,000
Average per unit incl. VAT	€ 3,500

The customer pays a subscription fee of 2,485 DKK (€ 333) annually for heating units (HIUs) in 20 years, incl. VAT. The fee consists of a construction contribution as well as a maintenance and administration contribution. The subscription is settled on the customer's heating bill, and collection starts on the first of the month after the customer's signature. Then, Annual payment and Pay-back time can be calculated as below:

The payment for the subscription over 20 years is 49.700 DKK (€ 6,671) per customer.

Before renovation of the grid the heating bill was 1.060.000 DKK/year (€ 142,281) for the 159 customers, of which 35% was lost in the internal heating grid behind the meter before reaching the customers. After renovation the customers only pay for the heat delivered to the individual household. This led to an annual saving on the heat bill of 2.333 DKK/year (35% of 6.667 DKK/year in average pr. Customer = € 313). Since the subscription fee cover all maintenance and service over a 20-year period they further save approximately 1200 DKK/year in average (€ 161)

All in all, the simple pay-back time can be calculated to:

(49.700 DKK / (2.333 DKK/year + 1200 DKK/year)) = **14 years**

The expected life span of the HIU is >20 years.

In addition, the customers avoided the individual investments in a new internal district heating system in the area as the old grid was worn down with corrosion, leaks and big heat losses. See also section 4.2.

3.3 User satisfaction

A survey made in google forms was sent out to the households in Østerby in September 2021, in total to 153 addresses through e-mail. The survey was written in Danish, so that the households would better understand the questions and could answer in their mother tongue. In the data analysis the answers were translated into English. 34 households choose to answer the survey which gives a rate of answers of about 20%. Although the rate of answers wasn't that high, the answers show a diversity of attitudes and answers, and at the same time capture some common qualities.

The survey study included four different parts:

- Questions about the conversion process (information, implementation, restoration of land)
- Questions about the district heating substation and heat and domestic hot water comfort
- Questions about the new customer relationship and the new price model
- Questions about being a part of a low temperature district heating system

3.3.1 Conversion process

The first section in the survey dealt with questions about the converting process, mainly the households experiences of the excavation work, the installation of the service pipes into the buildings and the new district heating substations in the flats. The first question was about the household's satisfaction

with the information they had received from Høje Taastrup Fjernvarme about the installation work of the pipes. The results can be seen in Figure 18.

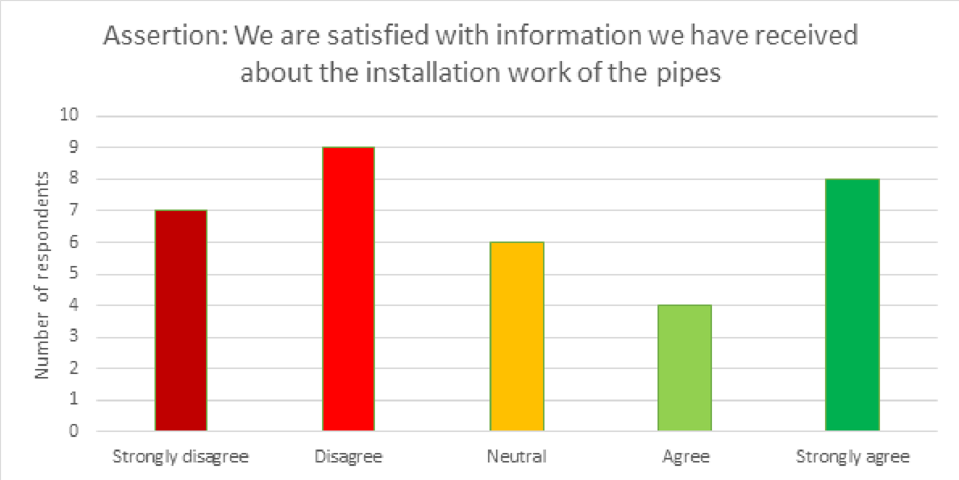


Figure 18. Household satisfaction with information about the excavation and installation phase.

As can be seen in Figure 18, the opinions about the information were rather scattered. Slightly more households were dissatisfied with the information than satisfied. In the survey, the households were able to comment in free text what they thought about the information. Only the households that were dissatisfied choose to include comments, these are reported down below:

- **Strongly disagree**
  - "Too many ambiguities and changes in conditions and terms in the years up to. On top of that with extra financial consequences due to double change of heat exchanger - first in old system and a few years later when changing to new system."
  - "No information along the way, took way too long, still does not have a nice lawn."
  - "Insanely long time with excavation work! Conflicting and incomprehensible messages."
  - "We received no information."
  - "Expectation of excavation work out in the road but it happened in the garden with inconvenience as a result."
  - "It was unclear where and when to dig."
- **Disagree**
  - "Very little information-poor information-late information."
  - "Came at short notice."
  - "Several times the information came very late. It was not considered that it was different installations that had to be made in the different blocks."
  - "Got late of knowing where they would finally dig."

In summary these households think that there has been a lack of information or that the information came very late. The households didn't know when the excavation was about to start, and the excavation was going on for a long time (this feedback was received even after several information meetings held and distribution of info-material.)

The next question was about the customer satisfaction of the laying of the service pipes into the houses. As can be seen in Figure 19, most of the households were satisfied or neutral, only a few stated that they were dissatisfied.

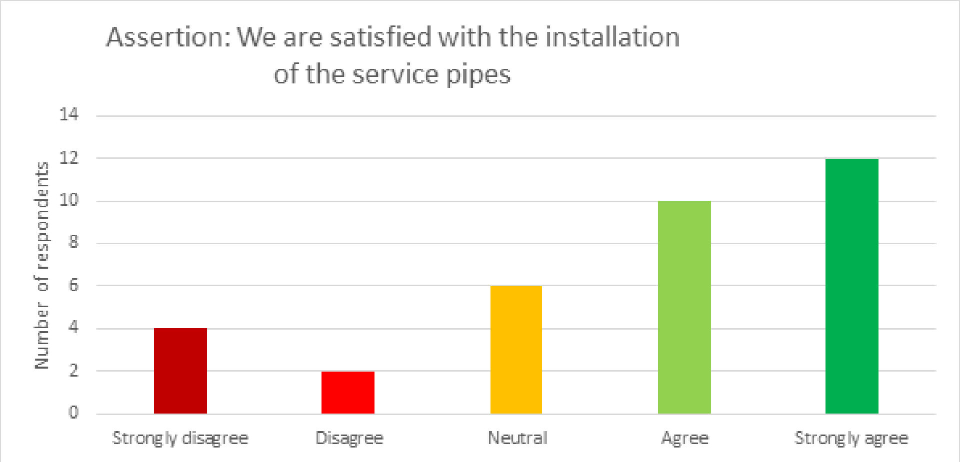


Figure 19. Household satisfaction of installation of service pipes to the houses.

The comments from the households have been sorted by degree of satisfaction (or dissatisfaction):

- **Strongly disagree**
  - "Hedge destroyed and not re-established. Drilling in the wall gave a week (!) with a hole for the outdoors, in the middle of winter. Very space consuming installation inside!!! Plus, it is connected to MY electricity bill?!?"
  - "It was just the second time Mr. XX (anonymized) failed due to "disease"."
  - "Several mistakes were made so they had to enter my house three times. Each time, I had to take time off from work"
  - "Re-establishment is incredibly poor, and still deficient."
- **Disagree**
  - "It took several months from the time it was dug up until more actually happened in the process."
- **Neutral**
  - "Piping has reduced space in our hallway."
  - "Very late and some clutter."
- **Agree**
  - "I do not completely agree because my garden looks like something I ..."
- **Strongly agree**
  - "After protesting against the first proposal for excavation, a sensible solution was found."

The third question was about how satisfied the households were with the work done to recover the land and gardens after digging down the service pipes. The result can be seen in Figure 20.

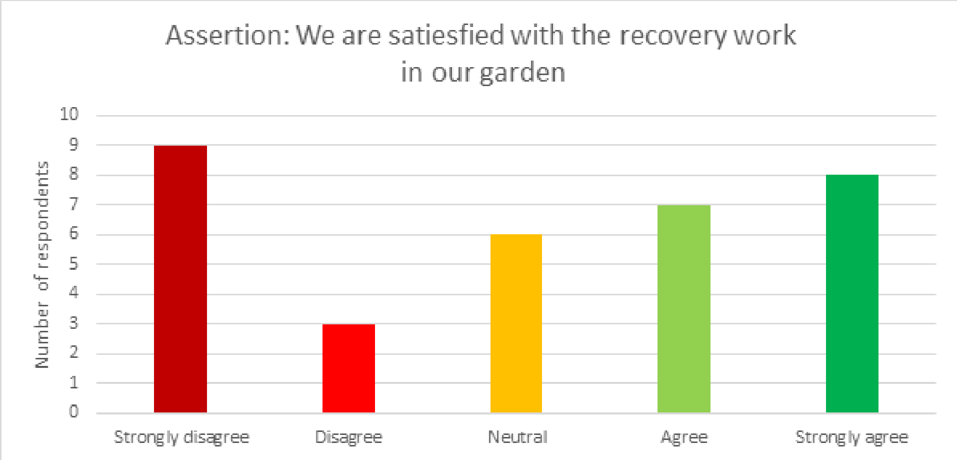


Figure 20. Household satisfaction with recovery work in their gardens.

Also, this question seemed to divide the opinions of the households in Østerby. Some households were strongly dissatisfied with the recovery work. In total thirteen out of 33 were dissatisfied with the recovery work, six were neutral and fifteen were satisfied (one household did not answer the question). Free text comments were given by all groups:

- **Strongly disagree**
  - "NO!! The hedge is broken. The lawn is ruined. The roof tiles on my shed are broken. Very long process ...!"
  - "Excavated soil was replaced with gravel, also where the new hedge plants were put. Beech hedges in gravel are not a good idea. Several plants around are dead, others are not doing well."
  - "No grass was sown and it took a long time before we replanted the hedge"
  - "Hedge plants wither, lawn withers due to the lack of soil layer on top of the heating pipes, too much gravel!"
  - "Still missing grass and several hedges. Badly accomplished and it took way too long."
  - "Our tiles subsequently lie as if they have just been thrown into place, and we get the message that this is "how it is" when digging."
  - "Soil mixing causes my hedge not to grow"
  - "The newly sown "grass" on the common areas looks more like weeds than grass."
- **Disagree**
  - "They had to be moved a few times"
  - "At my entrance, the tiles are laid at an angle, so that a very large puddle is formed when it rains"
  - "A few of the plants that were taken up did not survive the replanting"
- **Neutral**
  - "Too long recovery."
  - "It could well have been done better. The hedge is planted at an angle to the existing one and I have had to re-sow/plant the lawn myself."
  - "It was marked in red on my garden tiles and it took a very long time before it disappeared. The tiles became very dirty and required professional tiling afterwards. All the beech hedge plants in private gardens and in common areas that had to be replanted are the pure failure.

They are withered and only fill a fraction of the excavated hedges. Lawns were also not re-established satisfactorily."

- **Agree**
  - o "Positive with flexibility from contractor with purchase of extension of tile coverings and more".
  - o "Not southern good soil that came in the bed. Heavy and not easy to work with."
- **Strongly agree**
  - o "There was no need for excavation work on my land."

To summarize, many of the households were unhappy with the way the land and the gardens were recovered. The households wanted to have their gardens restored to the same level as they were before the service pipes were installed, but this was not the level they had got.

3.3.2 Knowledge and attitudes to low temperature district heating

There has been a long process to convince the four housing associations to do the conversion to low temperature district heating. It is interesting to get some views of the households living in these housing associations about the system.

In this section, three questions were asked:

1. Do you have good knowledge of what is meant by a low temperature district heating system?
2. Is it important to you that the heat comes from environmentally friendly heat sources?
3. What heat source is the most environmentally friendly heat source in a district heating system?

The responses to the first question are shown in Figure 21.

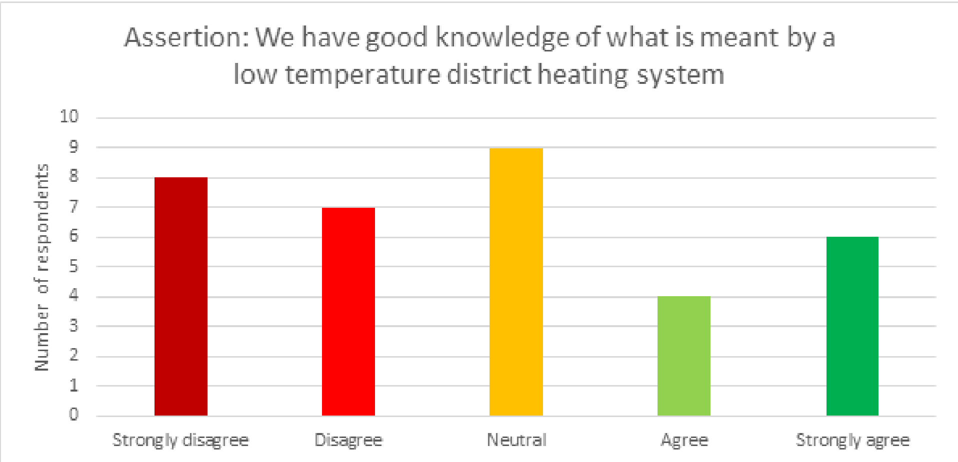


Figure 21. Households' self-assessment regarding how much knowledge they have about the concept of LTDH

The responses are scattered on the scale from strongly disagreeing to strongly agreeing. Having recently converted their heating system from traditional district heating to low temperature district heating, one would suspect that there had been some information from the district heating utility about the concept low temperature district heating. The result however shows that there are a lot of households that either haven't got the information or haven't been interested enough to learn about it.

The second question in this section was whether the households thought that it was important or not that the heat from the district heating system is produced from environmentally friendly heat sources. As can be seen in Figure 22, almost all households stated that they think this is important.

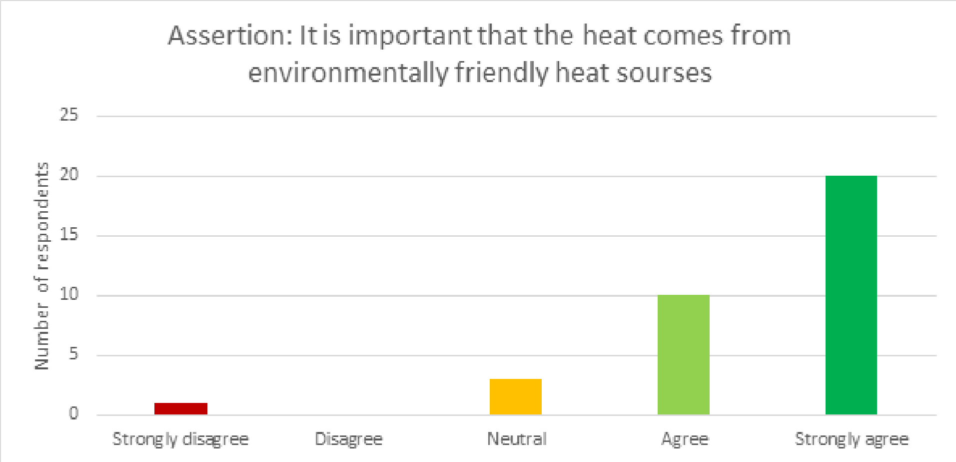


Figure 22. Households' attitudes towards the importance of the fact that the heat is produced from environmentally friendly heat sources.

Out of curiosity, we also thought it was interesting to see what energy sources the households' thought were the most environmentally friendly of the following alternatives: excess from industrial processes, combined heat and power production from biomass, combined heat and power production from waste incineration and the use of solar heat. The answers are compiled in Figure 23.

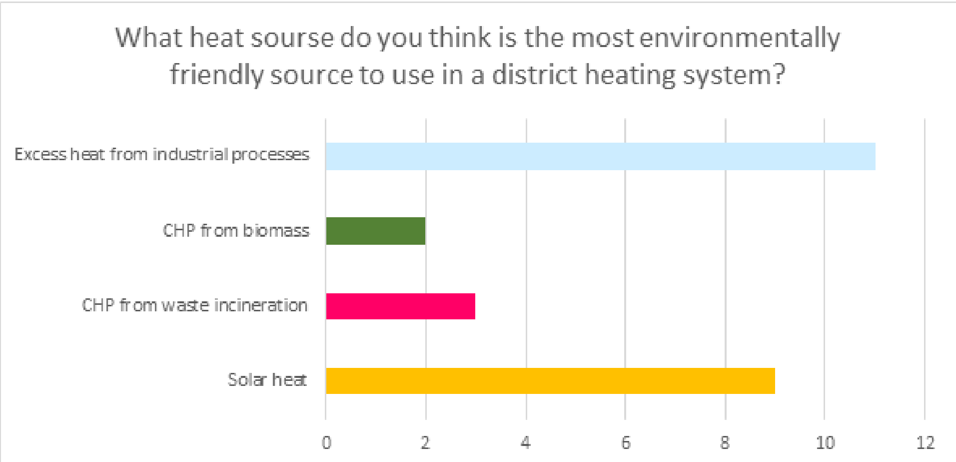


Figure 23. Households' opinions about which energy source is the most environmentally friendly in a district heating system.

As can be seen in Figure 23, excess heat from industrial processes is viewed to be the most environmentally friendly heat source by the Østerby households, closely followed by solar heat.

3.3.3 The district heating substation and heat and domestic hot water comfort

The next section of questions is about the district heating substation and the households' experiences of thermal comfort of indoor climate and domestic hot water. After the conversion, the households are getting their heat directly from the district heating utility, i.e., there is no secondary grid anymore, and all flats have their own district heating substation. When asked, the households either say that this conversion has been good or they are neutral to the change.

As can be seen in Figure 13 low supply temperatures in the new district heating grid in Østerby have been used since March/April 2021, mainly under the summer period, before that the supply temperatures have been more in level with conventional district heating. So, it is only a short period and mostly in summer time that the households really have experienced low temperature district heating in this survey.

The households were asked if they were satisfied with the placement of the district heating substation, the result is shown in Figure 24.

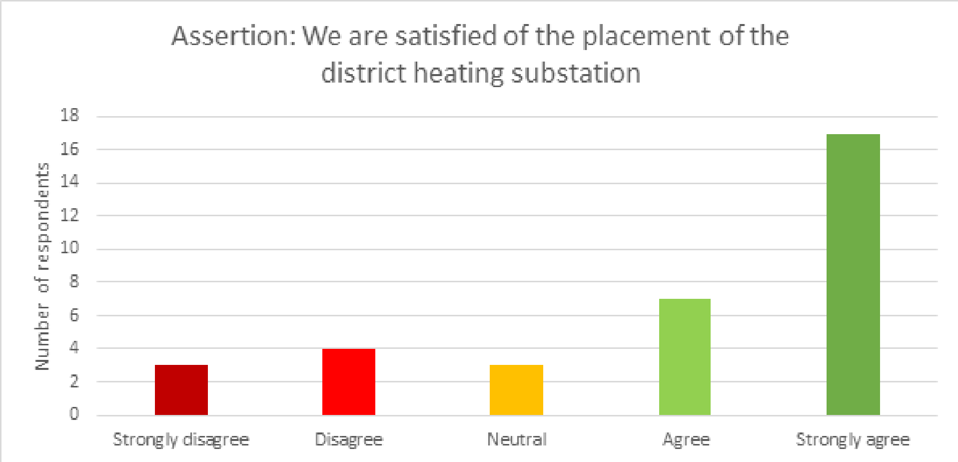


Figure 24. Household satisfaction of placement of district heating substation.

Most households appear to be satisfied with the placement of the district heating substation, only a few say they were dissatisfied. Judging by the free text answers reported down below, the problem has not been the placement of the district heating substation, rather it seems as if many households were not prepared for the district heating substation to take up so much space (that is: more space than the old installation without a heat exchanger):

- **Strongly disagree**
  - "Takes up too much space in a small room under stairs."
  - "Much more space consuming than previous solution! Why can it not sit outside ??"
- **Disagree**
  - "It fills the whole wardrobe"
  - "Not quite, because it is covering my cold-water valve to my outdoor water"
  - "It takes up too much space."
- **Neutral**
  - "Located in the same place as the previous heat exchanger. Can probably not be placed elsewhere."
  - "The location is ok so far, it's probably more the size."
  - "It fills up a lot in a small storage room. It is a lot bigger than the one we had before."
- **Agree**
  - "Okay, but takes up more space than the old one."
- **Strongly agree (**no comments).

The households were asked if they had tried to make any adjustments on the settings of the district heating substation, since it was installed. Only very few of the households stated that they had tried to adjust themselves (four out of the 33 that choose to answer the question). Normally, if the heating system is adjusted in a good way when the system is installed, the households don't need to make any changes of the settings on the district heating substation at all.

The households that answered yes to the question about adjusting gave the following reasons to the question on why they had adjusted:

- ”Filling with water.” (Probably in the radiator system)
- ”Poor circulation.”
- “Tried to get more heat on.”
- “One time I have filled some water.”

The households that answered no to the question gave the following reasons on why they didn´t make any adjustments:

- “We have not experienced any problems with heating. And we have been able to follow via HTF's online reading module that the return temperature has remained at an appropriate level.”
- “Satisfied with the settings.”
- “There has been no need.”
- “It has not been necessary.”
- “Do not know how it works so have not adjusted on it.”
- “Everything works as it should.”
- “I do not know why I should adjust the settings?”
- “I dare not! Lacks a thorough teaching of how it works.”
- “What should the settings be???”
- “Too technical for me.”
- “I´d got an employee from the district heating plant to look at it”
- “I do not think it's hot enough. I cannot adjust it myself.”
- “It works as it should.”

The answers show that the household either are satisfied with the settings as they are, or that they don’t have enough knowledge about the district heating substation to know what to change in the settings.

Next question is about whether the households realized any changes in the indoor climate comfort since they got their new low temperature district heating system installed. The results are shown in Figure 25.

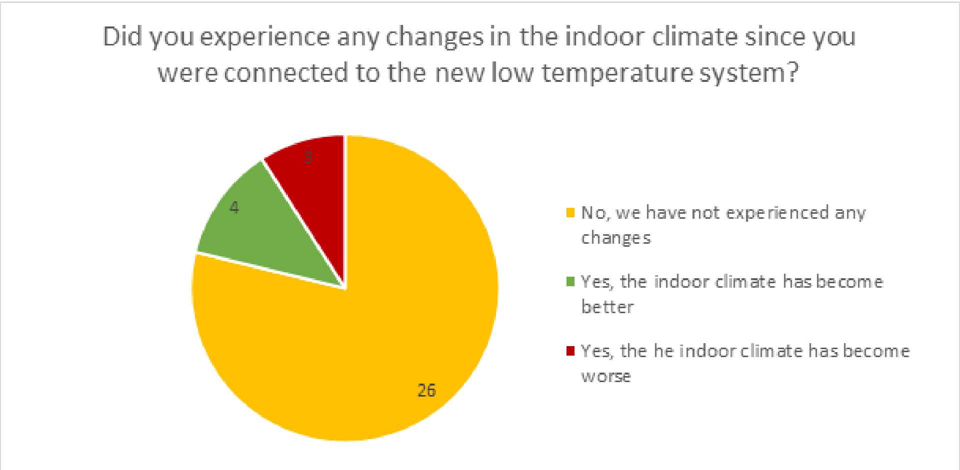


Figure 25. Household experiences of changes in the indoor clime since the new low temperature system was installed.

The lion´s share of the household said that they didn't realize any changes in their thermal comfort. A few households (four) stated that their thermal comfort had improved, and three that it had decreased. Down below, see the comments to the question "If you have realized any changes in the indoor climate, in what ways have this shown?"

- **No changes**
  - "I do not know if it has gotten better or worse. For example, still a lot of condensation on the windows in winter despite a lot of ventilation."
- **Better**
  - "Better heat in the radiators."
- **Worse**
  - "Poor heat distribution. No heat on the 1st floor"
  - "It is not to control."
  - "It is constantly too hot in the house."

A similar question was asked about the domestic hot water comfort, see Figure 26.

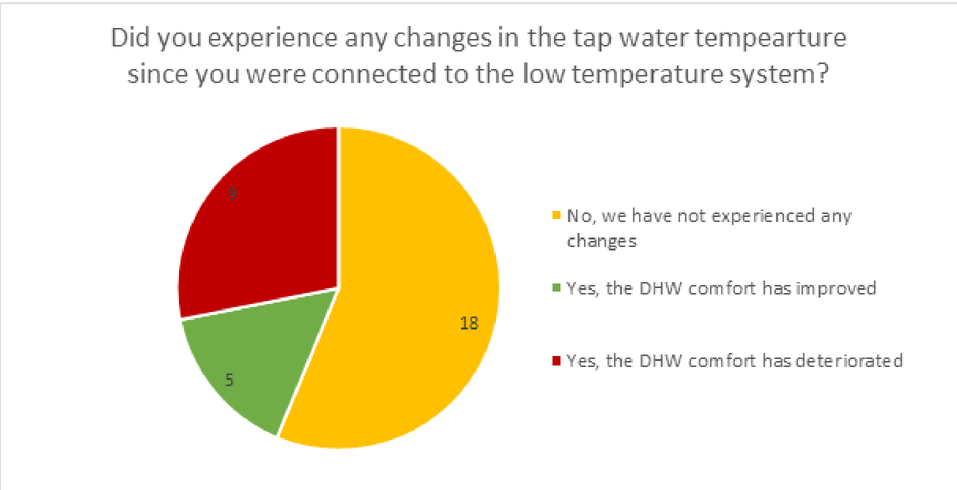


Figure 26. Household experience of domestic hot water comfort after changing to the low temperature district heating system.

It seems like most of the households haven't experienced any changes in domestic hot water temperatures, although some households stated that they have had some problems, see free text comments below:

- **No changes**
  - "Sometimes the hot water is not quite hot, but still rare"
  - "The heat exchanger responds more slowly to hot water than the old one, but only at start-up"
  - "I do not know if there has been any change. The shower water on the 1st floor is nice and warm, but the hot water in the kitchen on the ground floor is never really hot."
  - "I have only lived in the house since May 1, 2020."
- **The DHW comfort has improved**
  - The temperature is more stable
- **The DHW comfort has decreased**

- “Have to wait longer for the hot water. We cannot take a bath with hot water between 16.30-18”
- “The other day there was cold water in the morning in our part without us being notified.”
- “May lack hot water in the morning”
- “I have many times experienced that I only had cold water. Not always you get text message with information”
- “Many outcomes”
- “It takes a long time before the hot water is hot”
- “The water has become colder”
- “There has often been no hot water.”
- “Hot water for bathing in the summer is like a city in Russia”

The free text comments to the domestic hot water comfort indicate that there have been some initial problems with getting the right temperature at peak hours pointing at operational problems at the utility and some other answers indicate that the internal installations in some flats still may need adjustments.

3.3.4 Price model and heat costs

In district heating systems with lower system temperatures, it is very important that the customer installations work properly and efficiently. The dependence of lower grade heat sources makes it harder to raise the supply temperature if needed, and the systems have some limitations of how much they can increase the flow velocity, and if plastic pipes are used in the district heating grid these pipes cannot withstand too high temperatures. One measure to see if the customer’s installations are working efficiently is to look at the return temperature, where a high return temperature could imply that the customer installations are not working efficiently. One way to incentivise the households to maintain and keep their installations in good shape is to enforce a return temperature or flow component in the price model. Høje Taastrup Fjernvarme has chosen to include a return temperature component stating that a return temperature over 43°C gives an additional cost of 10 DKK[1]/MWh/year per degree Celsius (including VAT), whereas a return temperature under 43°C gives a bonus of 10 DKK/MWh/year (including VAT) per degree Celsius.

The households in Østerby where asked if they understand the new return temperature component in the price model or not. The results can be seen in Figure 27.

[1] 1 Danish krona equals to 0,13 euro (as rate for September 2022)

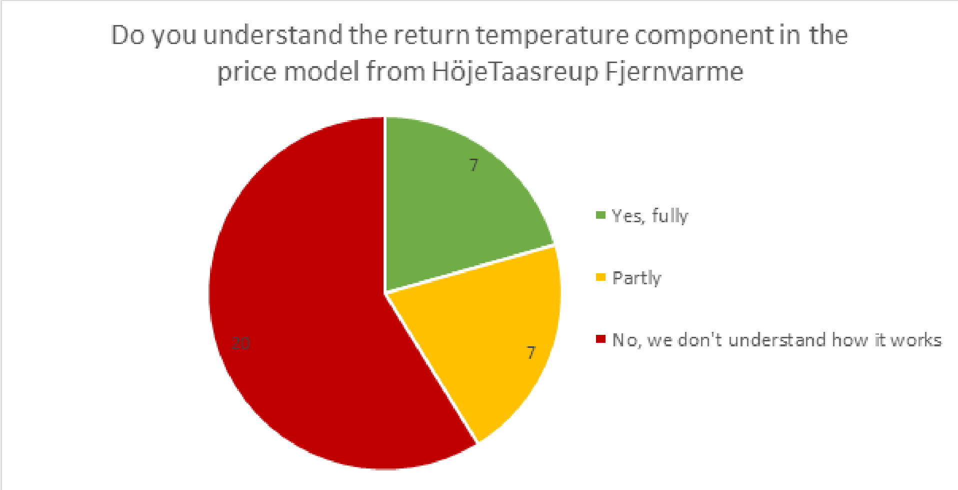


Figure 27. Household responses on the understanding of the new return temperature component in the district heating price model.

The households also got open questions about what they thought about the district heating company's reasons behind this return temperature component in the price model, what the households themselves think about the price component and if they understand what they can do to react on the price component in order to save money.

The answers to these questions have been structured based on how the household answered the question if the understand the price model or not.

First question: Why do you think that Høje-Taastrup Fjernvarme has introduced an incitement fee for return temperature?

- **Households stating, they fully understand the price component**
  - ”To make the individual user cool better”.
  - “For us to take care of the future. Make us more conscious of saving”.
  - “To reduce consumption”
  - ”Stop it.”

- **Households stating, they partly understand the price component**
  - “So I get my heating system set up correctly so that my heating costs are reduced. It is good for the economy and the environment”
  - “For better utilization of district heating.”
  - “I have understood from one of my neighbours (!) that the lower the return temperature is (and the more heat we use in the house) the less energy the system has to use to cool the return water.”
  - “In order not to get too high return temperature”

- **Households stating, they don´t understand**
  - “DO NOT KNOW”
  - ”Do not know”
  - ”I do not know”

- ”I do not know - have not heard of it”
- “???”
- “ ?”
- “I'm not familiar with that”
- “I have no idea, to save water?”
- “We could get grants”.
- ”To help the climate”
- “To make sure you have a good return temperature. But I do not know how to take care of it yourself.”
- “Crazy climate change hysteria”

Very few of the answers reflect any understanding of the district heating utility´s motives for introducing a return temperature component. Some households answer, “to get a low return temperature” and that is correct, but they don´t elaborate on why that is important. Only a couple of households express that is leads to kind of system benefit.

Second question: What do you think about the new price model with the return temperature component?

- **Households stating, they fully understand the price component**
  - ”It is good”
  - ”Fair”
  - “Ok”
  - ”Ok”
  - ”It´s ok”

- **Households stating, they partly understand the price component**
  - “Ok.”
  - ”I'm not familiar with that”
  - ” Have probably not read it otherwise I cannot remember it”.

- **Households stating, they don´t understand the price component**
  - ”It is fine”
  - “Good”
  - “?”
  - “NOTHING”
  - ”I'm not familiar with that”
  - “I'm not familiar with that”
  - ”I don´t want to speculate”
  - “Do not know if I do not know if we meet the requirements”
  - “Nothing! District heating is obsolete. The future is electric” Most households seem to be indifferent to the price model. They accept it, but they don´t care so much about it.

Third question: Do you know how you will get a low return temperature in your system and thereby get lower costs?

- **Fully understand**
  - ”Yes”
  - ”Yes”
  - “Yes, keep the bottom of the radiator cool”
  - “Do not turn up the heat too high”
  - “Do not change anything on the unit”
  - “2+2= 5 ok?”
  - ”No”
- **Partly understand**
  - ”No”
  - “No. It is as far as I know never been communicated from HTK.”
  - “No, but we expect the new substation to ensure this.”
  - “I'm not really familiar with that”
  - ”Neutral”
- **Don´t understand**
  - “YES”
  - “No” (8 answers)
  - ““No, not in details”
  - “No, unfortunately I do not know”
  - “No, but I should probably learn more about it”
  - “No, I can probably learn about it by reading, but I cannot answer straight ahead”
  - “No, why has it just suddenly become my problem. That's HTF's job, right?”
  - “Does not interest me. There has to be heat and that's what we pay expensively for”
  - “Keep heat on all units and not just one”

Some households said that they knew how to get a low return temperature, but very few of these gave any examples of actions that may lead to a lower return temperature. Most households didn’t have a clue what actions they should take to get a low return temperature from their heating system.

Another measure to see if the households are conscious about their costs for heat was to ask them if their heat costs had changed since they got connected to the low temperature district heating system, see Figure 28.

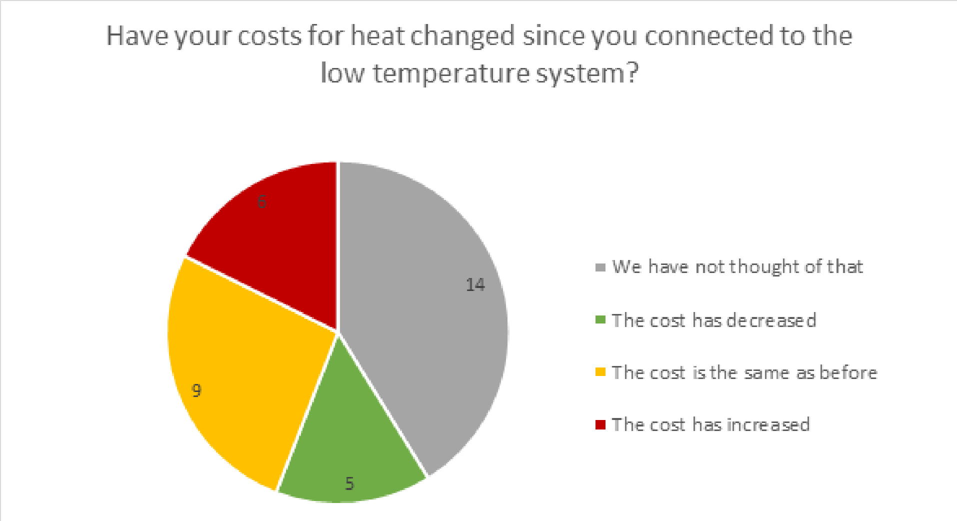


Figure 28. Household responses to if their heat costs had changed since they were connected to the new LTDH system.

As can be seen in Figure 28, 14 of 34 households stated that they haven't reflected on their heat costs, whereas nine of the households said that their costs for heat is the same as before and, five say that their costs have decreased and four that they have increased.

3.3.5 Conclusions from the survey study

Here follows some lessons learned that can be drawn from the results of the survey study.

Excavation and restoration phase

- Information is hard, but a clear communication about how the installations will be made, what the installations will look like and what the households can expect in the building process is important to avoid unnecessary surprises that could negatively affect the residents' view of the new heating system. Continuous updates on activities and plans are important for households to feel well informed. If the digging work takes time, inform about this and the reasons behind it. It is also important to agree on the way of communication and which channels should be used. How do you ensure that the information reaches the target audience? For example: Should the information be available on a specific website, or should there be periodic updates as sent by post?
- Digging down infrastructure will always lead to some inconvenience for the households/tenants. However, it is important to understand the fundamental values that the home and the garden has for many people. If the recovery work is not done properly, this might reflect on the feelings the tenants hold for the new heating system.

Space heating and domestic hot water comfort

- Most households that answered the survey stated that they didn't experience any changes in their indoor climate comparing how it was before and after they converted to the new low temperature district heating grid. But to be fair, they hadn't really had time to experience real low supply temperatures during the heating period when the space heating is on for the time of the survey.
- When it comes to domestic hot water comfort, somewhat more households stated that this had deteriorated (28%) since they converted to a new low temperature district heating grid. The free text answers indicated that there have been some initial problems with getting the right level of temperature at peak hours for some households, and that there still is need for adjusting in the

internal installations in some flats. This is something that the utility has been working hard with during 2022, so it would have been interesting to do a follow up study of the heat and hot water comfort after next heating season of 2023. Unfortunately, this will not be in the time frame of the COOL DH project.

Return temperatures and price component

- In order for a price component to be motivational enough to make the customers act on the price incitements the following requisites must be fulfilled:
    - The customers must understand how the price incitement works
    - The price incitement must be large enough to make bothering worthwhile
    - The customers must know what actions they can take to save money
    - For motivational reasons beyond the economic incitement, it is also good if the customers understand the motives behind the price component. In this case – why is important to get a low return temperature in the system? If the customers can understand that this may have environmental effects or that it can help saving costs for the whole system which could benefit the company and by extension also the customers, they might be more apt to respond to the price signal and the plea of getting a low return temperature back from the customers.
- From the results in this survey study, most households don't have the knowledge and sometimes not the interest to act on the price incitement that the return temperature component is meant to have. Either the utility must work much harder with the information to the customers, or maybe they should use more effort to allow further help to the customers making sure their installations work properly and efficiently. After all, it is foremost the district heating utility that profits from the increased system benefit that a low return temperature can provide to the system.

3.4 Conclusions

- New substations and DH units as HIUs showed the feasibility of using LTDH network in the single-family dwellings with much lower heat losses for the consumer to pay. Installing heating units in a short distance to the tap enables the reduction of DHW temperature to 50°C. The individual metering as a concept is used automatically in Østerby by installing these new substations. The advantage of this solution is that the end-user may easily regulate the use and that the DHW is produced locally, reducing the risk of Legionella proliferation. However, it makes the system more complicated and increases costs in terms of customer installations.
- Giving enough and necessary information to the residents is an important point to consider so that they understand how the new system is working and then they can have a better cooperation with utility to reduce return temperature and heat consumption.
- The higher supply and return temperatures (70/38°C) than designed (55/30°C) at the consumer show that there are still some issues within the network system to be solved. The supply temperature has been increased to provide the furthest users with enough heat, a problem that will be solved when installing a booster pump in the grid. The return temperatures can be lowered by working with the secondary systems on the customer side looking at the functionality of radiators, thermostatic bypasses / valves and sensors to see if there are some problems.

4 Converted LTDH network in Østerby

This part of the deliverable presents the implementation of the new district heating network applied to the demonstration case in Høje-Taastrup Municipality, where a new low-temperature network was designed to replace the old and obsolete one. In the network, the new plastic pipes developed during the COOL DH project was implemented. The design of the network was developed to minimize the heat losses by reducing the length of the pipes and minimizing the pipe diameters.

In 2015, the district heating supply consisted of a share of 51% fossil free energy from biomasses, solar energy, geothermal energy, etcetera. Using a larger share of low-grade surplus heat and increasing the system efficiency is an important step of reducing emissions even further. The LTDH network in Østerby is serving 158 dwellings in three neighbourhoods and one kindergarten, in total 12,604 m^2 heated floor area [1]. Figure 29 gives an overview of the area, highlighting the shopping mall (yellow area) and the Østerby district. The red highlighted area represents the part of the district that is supplied by the LTDH network. The heat supply by the LTDH network in Østerby is ensured by the nearby shopping mall CITY2 through a distribution pipe indicated by a green line in Figure 29.

Figure 29. LTDH area in Østerby (red) and its connection to CITY2 shopping mall (yellow)

The LTDH network will eventually expand to the neighbouring areas; 36,000 m^2 with 350 houses for a total of 413 users connected. It is yet to be determined when this will happen [1]. New buildings are planned in the development area of Høje Taastrup C and can be connected to the LTDH. The District Heating Company, Høje Taastrup Fjernvarme, is in charge of the implementation of LTDH. Figure 30 shows the areas expected to be connected to the new LTDH network in near future. The upper parts of the figure representing Cederlunden, Olivenlunden and Palmelunden including the areas “EF TORS I” and “AB TORS II” are already connected to the new LTDH network.

Figure 30. Overview of the housing associations and the kindergarten in Østerby district

The installation operations of the main pipes of the new LTDH network in the Østerby district took place in the period Spring-Summer 2019 and continued throughout the rest of the year with the installation of the service pipes and the connection of the users. Figure 31 shows a branch of the network and a buried service pipe in the area.

Figure 31. PE-RT pipe before laydown (Left) Installation of the service pipe (Right)

Leakage detection

In addition, there is a surveillance system to detect leakage and moisture in the pipes, this is new for plastic pipes. No failures on the system (no moisture in the insulation and no broken wires) has been detected so far. A sample of the system that is used in the Cederlunden neighbourhood is shown in Figure 32. In the top of the figure, the impedance measurement can be seen. The black curve represents the basis curve when the system was taken into operation and the red curve represents the present situation. The two curves are very close to each other, indicating that there are no changes as to how the situation was when the system was taken into operation. If moisture (and thereby leakage) occurs in the system, it will affect the impedance and be visible in the upper part of the figure.

In the bottom part of the figure the wire resistance is shown. The horizontal curve is showing that there are no broken warning wires in the loop. If there were no loop in the system (and thereby a flat curve) there would be a fracture in the wire.

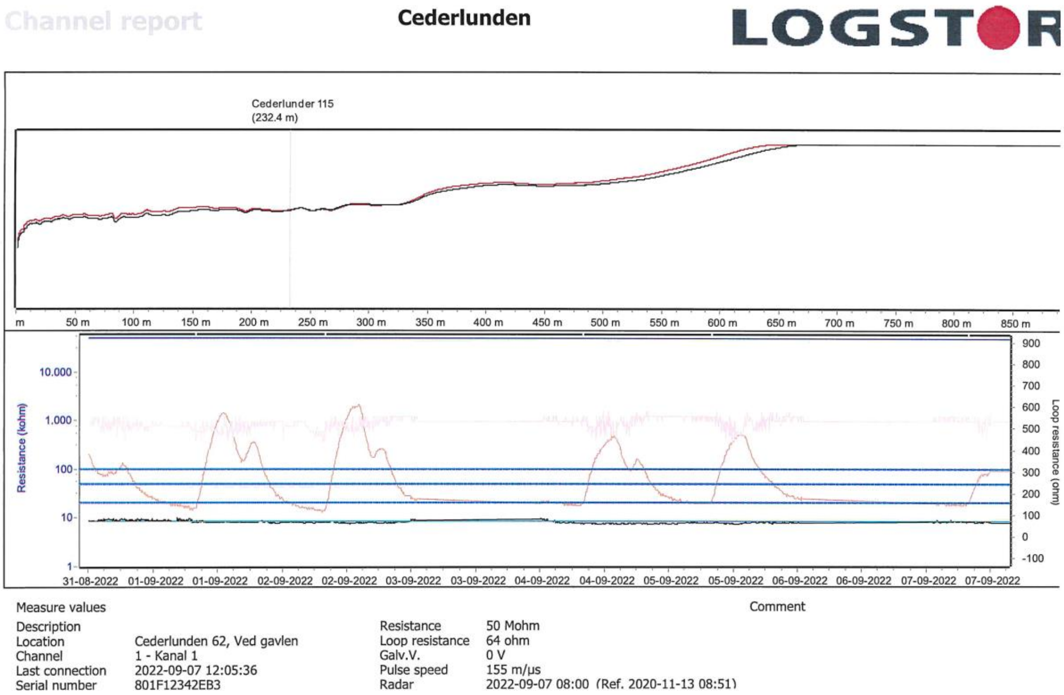


Figure 32. Sample of leak detection system

4.1 Energy performance

The measured supply and return temperatures for the Østerby district can be seen in Figure 33. The LTDH mode of the network has been active since March 2021, when the supply temperature was decreased from 86°C to 71°C, as seen in the figure. However, the supply temperature was increased again in December 2021, to provide sufficient heat for all the connected users, since several users faced some heating issues, especially the users furthest from the heat supplier.

It should be mentioned that in the system is converted from a conventional DH network with distribution temperatures of 85/55°C to an LTDH network of 55/30°C, at consumer, when the booster pump is installed.

According to the results (seen in the figure), the return temperatures are below 40°C with an average return temperature around 38°C. The supply temperatures, on the other hand, fluctuates between 60°C to 80°C to meet user requirements and comfort. The average of the supply temperatures was 70°C (from March 2021 to May 2022). It can be concluded that the network at present is working with distribution temperatures of 70/38°C on average. The reason why the flow temperature was kept high was to compensate for to low flow in the far end of the system as the booster pump for the district was not yet installed. The booster pump will be installed at shopping mall CITY2 and it is planned to supply the Østerby network by end 2022. This will decrease the need for high supply temperatures and enable the operation at the intended temperatures of down to 58°C flow temperature to grid. The details will be described in Chapter 6.

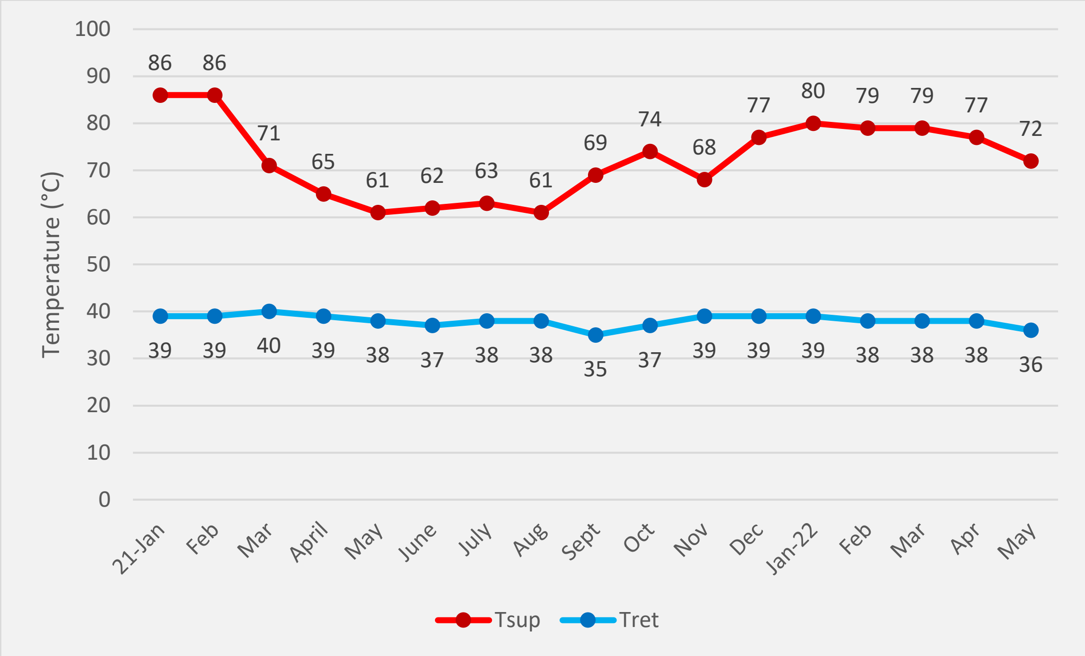


Figure 33. Distribution temperatures of LTDH network in Østerby

The total length of the LTDH network is 3,119 meters, more details are visible in Table 6. More than 93% of the network (2,911 m) is made from PE-RT plastic pipes. Steel pipes were used in the main pipelines. The heat demand of the area is 400 kW.

Table 6. Pipe dimensions of the LTDH network

	Pipe Length (m)							
Material	**Steel (Twin) 208 m**		**PE-RT (Twin) 2911 m**					**Sum**
Size	DN 40	DN 65	25/125	32/125	40/140	50/180	63/200	-
Main	10	170	0	0	0	0	207	387
Cederlunden	10	0	72	197	280	88	0	647
Olivenlunden	18	0	507	316	455	76	0	1372
Palmelunden	0	0	189	129	257	40	0	615
Kindergarten	0	0	0	98	0	0	0	98
Sum	38	170	768	740	992	204	207	**3,119**

The heating profile of Østerby and its LTDH network is shown in Figure 34.

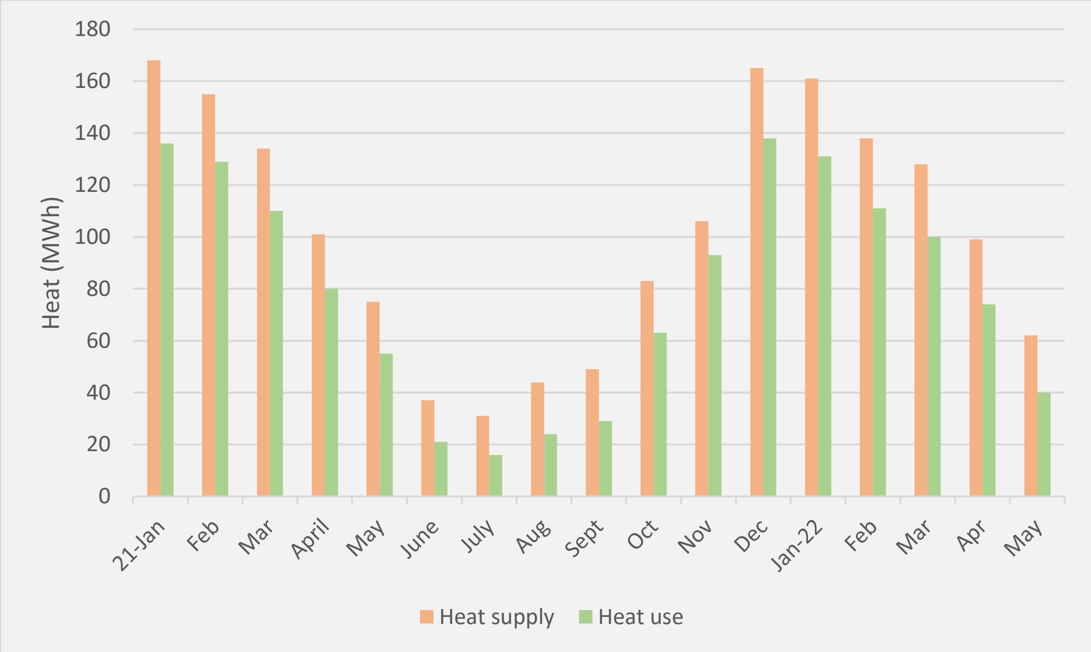


Figure 34. Heating profile of LTDH network in Østerby

The total heat supply of 2021 was 1.15 GWh while the heat use was 0.89 GWh. The results showed 22.6% losses within the network on average, with the lowest losses of 15.8% occurring in January 2021 and the highest losses of 48.4% in July 2021. This is due to the off-set higher operation temperature as previously explained. With the design temperatures in the grid (from 70/38°C-10°C = 44°C delta T mean to 55/30°C-10°C = 32,5°C delta T mean) the heat loss will be reduced from 22.6% to 16.7%. Considering transmission losses in the network, the measured heat losses correspond to 16 kW. This is within an acceptable range of the estimated heat losses of 13.2 kW (WP2, D2.7).

4.2 Economic analyses

Costs for Traditional upgrade of local DH system

Before the COOL DH project was initiated, the residents of Østerby were supplied via an internal district heating network. The old standard DH system and the installations in the buildings were ready to be updated at the start of the COOL DH project. The internal district heating network was connected to Høje Taastrup District Heating via a heat exchanger located at the centre of the residential area in Østerby.

The heat association (Varmelauget) and four housing associations (Andelsboligforeningen Egeskovgaard, Torstorp II and Torstorp III as well as Ejerforeningen Torstorp I) had over the years set aside for a renovation of the internal pipe networks. However, none of the associations had set aside sufficient funds to carry out the renovations. The residents thus could foresee costs to finance the improvement work.

The democratic and contractual conditions internally in the individual associations and among the other members of the heat association made it difficult to reach an agreement to initiate the renovation work in due time.

As the COOL DH project could offer a solution that was also economically more advantageous, each of the associations decided to accept the offer from Høje Taastrup Fjernvarme to switch to low temperature district heating in a 1:1 customer relationship between each homeowner / tenant and Høje Taastrup District heating.

The conversion to the new system was commissioned in 2020/21, after which the heating association could be closed.

If the associations had decided to implement a lifetime extension of the original district heating system, this would have costed the tenants about 12 million DKK incl. VAT (€ 1,610,700). In addition, there would be investments in DH-units in the dwellings, estimated to cost 1.2 million DKK incl. VAT (€ 161,000).

The tenant's total cost of purchasing heat in 2017 was incl. payment for the 35% internal heat loss a total of 1 million DKK (€ 134,200).

The total annual costs incl. financing costs were to be 2.2 million. DKK (€ 295,300), corresponding to DKK 13,800 / dwelling per year (€ 1852).

Costs for COOL DH upgraded system

The residents chose to accept the offer from Høje Taastrup District Heating, and the terms in the COOL DH project. The new low-temperature district heating system and the contractual simplicity made it possible to get the acceptance from the tenants.

The individual consumers now only must pay for their own heat consumption and not for the heat losses in the secondary grid. The supply temperature of the district heating system has been lowered without compromising the comfort in the homes.

The responsibility for ongoing maintenance and long-term renovation of the new LTDH-system will, in the future, be taken care of by a professional organisation with experience and competencies – instead of a local heating association. The transition from a heating association with an outdated heating network and lack of competencies as well as a democratically complex organization has been time consuming but has been necessary to succeed with the COOL DH project.

The residents have also been able to achieve a saving in energy costs compared to the old alternative. Residents have paid a connection fee of 6.2 million DKK (€ 832,200) and have entered a subscription scheme for the user installations in the homes of DKK 450,000 / year (€ 60,400). The new annual costs (in 2018 comparable prices) for the purchase of heat are DKK 900,000 / year (€ 120,800).

The total annual costs, including financing costs, are DKK 1.74 million (€ 233.600), corresponding to DKK 10,900 / dwelling per year (€ 1463 against € 1852 before). **With the LTDH solution via COOL DH, the average annual cost for the residents hereby has been reduced by 22% compared to the reference alternative.**

The overall benefits for the end users were estimated as below:

- The residents have new user installations and a LTDH system in the area.
- In the future, the residents have no responsibility in relation to future renovation of DH system or user installations.
- Net loss will be reduced
- The residents have a minimal risk of water leaks with major damage as a result and thus for sudden unforeseen expenses for repairs. Consequential damages are eliminated.

General expenses to convert DH network to LTDH one is seen in Table 7.

Table 7. Total Expenses to convert to LTDH network (VAT excluded)

Expenses	
Total cost	€ 1,600,000
Unit price	€ 513/m

Expenses in details can be seen in Table 8.

Table 8. Main costs for implementation of the LTDH network (VAT included, 1 EUR = 7.4532 DKK)

	Costs [Thousands DKK]	Costs [Thousands EUR]
Digging work	6,716	901
Pipe installation	1,699	228
Material	3,820	513
Meters	515	69
Other	317	43
Engineering/Design work	458	61
Commissioning	1,352	181
Total	**14,877**	**1,996**

Customers pay bills including different fees according to the tariff shown in Table 9. Subscription fee, energy fee and service fee are fixed but return temperature fee and consumption fee are variable according to using the energy by the customer. The reference temperature for return temperature fee is 43°C. Regarding return temperature fee, if the return temperature from customer side is higher than 43°C, the customer must pay 10 DKK/°C/MWh and on the other hand, if the return temperature is lower than 43°C, the customer will be refunded by 10 DKK/°C/MWh (€ 1.34).

Table 9. Costumer's energy tariff (VAT included) [8]

Subscription Fee	1194.75	DKK/year	€ 160
Energy Fee (fixed)	27.74	DKK/m²/year	€ 3.72
Consumption Fee (variable)	526.58	DKK/MWh	€ 70.7
Return Temperature Fee	±10	DKK/°C /MWh	€ 1.34
Service Fee	500	DKK/year	€ 67.1

Then, the total Customer payment bill for all customers of the network in 2021 in actual price level was:

$$1{,}104{,}775\ \text{DKK} = €\ 148{,}300\ \text{incl. VAT}$$

4.3 Experiences of the demonstrators

Interviews were conducted with the representatives from Kingspan (earlier Logstor), who developed and manufactured the pipes, and Høje Taastrup Fjernvarme (HTF) who put the pipes to use in the new LTDH network.

Experiences from HTF (DH utility)

The implementation of the new LTDH network gave some insights into the practical issues related to the installation of the new pipes:

- Twin pipes turned out to be quite rigid to work with during winter, when the outside temperatures are low and especially when the large casing was used. On the other hand, during the summer, shrink-fitting presented some challenges as the material in the connection became softer.
- During the connection of the twin pipes, two people were required to move the two endpoints and keep them together for the connection, especially in the case of larger diameters. In this way, a larger workforce was required with a consequent increase in the installation costs. In the case of single pipes, the installation process is easier.
- Since the process of development of the new pipes takes time to design, manufacture and make tests on the pipes, the project faced some difficulties of time shortages. This led to some delays in the laying of the pipes, and in some cases the plastic pipes had to be changed to conventional steel pipes to get the system up and running during the project time. Fortunately, even though it was necessary to implement steel pipes in some cases, it was still possible to use the newly developed insulation foam that ensures lower heat losses from the network. Overall, further development of connection methods is still needed, for example electro-welding sockets such as those used in water supply systems. However, this method must be tested and approved for district heating temperatures.

Experiences from Logstor / Kingspan (manufacturer of the pre-insulated PE-RT pipes)

- There are some advantages to using the new PE-RT pipes. They are flexible and come on coils, which means faster installation. Another advantage is the independence of steel welder since there is no need for this when laying the PE-RT pipes. It is well known in the piping-business that it can be difficult to find skilled steel welders.
- Some disadvantages with the PE-RT pipes: There is a size and casing limit for these pipes, especially for twin pipes. This leads to limitations in the degree of insulation. The pipes can be difficult to handle in cold weather below 10°C.
- The PE-RT pipes developed within this project are good products, but they are not the only product that can be used in a LTDH network. It is important to consider the best system for each specific project and to look at the possibility of using both plastic and steel pipes. Avoid generalization similar to other projects! Pipe sizes, temperatures, pressures etc. denote which kind of pipes are suitable.
- The mission in COOL DH was to develop media pipes with PE-RT and a leak detection system and coupling fusion welding, although the latter was not succeeded within the project because of time shortage. This would have simplified the making of the joints.

- There is an aluminum barrier in the pipes to secure water diffusion and oxygen diffusion in the pipes used in the COOL DH project, but now for future pipes it is changed this to polymer material instead.
- Logstor / Kingspan has realized some work safety issues when manufacturing and rolling the larger dimensions of the PE-RT pipes because of the stiffness of the larger pipes.
- The cost of the new PE-RT pipes is like normal PEX, but with the barrier it becomes somewhat more expensive. In comparison to steel pipes the casing limit leads to lower insulation and higher heat losses. Maybe in smaller dimensions, the PE-RT is somewhat cheaper than steel pipes. Cost savings are foremost achieved in the installation of the pipes.
- As a manufacturer of district heating pipes, Logstor / Kingspan experience an increased interest in low temperature district heating systems. For the specific product of PE-RT pipes, we have experienced an interest from Swedish and European customers. In Denmark, it seems that there is a certain skepticism towards plastic pipes, so the interest there has not been that great so far. Whether there will be an interest in the leak detections system for the plastic pipes that we have developed or not depends on the opinions of the energy companies in the market, because plastic pipes don’t have corrosion like steel pipes do.
- The most important factor for replicability and interest of the new product is getting it approved for EU standardization. We didn’t get the pipes through the EU standard for conventional district heating pipes, which we find strange since all the demands were met. Now, we hope to get the pipes approved as a LTDH product instead. We think this is crucial for the district heating companies’ interest to by this product. Then, the electrofusion coupling is also an important factor to be solved, something that we see is absolutely possible. When this is in place the work with connection pipe joints will become easier.

4.4 Conclusions

The new LTDH network in Østerby is an example on a conversion of a district heating network, where HIUs are installed to provide heating in the buildings. Such a network utilizes local heat sources as low-grade surplus heat which results in a reduction of emissions and savings in primary energy.

The results showed that a plastic pipe system can be used in LTDH networks. The functionality is fine, and no major concerns were reported during the time the network has been in operation. This shows the feasibility of using these new plastic pipes in future generations of DH systems. Obviously, the plastic pipes have advantages and disadvantages that should be considered when comparing to ordinary steel pipes. The most important advantages are flexibility, easier excavation, and no corrosion.

The major disadvantage of PE-RT pipes is that the laying of the lines becomes significantly more dependent on the weather. There were some issues regarding burying the pipes during the cold seasons. If installed in wintertime, the pipes needed to be pre-heated. The pressure limit is 13 bars(o) for the installed plastic pipes which is higher than other plastic pipes, but not as high as the pressure limit of steel pipes that can withstand 16 bars. This weakness is the main reason why plastic pipes are not used in ordinary DH grids nowadays along with diffusion into the media. Although the high pressure and temperature are not a main concern in a LTDH network, it should be considered. Working in higher pressures and temperatures should be avoided since it can reduce the lifespan of the pipes.

The network has a higher heat loss than planned because last winter the network was working in higher temperatures to supply heat for the customers furthest away. Therefore, probable customer installation issues should be considered to fix, and subsequently to reduce, the distribution temperature of the network together with a booster pump that ensures sufficient differential pressure at the consumers most far away.

The higher differential pressure will enable to increase the energy needed at lower supply temperature. The heat losses within the network will hereby be decreased when the distribution temperatures are reduced as planned.

In addition to the faster making of trenches, the flexible layout also implies that the line length could be quickly adapted to newly discovered obstacles. The benefits of the PE-RT pipes decrease with an increasing number of joints, which results in more trenches.

Finally, it should be mentioned that the PE-RT pipes are new products developed during the project which led to long fabrication and test process. Economies of scale and improvements of components such as electro-welding sockets may further cut the costs of materials and installation. The COOL DH project has contributed to training of the staff of the energy utilities and the subcontractors laying the pipes, lessons have been learned and future use of the pipes will be easier. Therefore, if these pipes are commercialized and become widely used in the district heating industry, then, the fabrication time and costs can be further decreased.

5 Main Line with Heat Recovery

The installation of heat recovery pipes to recover heating to the LTDH network in Høje Taastrup will be presented in this part. The aim of theses pipes is to carry different media and/or media at different temperature levels, minimising the pipe losses, possibly to zero. To achieve this, the multimedia pipes include two collector pipes that collect the heat loss from the media pipes and absorb extra heat from the surrounding ground. Afterwards, the heat is returned to the media pipes using a small heat pump. The heat pump and the monitoring equipment of the heat recovery system were installed in the shopping mall CITY2 in Høje Taastrup.

The collector pipes: 2 pcs PEM 40 x 2.4 mm, as shown in Figure 35, were installed on the main district heating pipe that supplies the district, for a total length of approximately 350 m. The entire length of the collector pipe was around 700 m.

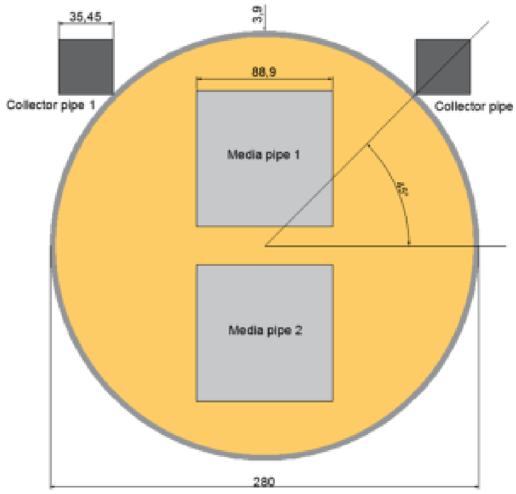


Figure 35. A sketch of heat recovery pipes with 2 collectors on top right and left

An illustration of the system with the multi-media heat recovery pipes attached can be seen in Figure 36.

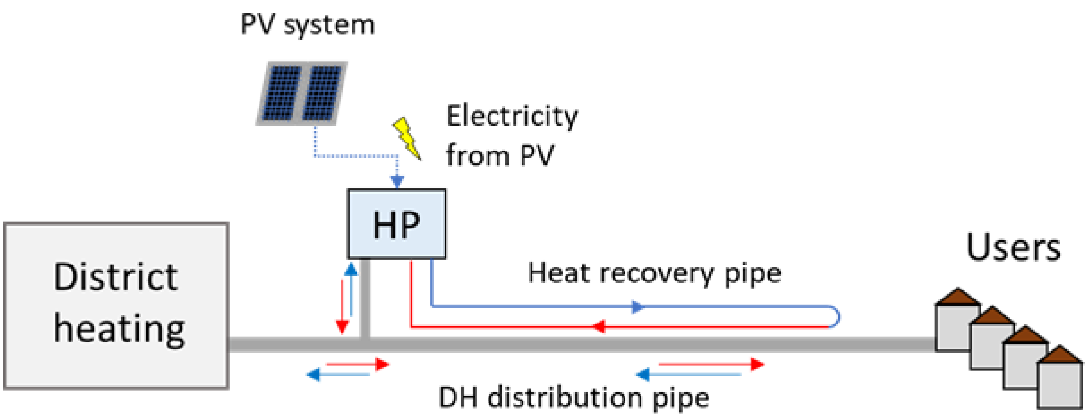


Figure 36. Principal diagram of the heat recovery system in the demo site in Høje Taastrup

A hanger (in the form of a plastic belt) has been attached to the main transmission pipe using plastic strips. The collector pipes have then been attached to the hanger using plastic strips as seen in Figure 37.

Figure 37. District heating pipe equipped with the collector pipe

The collector pipes were installed on the main transmission pipe between CITY2 and the Østerby area. The main pipe supplies LTDH from the shopping mall CITY2 in the north to the area in the south, as seen in Figure 38.

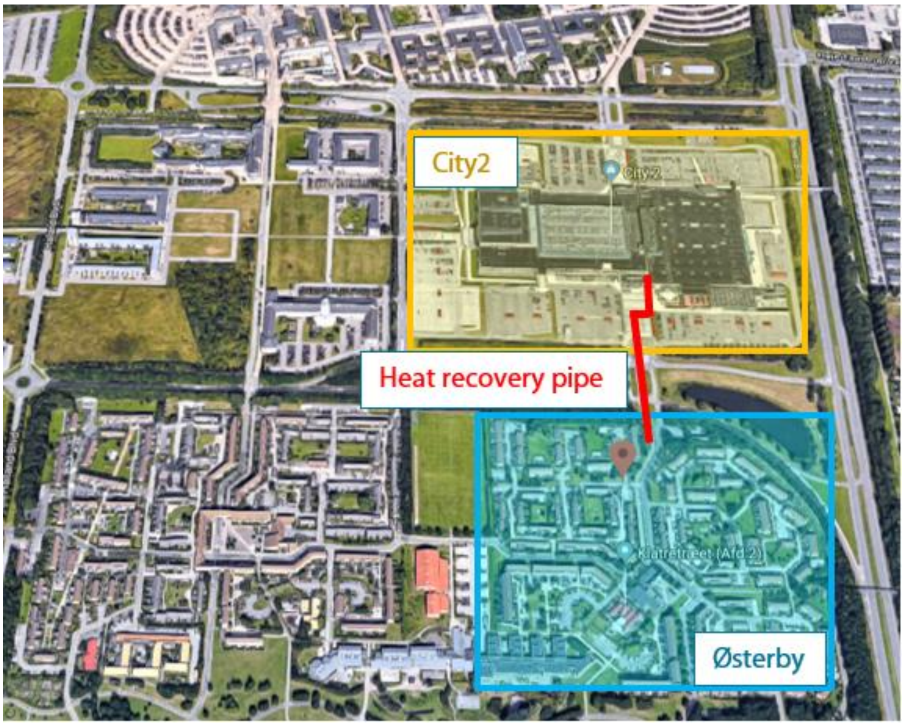


Figure 38. Overview of the Østerby district and the shopping mall CITY2

Data for the heat pump in the recovery system can be seen in Table 10.

Table 10. Data of heat recovery heat pump at CITY2

Model	Cooling Capacity	Heating Capacity	Power Consumption	COP
WW HT (SH A0.5-4AXH-1)	5.11 kW	6.16 kW	1.05 kW	5.9

5.1 Energy performance

Since the heat recovery demo and its connected HP were in short operation in July, August, and September 2022 within the project, only a limited evaluation can be made of the performance of this installation. The limited measured data are shown in Table 11. A potential for all 2022 has been calculated and reported in the table. The COP_{heat} for the heat pump was between 4.5 and 4.6. COP_{PE} means COP_{heat} in Primary Energy mode.

Table 11. Operational KPIs of HP

KPI	Jul 2022	Aug 2022	Sep 2022	Potential 2022
Recovered heat (MWh)	1.18	1.90	2.96	72
Electricity use (MWh)	0.34	0.53	0.95	22
Delivered heat (MWh)	1.52	2.43	3.91	94
COP_{heat}	4.5	4.6	4.1	4.3
COP_{PE}	2.1	2.2	2.0	2.0

5.2 Environmental impacts

As described in Section 2.2.1 and using values from Table 2, reduction in CO_2 emissions in July and August 2022 due to the recovery of heat from the heat losses and the ground can be calculated as below:

$$[(0.34\text{ MWh}\cdot 145.7\text{ kg/MWh}) + (0.53\text{ MWh}\cdot 128.2\text{ kg/MWh})] + (0.95\text{ MWh}\cdot 126.9\text{ kg/MWh}) - (7.86\text{ MWh}\cdot 40.9\text{ kg/MWh})$$

$$= \mathbf{-83\ kg}$$

To make the comparison more suitable for central European circumstances a comparison has also been made for the same system if supplied by natural gas:

$$(7.86\text{ MWh}\cdot 202\text{ kg/MWh}) - (7.86\text{ MWh}\cdot 40.9\text{ kg/MWh}) = \mathbf{+1266\ kg}$$

This shows that if we used natural gas as a fossil fuel, more than 1.2 tons CO_2 emissions could be saved by recovering the heat from heat losses and the ambient ground. (The carbon dioxide coefficient of natural gas in Denmark is presumed to be 202 kg/MWh).

Savings in primary energy (PES) is calculated as:

$$\text{PES} = \text{Q}_{\text{HP}} - (2.1 \cdot \text{P}_{\text{el}}) = 7.86\ \text{MWh} - (2.1 \cdot 1.82\ \text{MWh}) = \mathbf{4.0\ MWh}\ \text{over 3 months}$$

The environmental impacts of the heat recovery demonstration are shown in Table 12.

Table 12. Emissions and primary energy savings by using heat recovery of main line

KPI	Heat Recovery	NG	Potential 2022
CO_2 emissions (kg)	-83	+1266	-1000
PES (MWh)	4.0	-	48

5.3 Cost of the installation

The costs to implement the demo can be seen in Table 13.

Table 13. Total Expenses to implement heat recovery system

Expenses	
Length	700 m
Unit price	€ 9.6/m
Total cost	€ 6,711

It should be mentioned that there is not enough data to evaluate annual savings and payback time precisely by using heat recovery of the main distribution line since the HP was not in operation for a full year period and it worked in a short time. However, if September 2022 the monitored delivered heat was 3.91 MWh with an electricity use of 0.95 MWh i.e., an COP of 4.12.

Value of the extra sold heat excl VAT is: 56.6 €/MWh

Cost of electricity excl. VAT and energy tax is: 160 €/MWh (flat rate for the utility)

This could indicate a yearly saving of 826 € if September can be considered as an average month for the year.

Resulting in a simple payback period of € 6,711 / € 826 = **8.1 years**

In late 2022 the electricity cost has increased due to the energy crises as result of the conflict in Ukraine, and this of course has influence on the pay back, but even with the double electricity cost the investment could be justified.

5.4 Conclusions

This demonstration shows the possibility of using a conventional heat pump to recover heat from distribution losses in the district heating network and the ambient ground. The installation can be seen as a ground heat installation. The advantage of this solution is to be able to recover waste heat that normally would not be taken care of. Also, compared to the installation of a conventional ground heat installation, there are the benefits of the co-location of the district heating pipe and the collector hoses- it is less expensive to install a ground heating system when the excavation has already been made for the district heating pipes. On the negative side, the installation requires a more advanced system with the heat pump and installation works.

6 CITY2: PV-HP for Heat Production

The transition to low-temperature supply in district heating grids as well as the transition towards renewable heat sources allow the introduction of new technical solutions in the district heating production. The new heat pump system in the shopping mall CITY2 located in Høje-Taastrup Municipality is one of these solutions.

In the initial phase, and as part of the COOL DH project, the DH system supplies the new LTDH network in the Østerby area demo case by recovering the waste heat from the cooling machines at CITY2. The machines will operate partly on power from a more than 16,300 m² PV plant with an installed capacity of 2.07 MW, the largest roof mounted PV panels plant in the Nordic countries so far. The new heat pump / district cooling system has a capacity of 1.34 MW heat with expected 3,000 yearly full load hours, providing 4.03 GWh/year LTDH and 2.97 GWh/year district cooling. The capacity of the heat pump is 1,341 kW for the heating and 990 kW for the cooling system. In this case, the total $COP_{heat+cool}$ of the heat pump is 5.3 at full load.

Figure 39 presents the principal diagram of the new heat pump systems installed in CITY2. The connection of the heat pump to the cooling system, the traditional DH network, and the heat recovery system can be seen in this Figure. The new heat pump uses the return flow from the cooling system as a heat source to deliver heat to the Østerby area and partly used in CITY2. On the cold side, the heat pump provides part of the cooling load to the shopping mall. Furthermore, the extra cooling load is used to supply the district cooling network. Both the cooling system and the new heat pump for the LTDH heating are connected to the solar panels system, ensuring that the heating production is based on renewable sources. As can be seen in Figure 38, the Østerby area can be supplied either by the new heat pump or by the traditional DH network, which can work as back-up solution. Reaching the correct temperature levels in the LTDH network is ensured by the mixing loop located at the beginning of the network.

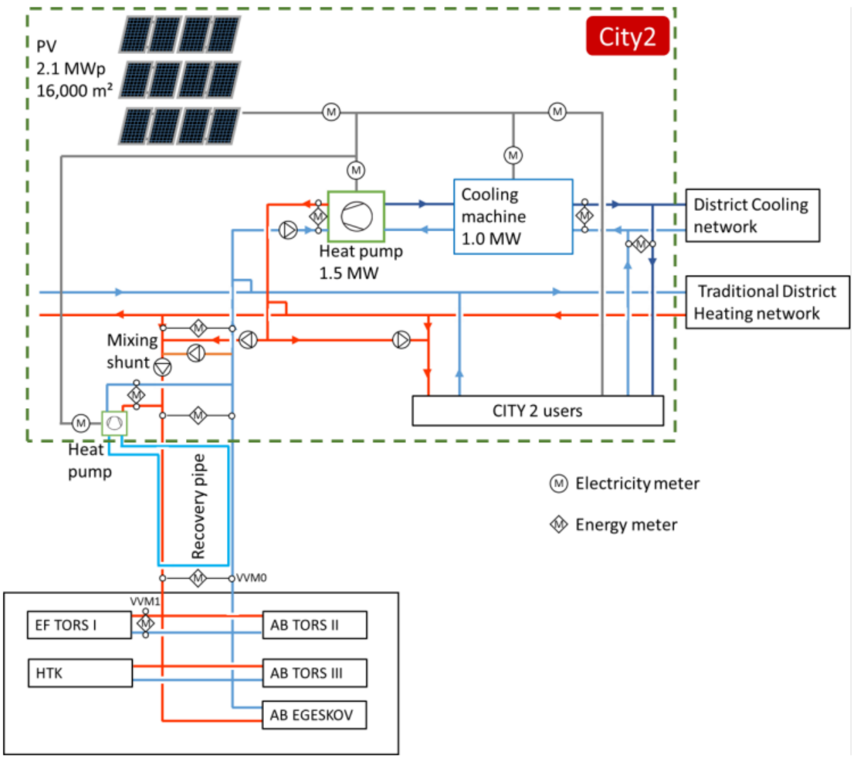


Figure 39. Simplified principal diagram of the new heat pump installed at CITY2 to provide LTDH network

As was mentioned before, the cooling system of the shopping mall CITY2 will also be connected to the local district cooling network, which will supply office buildings, hotels close by and Høje-Taastrup Train Station. The heat pump installed to supply the district heating network in Østerby is therefore also going to cover part of the demand of the district cooling network. The implementation of such a system with connection to both the district heating and the district cooling network is one of the first in Denmark. In fact, the system is one of the first examples of "prosumers", where a decentralized heat source is used to supply the DH network, while the building is still connected as DH consumer.

The unique solution demonstrated at CITY2 enables existing district cooling and district heating to serve as back-up and peak load e.g., when CITY2 demands more than 1 MW of cooling (max cooling demand in CITY2 is presently 1.5 MW, expected to grow to 2.8 MW). In periods where cooling is not needed in CITY2, the new HP system can still operate the heat pump for the LTDH supply since heat can be obtained from the district cooling network where there is always a demand for cooling because the district cooling network connects several consumers and more production units. The same situation prevails when it comes to heating since there is always demand for LTDH in Østerby (max about 400 kW) and the remaining production to serve the surrounding Høje-Taastrup C district. This means that the new combined heat pump for LTDH and district cooling technically can operate 24/7, all year-round.

However, Høje-Taastrup Fjernvarme (UTIL-DK) as energy provider will select the production unit with the lowest marginal operation cost since they have more production units in the system. The actual plant will therefore be operated primarily when the sun is shining providing surplus PV power at low cost. Furthermore, there are some contractual obligations in the contract with CITY2 with an obligation on minimum yearly power take-off and maximum capacity that must be respected in the actual operation strategy for the plant. This means that the plant is expected to operate minimum 3,000 full load hours per year. Break-even is expected achieved at around 1160 full load hours per year.

It should be mentioned that this part of the project has not been in constant operation because of some delays due to COVID-19, and a lack of cooling demand during the last cold season. The new HP system operated only in June 2022. Therefore, the data for monitoring is very limited and not enough for full evaluating this part of the project.

6.1 Energy performance

Table 14 below gives an overview of the supply and return temperatures at CITY2 and the Østerby district as well as the capacity of the system installed.

Table 14. Supply and return temperatures at CITY2: Planned vs. Actual values (Actual values are in parentheses)

	Supply Temp. (°C)	Return Temp. (°C)	Capacity [kW]
Traditional DH	85 (78)	45 (39)	-
CITY2 heating system	63-80 (71)	50 (38)	2,000
CITY2 heat pump 2	60-70 (65)	45 (53)	1,341
CITY2 heat pump 1 (Cooling machine)	6-12 (6)	10-15 (13.7)	990
Østerby area	55 (70)	30 (38)	400

Energy production and performance of the installed HP only in June 2022 as well as initial estimation are shown in Table 15. As abovementioned, the HP was in operation only in June 2022.

Table 15. Energy production and HP performance in CITY

KPI	Test in June 2022	Initial Estimation for a full year
Heat production (MWh)	10.0	4,023
Cooling (MWh)	6.8	2,970
Electricity Cons. (MWh)	3.2	1,322
COP for Heating	3.12	3.04
COP for Cooling	2.13	2.25
Total COP	5.25	5.29
COP_{PE}	2.5	2.5

6.2 Environmental impacts

6.2.1 CO_2

As described in Section 2.2.1 and considering Tables 2 and 15, there is a reduction in CO_2 emissions in June 2022 by using the heat pump:

$$(3.2\ \mathrm{MWh} \cdot 177.9\ \mathrm{kg/MWh}) - (10.0\ \mathrm{MWh} \cdot 40.9\ \mathrm{kg/MWh}) - (6.8\ \mathrm{MWh} \cdot 81.0\ \mathrm{kg/MWh})$$

$$= \mathbf{-390\ kg}$$

In next step a comparison is done with the Swedish side of COOL DH to see what would happen if this facility was working in the Brunnshög area in Sweden which includes waste heat from the research facility Max IV. Regarding local references, there would be a 2 kg increase in CO_2 emissions:

$$(3.2\ \mathrm{MWh} \cdot 39.1\ \mathrm{kg/MWh}) - (10.0\ \mathrm{MWh} \cdot 11.4\ \mathrm{kg/MWh}) - (6.8\ \mathrm{MWh} \cdot 1.3\ \mathrm{kg/MWh})$$

$$= \mathbf{+2\ kg}$$

This simple comparison shows the importance of local and regional conditions of the energy mix to evaluate a project. Although the Swedish and the Danish demonstration sites are very close to each other (around 80 km) and they have similar climatic conditions, totally different results are obtained. Finally, it should be considered that two environmentally friendly systems were compared to each other and if for example natural gas was used to produce the same amount of heat, the CO_2 emissions would be near to 1.6 tons.

6.2.2 PES

As described in Section 2.2.2 and considering Table 15, savings in primary energy in June 2022 can be calculated. In addition, allocation of electricity should be included since electricity is consumed for both heating and cooling purposes. One approach is to consider the heating system as a bonus to the original system and therefore no electricity allocated for it, i.e., PES is equal to the heat production by the heat pump:

$$\mathrm{PES} = \mathrm{Q_{HP}} = 10.0\ \mathrm{MWh}$$

However, another approach requests to allocate electricity according to the energy production of each system:

$$\mathrm{PES} = \mathrm{Q_{HP}} - (2.1 \cdot \mathrm{P_{el}}) = 10.0\ \mathrm{MWh} - (2.1 \cdot 3.2\ \mathrm{MWh}) = \mathbf{3.3\ MWh}\ \text{only in 1 month}$$

6.3 Costs for the installation

Costs details in CITY2 is shown in Table 16.

Table 16. Total Expenses to implement the new HP system (excl. VAT)

Expenses	
Total cost	€ 1,140,000
Unit price	877 €/kW

The calculation of the payback period is not possible to carry out because of the short-time operation of the system but it was estimated to be 8-10 years in the business plan.

6.4 Conclusions

Developing LTDH networks enables us to use surplus heat from local and low-grade heat sources such as the cooling machines at CITY2 shopping mall as a big prosumer. Coupling heating and cooling and cogeneration is another promising tool to increase thermal efficiency of engineering systems resulting in savings in primary energy, mitigation of CO_2 emissions, and gaining income from selling the energy. This kind of prosumer that exchanges heating and cooling with the main DH network will probably play a very important role in the future of DH systems. In this project, the recovered heat from the cooling systems at CITY2 along with traditional DH network can provide LTDH demand in the Østerby area. In addition, this coupling and cogeneration system is complicated and should be designed properly. However, COVID-19 effects and some technical issues caused a delay in starting the HP coupling operation and therefore this demonstration is not evaluated properly.

This system has advantages such as co-generation of cooling and heating, and the ability to use cheap electricity based on renewable PV cells. Therefore, if the electricity used in the system is based on PV-cells or cheap electricity when available, it can be a good business case. However, the system integration and optimal interplay with existing installations can be a challenge.

For the owner CITY2 it has become more beneficial to sell electricity to the market-price (feed-in tariff) than to the DH utility that can use the electricity for co-producing LTDH and DC. However, the DH utility still has a favorable flat rate and tax-free power purchase agreement that still justifies the operation of the co-production of heating and cooling with the heat pump at CITY2.

7 Connection of a Prosumer

Since the end of 2020, Høje Taastrup DH utility has used waste heat from the server room of Nordea Bank in Høje Taastrup to deliver heat to the DH network and provided server room cooling to Nordea with a nearly constant demand year-round. As part of COOL DH, a large prosumer heat pump system was installed, which can deliver 1.92 MW heating incl. pumps and 1.5 MW cooling. Figure 40 shows the principal diagram of the heat pump system installed in the server room. The datacentre campus has five different data subcentres, that mainly use water from ATES wells for cooling the installations. The life span is expected to be 20 years and the system can supply around 700 households with their yearly heat demand.

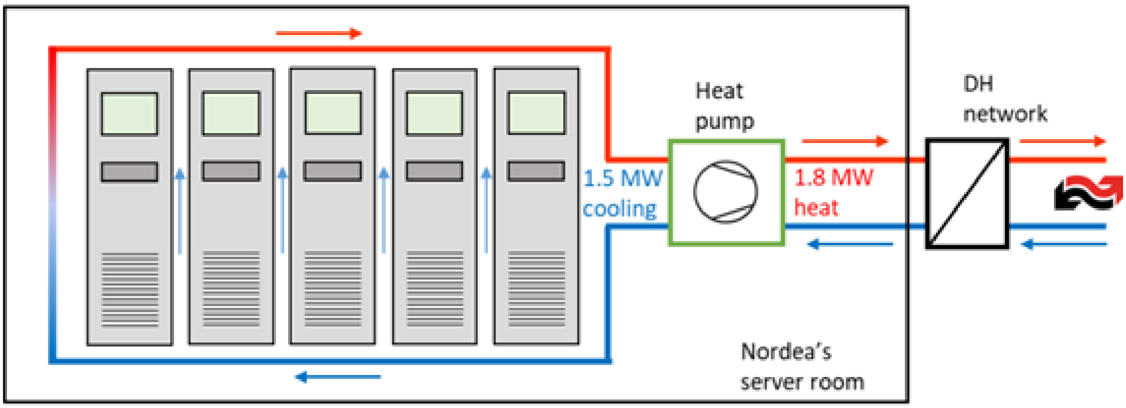


Figure 40. principle diagram of the HP system installed at Nordea's data center

7.1 Energy performance

The energy performance of Nordea as a prosumer is evaluated based on; delivered heating and cooling, supply and return temperatures for heating and cooling, and electricity consumption.

The monitored supply and return temperatures for delivered heating and cooling can be found in Figures 41 and 42, respectively. Notice the temperature difference on the y-axis between the two figures. As can be seen, the HP system is operating at relatively constant supply and return temperatures. The delivered heating and cooling temperatures, and the corresponding return temperatures, are within the expected target values, averaging 73/43°C for heating and 9/14°C for cooling supply. The temperatures are very stable, indicating a continues heating and cooling production of the heat pump.

It should be mentioned that the system was turned off in the summer of both 2021 and 2022 due to a lack of heating demand in the section of the connected district heating grid. Furthermore, the system had an overhaul which resulted in a low operation in February 2021. Therefore, these months has been in excluded in the following graphs.

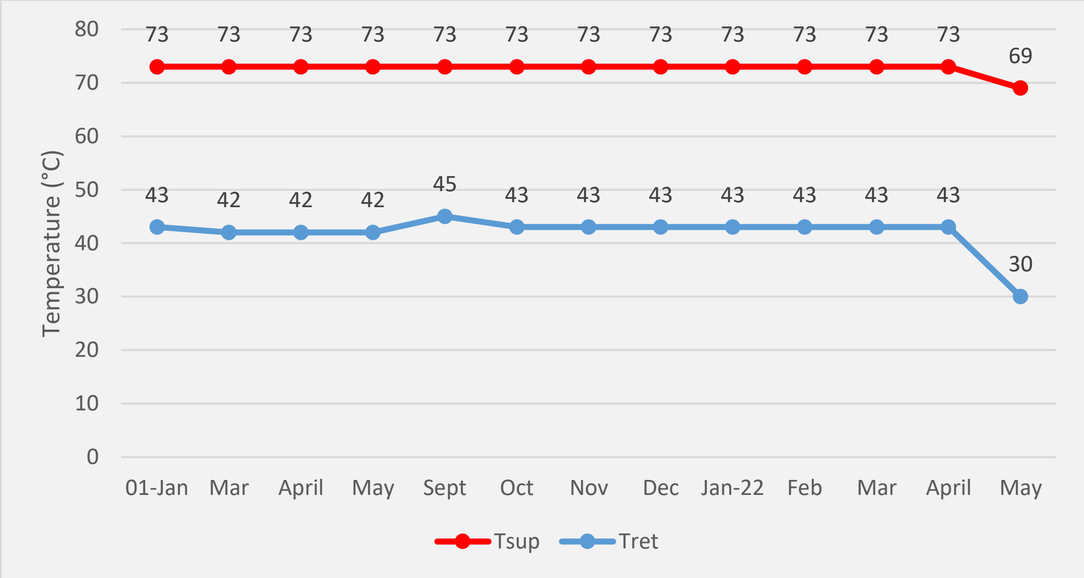


Figure 41. Supply and return temperatures for heating part of HP system

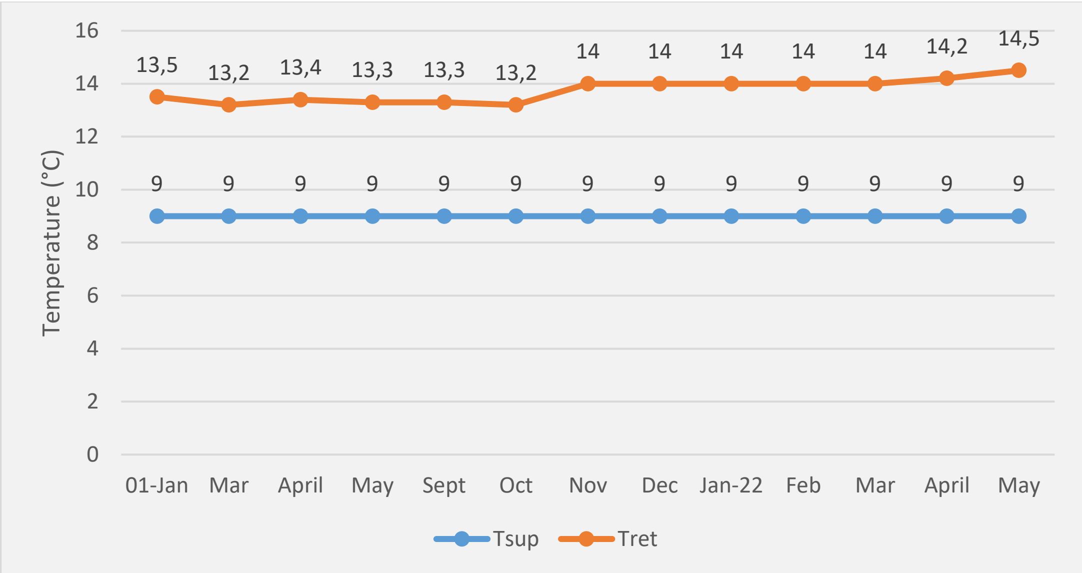


Figure 42. Supply and return temperatures for cooling part of HP system

The total monthly heating and cooling production delivered by the heat pump can be seen in Figure 43. The results are based on measurements at the heat pump. Non- and very low-operation months are excluded in this figure. It can be observed, that the highest both heating and cooling productions were in March 2021 with 1,295 MWh heating and 921 MWh cooling, respectively. The lowest productions occurred in May 2022 with 511 MWh and 363 MWh for heating and cooling respectively.

The highest electricity consumption of 626 MWh occurred in April 2021 and the lowest electricity consumption of 141 MWh in May 2022. However, the system was only in operation in 20 days in May 2022.

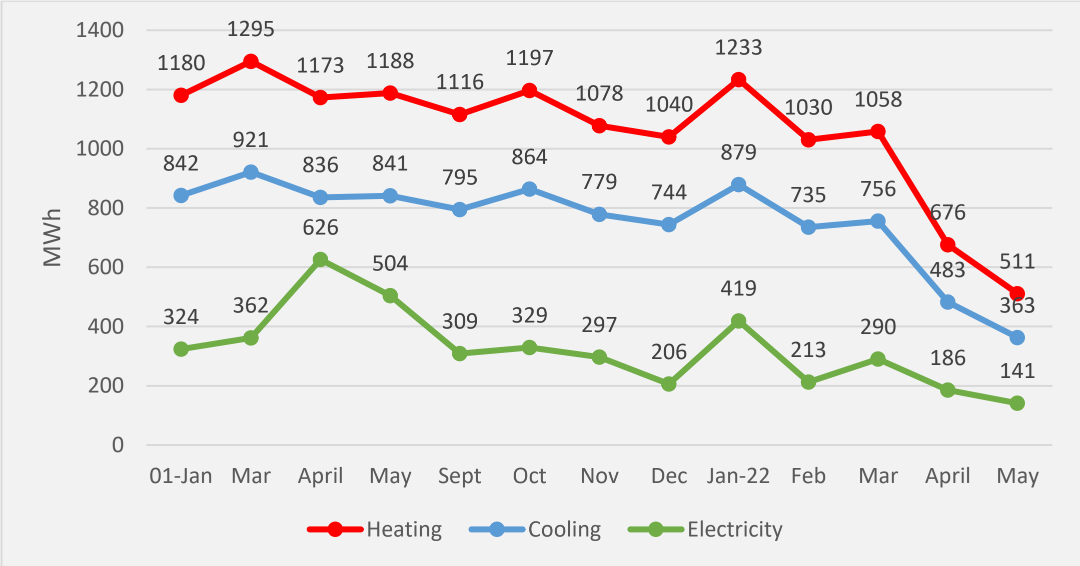


Figure 43. Heating and cooling production of the heat pump

Not including the measurements that were considered inconclusive (February 2021, and the summer of both 2021 and 2022), the following averages were calculated in Table 17.

Table 17. Average heating and cooling production, and electricity consumption excl. inconclusive measurements

	Heating production	**Cooling production**	**Electricity consumption**
Average monthly results excl. inconclusive measurements	1,060 MWh	757 MWh	324 MWh

The calculated resulting COPs were based on the delivered heating and cooling, and the measured electricity consumption of the heat pump, as described in the methodology section. The COP results can be found in Figure 44. As can be seen, the calculated COPs fluctuate significantly over the course of the measured year.

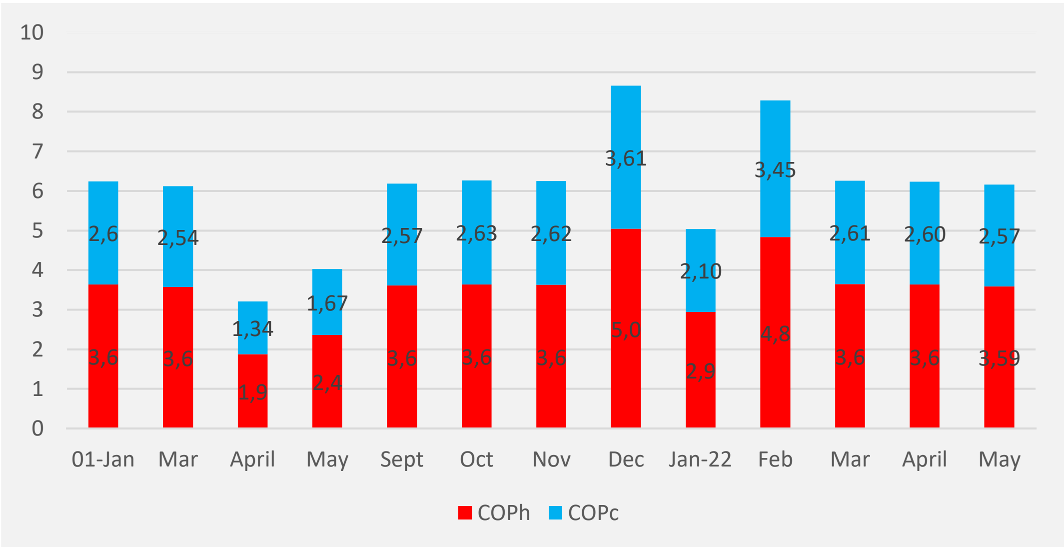


Figure 44. Calculated COP heating and cooling of the heat pump

Like the previous results, not including measurements that are considered inconclusive, the average values were calculated during the monitored period. Excluding the irregular measurements both the COP of heating and cooling of the heat pump provides relatively stable results within a reasonable range during the monitored period. The energy flow in Nordea HP is shown in Figure 45.

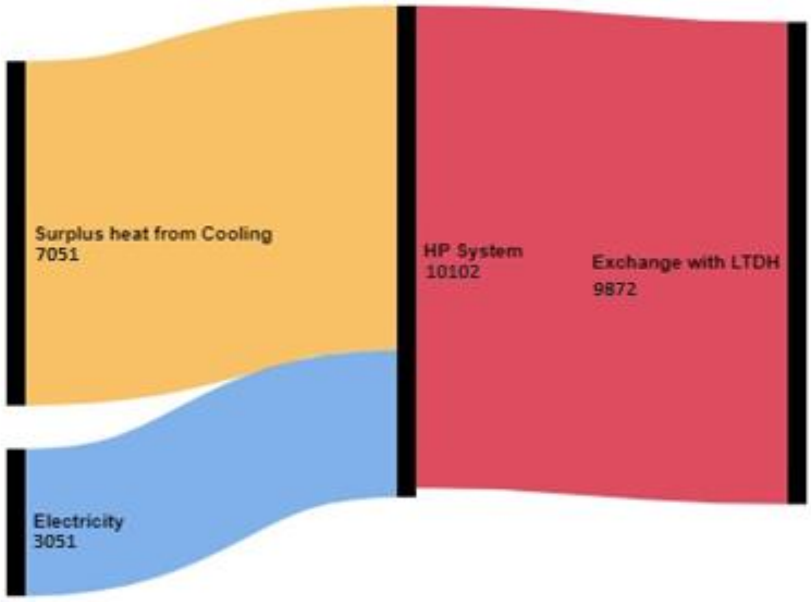


Figure 45. Energy flow of Nordea HP measured data [MWh]. Measurement period: January 2021 - December 2021

Finally, specifications of technical data of the heat pump system installed in Nordea can be seen in Table 18. According to this table, and not considering non-representative measurements, the average results by the heat pump in Nordea is very good and the use of the prosumer can be considered a success.

Table 18. Technical data of the heat pump system installed at Nordea's server room

	Initial Estimation	2021 (8 months)	2022 (5 months)	Yearly Potential
Heat production (MWh)	12,500 per year	9,267	4,508	11,162
Monthly average heat production (MWh)	1042	**1,158**	564	930
Cooling production (MWh)	11,700 per year	6,622	3,216	7,971
Monthly average cooling production (MWh)	975	828	643	664
Power consumption (MWh)	3,424 per year	2,957	1,249	3,408
Monthly average power consumption (MWh)	285	370	156	284
Operational hours	6,500 per year	5,405	2,617	6,500
Operational hours per month	542	676	523	542
Heating capacity (MW)	1.92	1.71	1.72	1.72
Cooling capacity (MW)	1.5	1.23	1.23	1.23
COP for heating	3.65	3.13	**3.61**	3.28
COP for cooling	3.41	2.24	2.57	2.34
Total COP	7.06	5.37	6.18	5.62
COP_{PE}	3.36	2.56	2.94	2.68

7.2 Environmental impacts

7.2.1 CO2

As described in Section 2.2.1 and using values from Tables 2 and 18, there is a significant reduction in CO_2 emissions in 2021 by using heat recovery heat pump in 8 months:

$$(2{,}957\ \text{MWh} \cdot 181.5\ \text{kg/MWh}) - (9{,}267\ \text{MWh} \cdot 40.9\ \text{kg/MWh}) - (6{,}622\ \text{MWh} \cdot 81.0\ \text{kg/MWh})$$
$$= \mathbf{-379\ tons}$$

In the next step a comparison is done with the Swedish side of COOL DH to see what would happen if this facility was working in Sweden. Regarding local reference, there would be 9 tons increase in CO_2 emissions**:**

$$(2{,}957\ \text{MWh} \cdot 41.9\ \text{kg/MWh}) - (9{,}267\ \text{MWh} \cdot 10.0\text{kg/MWh}) - (6{,}622\ \text{MWh} \cdot 2.75\ \text{kg/MWh})$$
$$= \mathbf{+13\ tons}$$

If natural gas was used to produce the same amount of heat, CO_2 emissions would be close to 1,367 tons.

7.2.2 PES

As described in Section 2.2.2 and considering Table 18, savings in primary energy in 2021 can be calculated. In addition, an allocation for electricity should be made since the electricity is consumed for both heating and cooling purposes. One approach is to consider the heating system as a bonus to the original system and therefore no electricity allocated for it, i.e., PES is equal to heat production by the heat pump:

$$\text{PES} = \text{Q}_{\text{HP}} = 9.3\ \text{GWh}$$

However, another approach requests to allocate electricity according to energy production of each system:

$$\text{PES} = \text{Q}_{\text{HP}} - (2.1 \cdot \text{P}_{\text{el}}) = 9{,}267\ \text{MWh} - (2.1 \cdot 2{,}957\ \text{MWh}) = \mathbf{3.1\ GWh}\ \text{over 8 months}$$

Both approaches show significant savings in primary energy usage. It was estimated to have savings of 7.2 GWh in primary energy per year.

7.3 Economic analyses

Costs of this demonstration is shown Table 19.

Table 19. Total Expenses to implement the new HP system

Expenses	
Total cost	€ 1,610,000
Unit price	850 €/kW

The pay-back period can be calculated below (monitored in 5405 operation hours in an 8-month period):

- Heat value:

$$9{,}267\ \text{MWh} \cdot 33\ €/\text{MWh} = €\ 305{,}811$$

- Cooling value:

$$6{,}622\ \text{MWh} \cdot 35\ €/\text{MWh} = €\ 231{,}770$$

- Additional electricity cost:

$$1{,}723\ \text{MWh (Allocated to heating)} \cdot 240\ €/\text{MWh} = €\ 413{,}520$$

- Annual saving:

$$€\ 305{,}811 + 231{,}770 - €\ 413{,}520 = €\ 124{,}051$$

$$\text{Payback time} = \frac{€\ 1{,}610{,}000}{€\ 124{,}051} = 13\ \text{years}$$

(The estimated future annual full load operation hours will be 6500 h reducing pay-back to 10.8 years in 2021 price level of energy costs)

7.4 Conclusions

The demonstrated system has the advantage of being a co-production system of both cooling and heating and at the same time a system that saves money for the prosumer. It is seen to be a good business case for the DH utility due to the high number of full load hours.

8 Final Conclusions

The transition to LTDH networks requires new technologies and technical solutions to meet the heat requirements of the consumers and to guarantee Legionella safety in the domestic hot water systems. Heat sources to provide heat, pipelines to transfer the heat, and heat consumers and their installations are three key elements in DH systems, in which this project has provided new knowledge and novel designs to all categories, in order to improve district heating efficiency and development and making use of more waste heat.

Several demos and installations have been designed, built in a real scale, and put in operation in the project in the Østerby area, supplying 159 customers equipped with individual heat units. The area is partly being supplied by waste heat from the cooling systems in the CITY2 shopping mall, with temperature raised with the help of a heat pump. An old secondary network has been retrofitted

In the project new PE-RT plastic pipes have been developed. The aim was reduction in heat losses and to enable use of low-grade heat sources. In addition, there is a mixing loop in CITY2 to connect to the conventional DH system as a back-up. The heat pump recovers heat from cooling machines.

The demos have been monitored and evaluated in terms of the overall impact of the low temperature district heating project with regards to energy use and performance of involved plants and buildings, environmental impact, and social impact in terms of economy and experiences of using the systems for the end users and the interest of connecting to the LTDH system for the real estate owners. Key performance indicators such as utilized low-grade waste heat, increased share of renewables, primary energy savings, reduction in greenhouse gas emissions have been accounted in this report for the different demos, as well as costs and payback time for the installations. The functionality of the demos and installations have been evaluated based on experiences from the building phase as well as the operating phase.

Below follows a summary of the main findings in the different demonstrators:

Building a new converted low temperature district heating network in Østerby area with a new type of plastic pipes:

- Implementing the PE-RT plastic pipes designed and manufactured within the project and this new LTDH system comes from making use of low-grade surplus heat.
- The demonstration of the heat recovery pipe shows the possibility of taking care of heat losses from district heating pipes as well as heat from the ground surrounding it. The installation is to be regarded as a ground heat pump installation with co-laying advantages as district heating pipes are laid in the ground. The co-installation can however lead to possible maintenance problems.

Recovering surplus heat from cooling machines:

- Recovering surplus heat from cooling machines using heat pumps increases thermal efficiency and decreases primary energy use. It reduces CO_2 emissions significantly as compared to natural gas which is mainly used in Central European countries for heating. Therefore, shifting from using natural gas toward using surplus heat in LTDH networks is very promising to save primary energy and mitigate climate change. Although, the installed HP system at CITY2 had an operational delay and very short operation within the project frame, after fixing the technical issues the HP system will provide heat for the Østerby area as planned. In addition, a mixing loop is embedded to connect to the conventional DH network as a back-up and balance the heat supply. The short follow up period shows potential of reduction in CO_2 emissions and savings in primary energy in the system.

Testing individual heating units in customer side for low supply temperatures in Østerby:

- Individual heating units have been installed and tested in 158 chain house apartments and one Kinder Garten. Advantages of the system are that the tenants themselves can set the desired temperature and that the system allows for individual measurement and charging of the energy usage. Also, since there are very short distances between the heat exchanger and the tap point, Legionella safety is enforced. The drawback is the higher investment cost for flat-wise HIUs. The system requires demands on good adjustment and troubleshooting of the installations for the system to function well.

Even though the project was extended by about a year, due to the Covid-19 pandemic, it can be stated that it is a challenging task to be able to make time for all phases of designing new components and network configurations, for manufacturing new components, laying the pipes in the LTDH network and installing the customer installations, as well as operating the new system and its installations and evaluating and follow up on the performance and the experiences of the users and key actors in the project.

The project experienced problems with delays in the PV-HP operation in CITY2 and the heat recovery of the main distribution line. This had also had consequences for follow-up and evaluation. A longer monitoring and evaluation period would have given the opportunity for comparisons between years.

Operating a LTDH system means smaller operating marginals compared to a high temperature system since the system is dependent on waste heat recovery and the supply temperature cannot be raised as easily as in a conventional DH system. This places higher demands on the efficiency of the system and on the efficiency of the customers' facilities. Adjustments, maintenance, and service of the customer installations are of vital importance for the system total efficiency. The evaluation on customer experiences shows that this is a challenging task that requires new ways of servicing the customers. It is not enough only to use an incentive in the price model for the charge of district heating, the customers must be well informed on system functionality and the responsibility for good system functionality should ideally lie with the district heating company rather than with the customer.

The results of the evaluation of the demonstrations in the COOL DH project imply that a combination of making use of more surplus heat, using new materials and new components like plastic pipes and HUIs in every apartment, and having more energy efficient buildings, can significantly improve the energy matrix in a region or a county. This is a very promising feature of COOL DH to satisfy all involved partners including municipality, utility, and customers regarding regulations, business model, and heat demand. This project can be considered as a step in Heat Roadmap Europe towards low-carbon heating and independency of fossil fuels.

9 References

[1] Website of COOL DH project: http://www.cooldh.eu

[2] Statistics Denmark database on https://www.statistikbanken.dk/

[3] Website of Denmark's Nature Conservation Association https://www.dn.dk/

[4] Environmental assessment for the energy supply company VEKS. Available online at: Miljødeklaration, 2021 (https://veks.dk)

[5] Database of Electricity Map Application (https://app.electricitymaps.com)

[6] Acquaviva, Andrea; Apiletti, Daniele; Attanasio, Antonio; Baralis, Elena; Bottaccioli, Lorenzo; Castagnetti, Federico Boni; Cerquitelli, Tania; Chiusano, Silvia; Macii, Enrico; Martellacci, Dario; Patti, Edoardo (2015). Energy Signature Analysis: Knowledge at Your Fingertips. In: IEEE International Congress on Big Data (BigData Congress) 2015, New York, USA, 27 June 2015 -2 July 2015. pp. 543-550

[7] Hayati, A.; Akander, J.; Eriksson, M. A Case Study of Mapping the Heating Storage Capacity in a Multifamily Building within a District Heating Network in Mid-Sweden. Buildings 2022, 12, 1007.

[8] Tariff sheet 2021 of Hoje Taastrup Fjernvarme at https://www.htf.dk

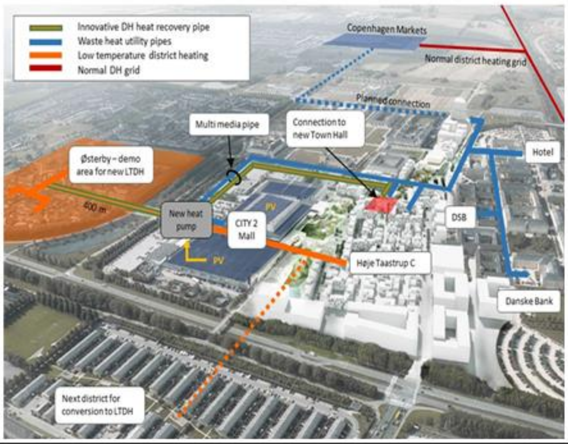
COOL DH - Høje Taastrup

General Data

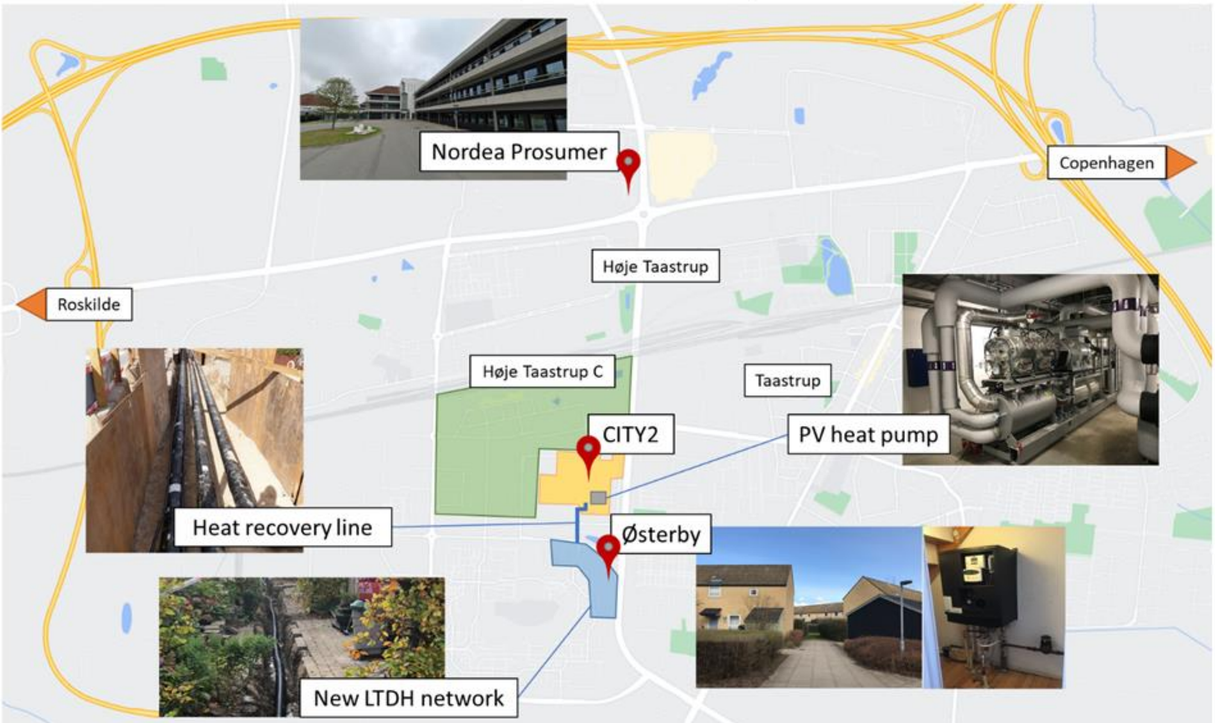
56°09'N 10°13'E

Country	Denmark
Region	Capital Region
City	Høje Taastrup
Start of COOL DH activities	1st October 2017
End of COOL DH activities	30 September 2022

COOL DH
COOL DISTRICT HEATING



Demonstration	Østerby DH	CITY2	Nordea	CITY2 Heat recovery
Type of RES	RES based Low Temperature District Heating network	PV / heat pump	Heat pump	Heat recovery heat pump
Installation type	PE-RT plastic pipes	Cooling and heating co-production	Datacenter surplus heat recovery	Pipe heat loss recovery and heat pump
Year of installation	2019	2020	2020	2020
Adress	Østerby district, 2630 Taastrup	Cityringen 4, 2630 Taastrup	Helgeshøj Alle 33, 2630 Taastrup	Cityringen 4, 2630 Taastrup



COOL DH
COOL DISTRICT HEATING

Østerby - LTDH

General Data

Cederlunden, Olivenlunden and Palmelunden, Høje Taastrup

Year built	1986
Window refurbishment	2012-2014
Address	Østerby district, 2630 Taastrup:
Building function	Residential
Building type	Terraced houses
Number of Apartments	158 + 1 (institution)
Number of houses	413 in total district
Gross Floor Area (m²)	12.604
Gross Volume (m³)	31.730
Total Investment cost [Euro]	1.99 mio. €

	Before (1986)	**Actual (2021)**
Roof [W/m^{2}K]	0,2	0,2
Ground floor [W/m^{2}K]	0,3	0,3
Windows [W/m^{2}K]	2,9	1,8
External walls [W/m^{2}K]	0,4	0,4

Period	**Total heating delivered** Total MWh	Total/m² kWh/m²	**Heat consumption (users)** MWh	**Heat losses *)** MWh	**Supply temperature to Østerby** °C	**Return temperature to Østerby** °C
January 2021	168	13,3	136	32	86	39
February 2021	155	12,3	129	26	86	39
March 2021	134	10,6	110	24	71	40
April 2021	101	8,0	80	21	65	39
May 2021	75	6,0	55	20	61	38
June 2021	37	2,9	21	16	62	37
July 2021	31	2,5	16	15	63	38
August 2021	44	3,5	24	20	61	38
September 2021	49	3,9	29	20	69	35
October 2021	83	6,6	63	20	74	37
November 2021	106	8,4	93	13	68	39
December 2021	165	13,1	138	27	77	39
Total	**1.148**	**7,6**	**894**	**254**	**70,3**	**38,2**
January 2022	161	12,8	131	30	80	39
February 2022	138	10,9	111	27	79	38
March 2022	128	10,2	100	28	79	38
April 2022	99	7,9	74	25	77	38
May 2022	62	4,9	40	22	72	36
June 2022	34	2,7	n.a.	n.a.	63	37
July 2022	34	2,7	n.a.	n.a.	62	38
August 2022	37	2,9	n.a.	n.a.	66	39
September 2022	56	4,4	n.a.	n.a.	69	37
October 2022	63	5,0	n.a.	n.a.	67	41
November 2022						
December 2022						
Total	**812**	**6,4**	**456**	**132**	**71,4**	**38,1**

*) at interrim elevated temperatures 77/38°C in 2022

CITY2 - Heat pump

General Data

Cityringen 4, 2630 Taastrup

New RES	Heat pump: Heating and cooling
Year installed	2020
Installation type	Cooling and heating co-production - Heat pump
Address	Cityringen 4, 2630 Taastrup
Installed heating capacity	1.34 MW
Installed cooling capacity	1.0 MW
Estimated annual energy production at 3,000 full load hours	4,023 MWh heating + 2,970 MWh cooling
Total Investment cost [€]	1.14 mio. €
Supply/return temperatures, loop 1	60-70°C / 45°C
Supply/return temperatures, loop 2	55°C / 30°C
Cooling: supply/return temperatures, summer	6°C / 12°C
Cooling: supply/return temperatures, winter	10°C / 15°C

Period	**Operation hours** h	**Heat delivered to CITY2** MWh	**Heat delivered to CITY2 north** MWh	**Heat delivered to CITY2 south** MWh	**Supply temperature to CITY2** °C	**Return temperature to CITY2** °C
January 2021	n.a.	1.096	331	765	n.a.	n.a.
February 2021	n.a.	1.103	417	686	n.a.	n.a.
March 2021	n.a.	850	313	537	n.a.	n.a.
April 2021	n.a.	681	244	437	n.a.	n.a.
May 2021	n.a.	338	125	213	n.a.	n.a.
June 2021	744	86	21	65	62	37
July 2021	720	82	20	62	63	38
August 2021	744	129	36	93	61	38
September 2021	840	184	56	128	69	35
October 2021	n.a.	383	127	257	74	37
November 2021	n.a.	594	172	422	68	39
December 2021	n.a.	954	281	673	77	39
Total	**3.048**	**6.479**	**2.142**	**4.337**	**67,7**	**37,6**
January 2022	744	890	259	631	81	37
February 2022	672	779	230	549	81	36
March 2022	743	641	192	449	82	38
April 2022	720	451	134	317	76	36
May 2022	744	218	64	154	65	64
June 2022	720	122	30	92	65	64
July 2022	672	77	22	55	62	38
August 2022	840	94	25	69	66	39
September 2022	720	145	35	110	72	36
October 2022	744	231	62	169	74	40
November 2022						
December 2022						
Total	**7.319**	**3.648**	**1.052**	**2.596**	**72,4**	**42,8**

COOL DH
COOL DISTRICT HEATING

CITY2 - Heat pump

General Data

Cityringen 4, 2630 Taastrup

New RES	Heat pump: Heating and cooling
Year installed	2020
Installation type	Cooling and heating co-production - Heat pump
Address	Cityringen 4, 2630 Taastrup
Installed heating capacity	1.34 MW
Installed cooling capacity	1.0 MW
Estimated annual energy production at 3,000 full load hours	4,023 MWh heating + 2,970 MWh cooling
Total Investment cost [€]	1.14 mio. €
Supply/return temperatures, loop 1	60-70°C / 45°C
Supply/return temperatures, loop 2	55°C / 30°C
Cooling: supply/return temperatures, summer	6°C / 12°C
Cooling: supply/return temperatures, winter	10°C / 15°C

Period	Total cooling delivered MWh	Volume m^3	Supply temperature to CITY2 MWh	Return temperature to CITY2 MWh	Electricity consumption MWh	COP_h	COPc
January 2021	n.a.	n.a.	10,0	15,0	n.a.	n.a.	n.a.
February 2021	n.a.	n.a.	10,0	15,0	n.a.	n.a.	n.a.
March 2021	n.a.	n.a.	10,0	15,0	n.a.	n.a.	n.a.
April 2021	n.a.	n.a.	10,0	15,0	n.a.	n.a.	n.a.
May 2021	0,6	722	10,0	15,0	n.a.	n.a.	n.a.
June 2021	218	29.035	10,0	16,4	n.a.	n.a.	n.a.
July 2021	399	51.723	9,0	15,6	n.a.	n.a.	n.a.
August 2021	230	32.540	9,0	14,1	n.a.	n.a.	n.a.
September 2021	117	15.111	9,0	15,7	n.a.	n.a.	n.a.
October 2021	n.a.	n.a.	10,0	15,0	n.a.	n.a.	n.a.
November 2021	1,0	n.a.	10,0	15,0	n.a.	n.a.	n.a.
December 2021	n.a.	n.a.	10,0	15,0	n.a.	n.a.	n.a.
Total	**966**	**129.131**	**9,8**	**15,2**	**n.a.**	**n.a.**	**n.a.**
January 2022	n.a.	n.a.	10,0	15,0	n.a.	n.a.	n.a.
February 2022	n.a.	n.a.	10,0	15,0	n.a.	n.a.	n.a.
March 2022	n.a.	n.a.	10,0	15,0	n.a.	n.a.	n.a.
April 2022	n.a.	n.a.	10,0	15,0	n.a.	n.a.	n.a.
May 2022	n.a.	n.a.	10,0	15,0	n.a.	3,14	5,29
June 2022	122	13.811,0	6,0	13,7	3	3,13	5,25
July 2022	305	n.a.	7,0	13,4	n.a.	n.a.	n.a.
August 2022	468	n.a.	7,3	14,7	n.a.	n.a.	n.a.
September 2022	90	n.a.	9,0	14,8	n.a.	n.a.	n.a.
October 2022	0	n.a.	10,0	15,0	n.a.	n.a.	n.a.
November 2022					n.a.	n.a.	n.a.
December 2022					n.a.	n.a.	n.a.
Total	**984**	**13.811**	**8,9**	**14,7**	**n.a.**	**3,13**	**5,26**

Nordea Heat Pump

General Data

Helgeshøj Alle 33, 2630 Taastrup

New RES	Heat pump
Year installed	2020
Installation type	Data center surplus heat
Address	Helgeshøj Alle 33, 2630 Taastrup
Installed heating capacity	1.8 (1.92) MW_{heat}
Installed cooling capacity	1.5 MW_{cool}
Total Investment cost	1.61 mio. €
Annual total CO2 savings	1690 [t]
Primary energy factor (electricity)	2,1

Period	**Operation hours** h	**Heating delivered** MWh	**Volume** m^3	**Supply temperature** °C	**Return temperature** °C
January 2021	408	1.180	35.791	73	43
February 2021	27	43	1.214	73	41
March 2021	778	1.295	38.384	73	42
April 2021	697	1.173	34.626	73	42
May 2021	703	1.188	34.872	73	42
June 2021	23	40	1.265	73	44
July 2021	n.a.	n.a.	n.a.	n.a.	n.a.
August 2021	165	522	18.381	73	47
September 2021	692	1.116	38.126	73	45
October 2021	755	1.197	33.686	73	43
November 2021	695	1.078	30.182	73	43
December 2021	677	1.040	30.207	73	43
Total	**5.620**	**9.872**	**296.734**	**73,0**	**43,2**
January 2022	459	1.233	35.466	73	43
February 2022	671	1.030	29.935	73	43
March 2022	706	1.058	30.742	73	43
April 2022	450	676	19.695	73	43
May 2022	331	511	15.439	69	30
June 2022	Summer closed	n.a.	n.a.	n.a.	n.a.
July 2022	Summer closed	n.a.	n.a.	n.a.	n.a.
August 2022	Summer closed	n.a.	n.a.	n.a.	n.a.
September 2022	529	771	24.012	69	32
October 2022	746	1.217	34.625	69	39
November 2022					
December 2022					
Total	**3.892**	**6.496**	**189.914**	**71,3**	**39,0**

Nordea Heat Pump

General Data

Helgeshøj Alle 33, 2630 Taastrup

New RES	Heat pump
Year installed	2020
Installation type	Data center surplus heat
Address	Helgeshøj Alle 33, Taastrup
Installed heating capacity	1.8 MW_{heat}
Installed cooling capacity	1.5 MW_{cool}
Total Investment cost	1.61 mio. €
Annual total CO2 savings	1690 [t]
Primary energy factor (electricity)	2,1

Period	**Cooling delivered** MWh	**Volume** m^3	**Supply temperature** °C	**Return temperature** °C
January 2021	842	161.837	9,0	13,5
February 2021	31	6.893	9,0	12,9
March 2021	921	187.152	9,0	13,2
April 2021	836	164.908	9,0	13,4
May 2021	841	166.097	9,0	13,3
June 2021	28	5.006	9,0	13,8
July 2021	n.a.	n.a.	9,0	n.a.
August 2021	370	72.733	9,0	13,4
September 2021	795	158.160	9,0	13,3
October 2021	864	176.042	9,0	13,2
November 2021	779	144.811	9,0	14,0
December 2021	744	136.840	9,0	14,0
Total	**7.051**	**1.380.479**	**9,0**	**13,5**
January 2022	879	149.574	9,0	14,0
February 2022	735	125.104	9,0	14,0
March 2022	756	129.376	9,0	14,0
April 2022	483	79.992	9,0	14.2
May 2022	363	56.803	9,0	14,5
June 2022	n.a.	n.a.	n.a.	n.a.
July 2022	n.a.	n.a.	n.a.	n.a.
August 2022	n.a.	n.a.	n.a.	n.a.
September 2022	551	82.242	9,0	14,6
October 2022	870	124.718	9,0	15,0
November 2022				
December 2022				
Total	**4.637**	**747.809**	**9,0**	**14,4**

Nordea Heat Pump

General Data

Helgeshøj Alle 33, 2630 Taastrup

New RES	Heat pump
Year installed	2020
Installation type	Data center surplus heat
Address	Helgeshøj Alle 33, Taastrup
Installed heating capacity	1.8 (1.92) MW_{heat}
Installed cooling capacity	1.5 MW_{cool}
Total Investment cost	1.61 mio. €
Annual total CO2 savings	1690 [t]
Primary energy factor (electricity)	2,1

		Calculations		
Period	**Electricity from grid** MWh	**Primary energy saved** MWh	**COPh including pump** -	**COPtotal including pump** -
January 2021	324	1.342	3,60	6,20
February 2021	5	63	6,74	6,20
March 2021	362	1.456	3,54	12,48
April 2021	626	694	2,34	6,09
May 2021	504	971	2,67	3,67
June 2021	0	68	n.a.	4,34
July 2021	n.a.	n.a.	n.a.	n.a.
August 2021	89	705	5,16	9,31
September 2021	309	1.262	3,57	9,31
October 2021	329	1.370	3,63	6,15
November 2021	297	1.233	3,62	6,25
December 2021	206	1.351	4,61	6,25
Total	**3.051**	**10.515**	**3,31**	**5,62**
January 2022	419	1.232	3,10	5,04
February 2022	213	1.318	4,45	8,29
March 2022	290	1.205	3,61	6,26
April 2022	186	768	3,60	6,23
May 2022	141	578	3,57	6,20
June 2022	n.a.	n.a.	n.a.	n.a.
July 2022	n.a.	n.a.	n.a.	n.a.
August 2022	n.a.	n.a.	n.a.	n.a.
September 2022	216	868	3,55	6,12
October 2022	335	1.384	3,60	6,23
November 2022				
December 2022				
Total	**1.800**	**7.353**	**3,58**	**6,19**

CITY2 - Heat recovery heat Pump

General Data

Cityringen 4, 2630 Taastrup

New RES	Heat pump
Year installed	2020
Installation type	Pipe heat loss recovery - Heat pump
Address	Cityringen 4, 2630 Taastrup
Installed capacity [kW]	6 kW
Pipe length	350 m double (700 m total)
Est. annual prod.	70.5 MWh
Total Investment cost [€]	6.711

Period	Operation hours	LTDH		Brine		Recovered heat	Electricity consumed	Delivered heat
		Supply temperature °C	Return temperature °C	Supply temperature °C	Return temperature °C	MWh	MWh	MWh
January 2021	n.a.	86	39	n.a.	n.a.	n.a.	n.a.	n.a.
February 2021	n.a.	86	39	n.a.	n.a.	n.a.	n.a.	n.a.
March 2021	n.a.	71	40	n.a.	n.a.	n.a.	n.a.	n.a.
April 2021	n.a.	65	39	n.a.	n.a.	n.a.	n.a.	n.a.
May 2021	n.a.	61	38	n.a.	n.a.	n.a.	n.a.	n.a.
June 2021	n.a.	62	37	n.a.	n.a.	n.a.	n.a.	n.a.
July 2021	n.a.	63	38	n.a.	n.a.	n.a.	n.a.	n.a.
August 2021	n.a.	61	38	n.a.	n.a.	n.a.	n.a.	n.a.
September 2021	n.a.	69	35	n.a.	n.a.	n.a.	n.a.	n.a.
October 2021	n.a.	74	37	n.a.	n.a.	n.a.	n.a.	n.a.
November 2021	n.a.	68	39	n.a.	n.a.	n.a.	n.a.	n.a.
December 2021	n.a.	77	39	n.a.	n.a.	n.a.	n.a.	n.a.
Total	**n.a.**	**70,3**	**38,2**	**n.a.**	**n.a.**	**n.a.**	**n.a.**	**n.a.**
January 2022	n.a.	80	39	n.a.	n.a.	n.a.	n.a.	n.a.
February 2022	n.a.	79	38	n.a.	n.a.	n.a.	n.a.	n.a.
March 2022	5	79	38	n.a.	n.a.	5,90	0,02	0,05
April 2022	n.a.	77	38	n.a.	n.a.	n.a.	n.a.	n.a.
May 2022	n.a.	72	36	n.a.	n.a.	n.a.	n.a.	n.a.
June 2022	5	70	47	n.a.	n.a.	0,03	0,02	0,05
July 2022	78	62	38	16	21	1,18	0,34	1,52
August 2022	122	68	37	17	22	1,90	0,53	2,43
September 2022	196	72	34	16	21	2,96	0,95	3,91
October 2022	204	69	38	16	21	2,72	1,35	**4,07**
November 2022								
December 2022								
Total	**610**	**72,8**	**38,3**	**16,3**	**21,3**	**14,69**	**3,21**	n.a.

Monitored at interim conditions