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
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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The participants of the COOL DH consortium do not take any responsibility for the further use of the presented project results and deliverables as whole or in part.

The report is based on knowledge of how the system is constructed, in some cases the future output may differ somewhat from the systems described in this deliverable.

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 impact of building and operating the included DH systems.

This monitoring report is focusing on monitoring of energy performance, environmental impacts, economic analysis as well as social studies of Swedish side of COOL DH and evaluation of:

- Xplorion: Innovation and demonstration building in Brunnshög
- Low temperature District Heating (LTDH) network in Brunnshög
- Friskis & Svettis Gym: Heat recovery pipes in Lomma
- Surplus heat recovery at MAX IV facilities
- Incorporating a distributed local waste heat source into LTDH network in Brunnshög
- Heated benches in Brunnshög

Context of deliverable

The monitoring report includes data monitoring and evaluation of Swedish side of COOL DH in terms of energy flows, environmental impacts, production sites, cost of the DH network, customer installations, social studies, special innovations, and heat recovery pipes.

Perspective of deliverable

The monitoring report is to be used for monitoring the related and necessary collected measurements and then evaluation of Swedish side of COOL DH. As well it is intended to inspire utilities to replicate solutions were found feasible.

Involved partners

Lund University (UNI-SE) was responsible for compiling the monitoring report. In the process for developing this report, representatives from UNI-SE (lead), Kraftringen AB (UTIL-SE), LKF (HOUSE-SE) and COWI (COWI-DK) have been involved.

Summary

Different demos in the Swedish side of the COOL DH project are monitored and evaluated in terms of energy performance, environmental impacts, economic costs, and social studies. All these analyses have been done for each installation if it is applicable. In a general perspective, this part of the project showed the functionality and viability of using Low Temperature District Heating (LTDH) system in a real scale successfully and in a techno-economic way. However, there is a large space still to improve the system and the quality of services to the customers and end-users.

A new LTDH network was built as a combination of PE-RT plastic and steel pipes with leak detection in Brunnshög area of Lund. The network is still developing and is thus not complete yet, but it denotes the possibility of using PE-RT pipes in a LTDH network to supply heat.

Several innovative solutions were implemented in the Xplorion building in Lund such as a booster Heat Pump (HP) to implement an Ultra-Low District Heating (u-LTDH) system to provide heat for a new Heat Interface Unit (HIU) concept through a 3-pipe system instead of conventional 5-pipe systems. There were some issues regarding high return temperatures, and it had affected the booster HP for providing u-LTDH system in the building. However, this HP could run after fixing the issue. This demo showed the capability of LTDH and even u-LTDH systems to provide heating of a building with separated heating units for each flat.

The heat recovery pipes, to recover heat from pipe losses, were implemented to provide Domestic Hot Water (DHW) in a gym in Lomma city using a conventional HP. Although, the COVID-19 pandemic affected the operation of this HP it showed a normal operation to provide hot water in the gym, finally.

Another innovation within COOL DH is recovering surplus heat from cooling machines in the MAX IV facility using heat pumps as a heat source to supply heat for DH systems. There is plenty surplus heat to use that would otherwise be wasted. It increases energy efficiency and saves significant amount of primary energy usage of the system.

A hotel as a prosumer is incorporated to the DH network and the hotel can exchange heating and cooling with the network. This installation implies on importance of prosumers role in future DH systems.

In addition, there are other extra installation such as heated benches and ground heating for tram stations are included in the project to show wider use of LTDH systems in human life.

KPI's:

2021	Xplorion demo-house 54 flats, 4374 m²	LTDH system in Brunnshög area 2400m	Heat loss recovery on DH twin pipe 100 m	Surplus heat recovery at MAX IV 5.8 MW heat	Distributed local energy source - Hotel 0.5 MW	**Total** demo case
Utilised low-grade heat (MWh/y)	(163)	*	(11,7)	17,100	145	17,420
Increased non-fossil supply (MWh/y)	(187)	*	(17)	24,800	n.a.	25,004
Primary Energy savings (MWh/y)	(150)	*	(6)	6,300	n.a.	6,456
CO_2 reduction (tonnes/y)	(1)	*	(0,062)	-73**	n.a.	-72
Simple pay-back period (years)	35	n.a.	(13)	12	n.a.	~15
Investment excl. VAT (€)	547,170	€ 648,000 for 872m	11,700	5,310,000	n.a.	6,516,870

() Figures in brackets are estimated values in 2022

* Included in co-production from MAX IV

** It means that there is an increase in CO_2 production, if the electricity used is considered renewable then the CO_2 savings is 295 tons per year.

Abbreviations

3GDH	3rd Generation of DH
4GDH	4th Generation of DH
AP	Acidification Potential
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
EP	Eutrophication Potential
ESS	European Spallation Source
EU	European Union
GHG	Green House Gas
GWP	Global Warming Potential
HOUSE-SE	See LKF
HP	Heat Pump
HIU	Heat Interface Unit
IND-SE2	Cetetherm
KPI	Key Performance Index
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LKF	Lunds Kommuns Fastighetsbolag (The public housing company in Lund Municipality)
LTDH	Low-Temperature District Heating
NG	Natural Gas
OPEX	Operational Expenses

PCOC	PhotoChemical Ozone Creation
PE	Primary Energy
PEF	Primary Energy Factor
PES	Primary Energy Saving
PE-RT	Poly-Ethylene for Raised Temperature
PEX	Cross-linked polyethylene
PV	Photo Voltaic
RES	Renewable Energy Source
SH	Space Heating
u-LTDH	Ultra-Low Temperature District Heating
UNI-SE	Lund University
UTIL-SE	Kraftringen AB
WP	Work Package

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1 Introduction

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

The aim of deliverable D5.2 is to report the results, findings and conclusions from the monitoring activities related to the READY project in the Swedish side of COOL DH in Lund as presented in Figure 1.

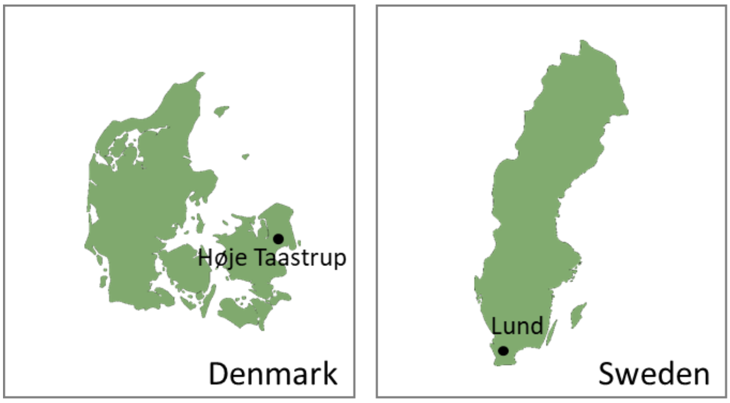

Figure 1. Map representing the two demonstration communities, Høje Taastrup in Denmark, and Lund in Sweden

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 should be performed at different aggregation levels. To be able to perform 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).

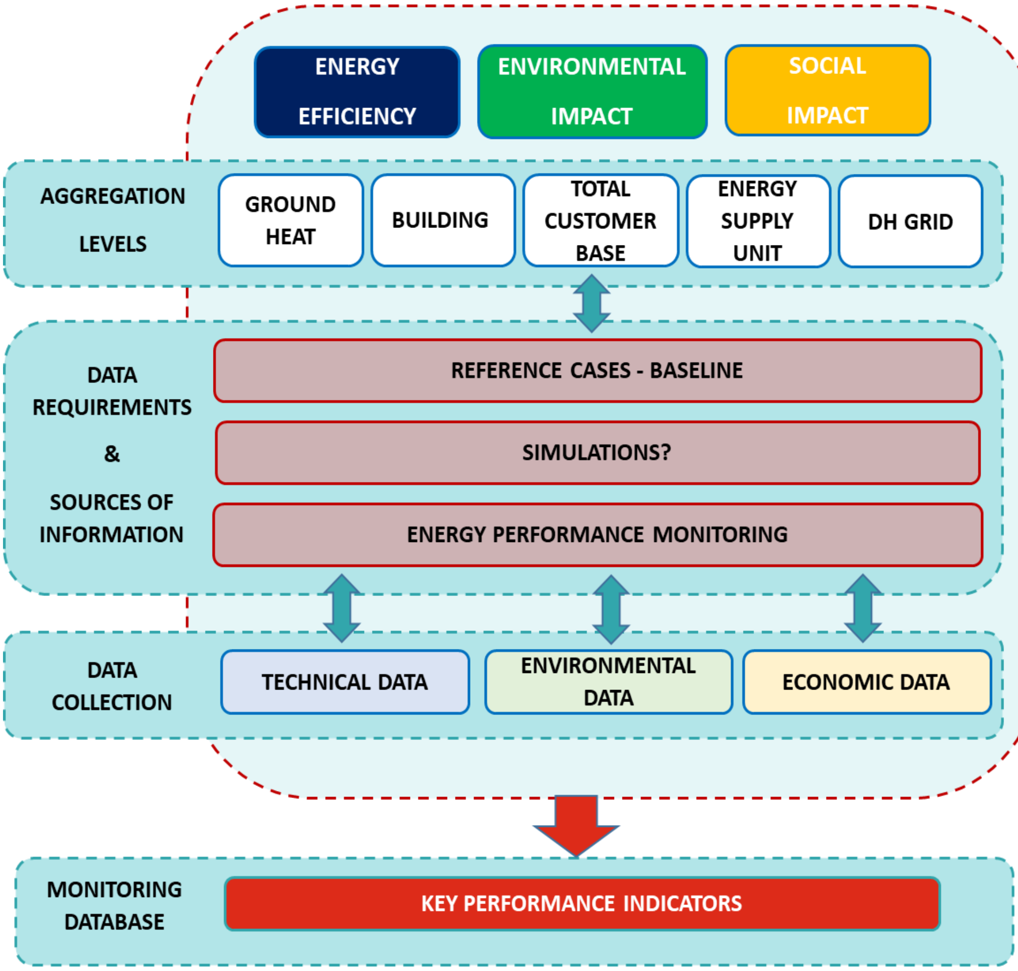

Figure 2. Principle sketch of project monitoring.

1.2 Objectives

The COOL DH Data monitoring is developed as a working plan to monitor the energy flow of the involved plants and buildings in two LTDH systems in Brunnshög in Lund, Sweden, and in the Østerby area 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 impacts.

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

- Xplorion: Innovation and demonstration of a building connected to a u-LTDH network in Brunnshög
- New LTDH network in Brunnshög
- Friskis & Svettis gym: Heat recovery pipes in Lomma
- Surplus heat recovery at MAX IV facilities
- Motel L as a prosumer: Incorporating a local waste heat source into DH network in Brunnshög
- Heated benches and ground heating in Brunnshög

The specific measurements taken in each Swedish part of the project can be seen in Table 1 below.

Table 1. Data collection of each site

Site	Heat delivered	Heat use	Heat losses	Cooling delivered	Flow Temp.	Return Temp.	Electricity use	COP
Xplorion	Green	Green	Blue	Gray	Green	Green	Green	Blue
LTDH in Brunnshög	Green	Green	Blue	Gray	Green	Green	Gray	Gray
Heat recovery pipe	Green	Green	Gray	Gray	Green	Green	Green	Blue
Coupling HP at MAX IV	Green	Green	Gray	Green	Green	Green	Green	Blue
Prosumer: Hotel	Green	Gray	Gray	Green	Gray	Gray	Gray	Gray

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, discussions with different participants in the project have been important input. Discussions have been both formal meetings and informal face to face meetings or meetings over telephone or Teams.

1.4 Lund Demonstrations

Lund is a fast-growing city with close to 130,000 inhabitants in the municipality [1]. The municipality has a political goal to substantially reduce its environmental and climate impact. During the period 1990–2020 the total amount of Green House Gas (GHG) emissions was decreased by more than 50%, including the emissions from the people living in the city. In 2050 the GHG emissions should be nearly zero [2].

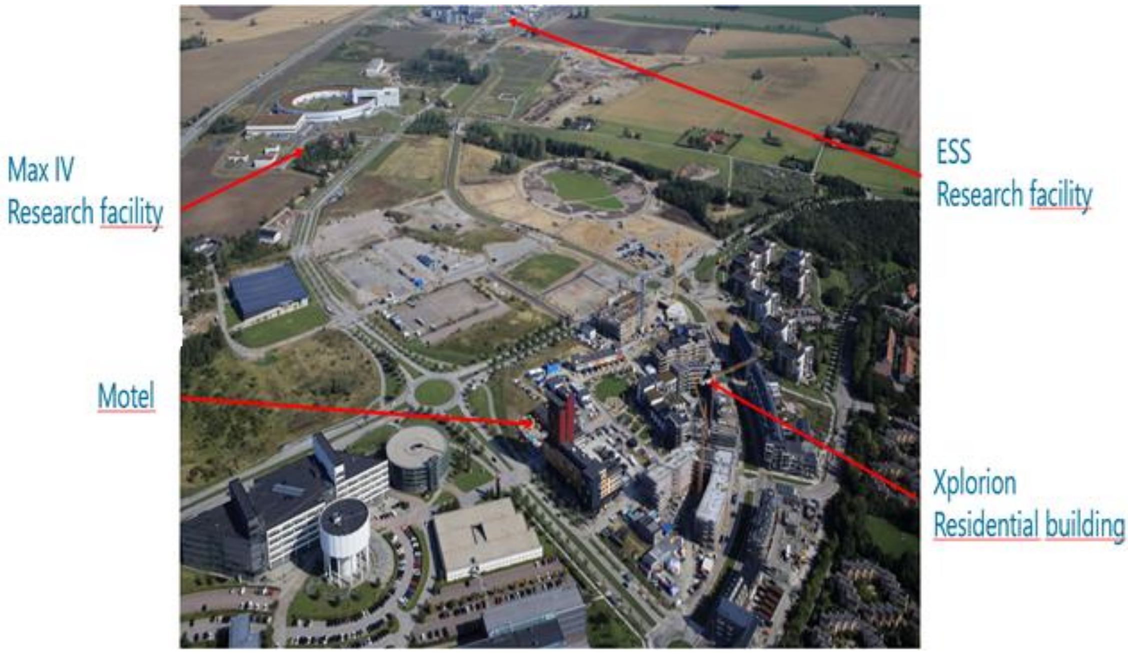

Figure 3. Demonstrations of Swedish side of COOL DH in Brunnshög [2]

Lund University which is among the top 100 universities in the world with 46,000 students and 5,600 researchers located in Lund [3]. Brunnshög area is also home to the research facilities MAX IV (synchrotron light) and the European Spallation Source, ESS (a new joint European particle accelerator), as well as to the Science Village Scandinavia with estimated 10,000 high level employees in near future [2].

As said, this monitoring and evaluation report are focusing on the demonstrations made in the project that are situated in Sweden. The main demonstration site is in Brunnshög, which is a development area in Northeast in the city of Lund. As can be seen in Figure 3, Brunnshög area is an ambitious project, with the goal to offer the best research and innovation environment in the world and to showcase sustainable urban development. In Brunnshög two world class research facilities, MAX IV and ESS, are located. Max IV is already in operation and ESS is under construction. Brunnshög is planned to be one of Northern Europe's most attractive environments for enterprise, research, and education. Low-grade surplus heat recovered from the research facilities of ESS and MAX IV will heat the entire area. It is foreseen that up to 40,000 people will live and work in Brunnshög in the future. It is planned to be fully developed in 2050 in a dense and mixed urban environment that accommodates varied housing and lush parks, restaurants, culture, special meeting places, shops and schools, workplaces, and services. The development of the city area will continue for many years to come [4].

Forming a part of Brunnshög is the Science Village Scandinavia. Covering 18 hectares of land between the MAX IV and ESS facilities, the plan is to build approximately 250,000 m^2 of gross floor area to provide space for businesses, services, accommodation, leisure, educational facilities, campuses, and research in the field of innovation and cutting-edge material research etcetera. There are several developers aiming to design the buildings for LTDH, which is optimally given the availability of large amounts of low-temperature heat from ESS and MAX IV [2].

The Brunnshög area is planned with high ambitions on environmental and energy matters. During the project period, the local district heating company, Kraftringen (UTIL-SE) has built a low temperature district heating grid that provides part of the Brunnshög area with low temperature district heating at a supply temperature of about 67°C using surplus heat from the research facility MAX IV. When ESS will be in operation, surplus heat can be used also from this research facility. Figure 4 is a city sketch of the long-term vision of Brunnshög.

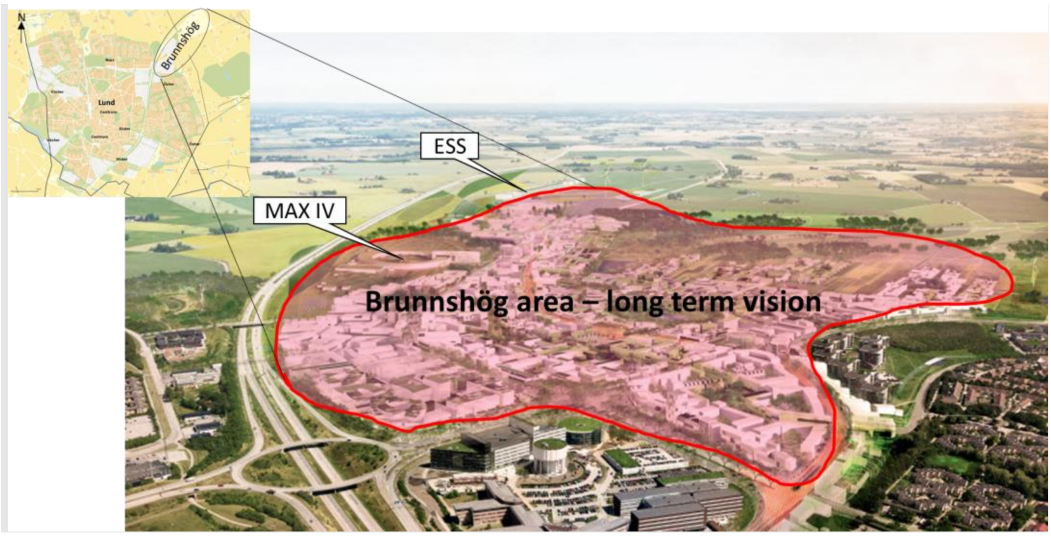

Figure 4. Long term vision of the Brunnshög area [4]

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 Swedish side of the COOL DH project. The report is structured as follows: At first, a brief introduction to different parts of the project and monitoring is described in this chapter. Then, the methodology used to evaluate the project will be explained in Chapter 2. The monitoring plan for the objects in focus within this report is presented in chapters 3 through 8, where each main section is focusing on a main demonstration area:

- Chapter 3: Demonstration of Xplorion building, connected to Ultra-Low Temperature District Heating (u-LTDH) system. The focus areas for demonstrations and innovations that are relevant for monitoring are:
  - u-LTDH connection with utilisation of a heat pump.
  - Heat Interface Units (HIUs) with a built-in heat exchanger.
  - 3-pipe internal distribution system.
- Chapter 0: Construction of a new LTDH network in Brunnshög area.
- Chapter 5: Demonstration of heat recovery pipe, a multi-media pipe with heat recovery system for utilizing heat losses from the DH pipe in Lomma.
- Chapter 6: Using surplus heat recovery from cooling system at MAX IV facility to provide heat for both traditional DH and new LTDH network.
- Chapter 7: Integration a motel as a prosumer into LTDH network in Brunnshög for exchanging surplus heat of cooling with the network.
- Chapter 8: Demonstration of other installations including heated benches and ground heating at tram stations in Brunnshög area.
- Chapter 9: Conclusions.
- Appendix: Monitoring Fact sheet for the Swedish side of COOL DH.

2 Methodology

How to perform the evaluations is described 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 heat losses 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 pumps 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 the 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 Evaluation of Environmental Impacts

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. Reference values for CO_2 emission factors for the heating and cooling sections in 2021 are 10.0 kg/MWh and 2.75 kg/MWh, respectively [5]. Although, the reference value for CO_2 emission intensity for electricity in 2021 is 0 kg/MWh the values of Table 2 were considered for the evaluation. The reason behind giving 0 kg/MWh for CO_2 intensity was that electricity of this part of the grid is provided by renewable sources. However, on the other hand, the total market and marginal values should be considered as well. In addition, it should be mentioned that for calculations of 2022, the corresponding data of the same month in 2021 is considered since only data of 2021 was available for monitoring.

Table 2. Average CO_2 values for electricity (in kg/MWh) in 2021 used for the environmental evaluation [6]

Month in 2021	Average $CO_{2,}$eq emissions	Average CO_2 marginal emission	Average of emission production	Average carbon intensity import
January	48.2	33.7	43.7	106.9
February	51.2	33.3	42.8	159.6
March	42.9	31.0	40.7	151.0
April	40.0	30.5	38.8	139.0
May	41.8	29.0	37.9	129.1
June	39.1	29.3	36.5	147.5
July	36.1	29.8	35.8	55.0
August	39.2	28.5	34.8	150.5
September	40.8	29.4	38.2	116.5
October	36.5	30.0	36.2	69.0
November	39.9	31.1	38.3	100.8
December	47.8	33.0	43.2	138.8
Total	**41.9**	**30.7**	**38.9**	**122.1**

2.2.2 Primary Energy Saving (PES)

In this section, the primary energy savings are 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 previously explained, PEF = 2.1 is used for electricity and PEF = 1.0 is considered for DH in this project. Therefore, PES in a system including electricity use and heating production in DH is calculated as below:

$$PES = (1.0 \times Q_P) - (2.1 \times P_{el}) \quad (24)$$

Where Q_P is the heat production of the system.

2.3 Evaluation of Costs

To provide a basis for operators who are interested in establishing a LTDH system, an evaluation of the system will be made. For investors, authorities, and energy companies, it may be 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.

The evaluation of costs and economic feasibility of the LTDH system will start from a Life Cycle Cost (LCC) perspective. With a LCC analysis the entire life cycle is considered, indicating the cost for investments and operation during the calculated time-period. For electricity cost during the operational phase a flat electricity rate is used.

2.4 Social Studies

For the evaluation of the demonstrations in Lund, the following studies have been carried out:

- A survey study was conducted with tenants in the Xplorion building to investigate the tenants' attitudes towards low temperature district heating and their experiences of the space heating and the hot water comfort in the building.
- An interview study was made with real estate companies in the Brunnshög area to examine the attitudes to the new low temperature district heating grid
- An interview study was made with key persons involved in the COOL DH project to collect experiences from the demonstrations, obstacles, and success factors.

3 Xplorion: Innovation and demonstration building

The Xplorion building is built in Southern Brunnshög, in the city of Lund, in an area called Solbjer. A picture of the building is shown in Figure 5. Xplorion is a world-class building where high-level climate-smart solutions were established to ensure a sustainable life for the tenants. Xplorion is a multi-storey and passive house building with a total gross area of 4,374 m^2 and heated area of 3,606 m^2 comprising 54 flats and a restaurant at the corner. Xplorion hosted the first group of tenants in November 2020.

Figure 5. Xplorion Building as a passive building [2]

3.1 Installations

Three solutions within COOL DH are demonstrated in Xplorion: A local energy solution with a hot water booster heat pump, an innovative three-pipe solution, and a heat interface unit (micro heat exchanger) installed at every flat.

3.1.1 Local energy solution for testing low supply temperatures

UTIL-SE (Kraftringen) has demonstrated a supply and user installation of u-LTDH at the Xplorion building. The area where Xplorion is situated is not connected to the low temperature district heating grid, but to the traditional district heating grid with conventional supply temperatures of 70-100°C. Therefore, an experimental setting was installed to be able to test ultra-low to low supply temperatures at the Xplorion building. To provide LTDH in this building a heat exchanger from IND-SE2 (Cetetherm) was used, that can also work as the permanent heat exchanger when the project is finished or as back-up supply in case the heat pump fails to work. This booster heat pump (which will be explained in detail later) is implemented to provide both space heating and hot water requirements for the tenants. The incoming district heating water temperature can be changed between 35-65°C to provide the heat pump with different temperatures to test various heating scenarios. After the main heat exchanger, the heat pump system is installed as it is presented in the simplified principal diagram in Figure 6. The heat pump can also be manually by-passed if problems occur, ensuring required temperatures and energy needs of the residents.

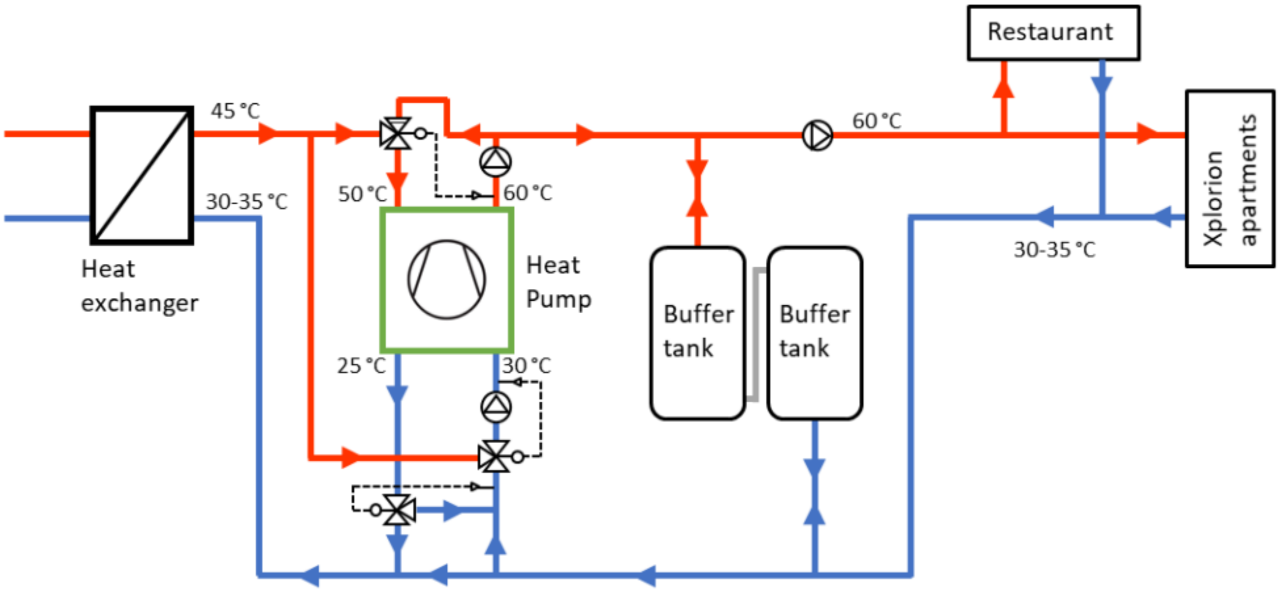

Figure 6. A simplified sketch of the hot water booster system in the basement of Xplorion

In principle the system can be considered an energy efficient way of using electric heating to boost the DHW temperature in the building. The heat pump may use renewable energy from a local PV system, which has a total panel area of 226 m². The benefit is that the building can be served with 45°C flow temperature from the u-LTDH network and still provide 50°C DHW at the tap. At the same time the return temperature is lowered, which lead to economic savings due to incitement tariff for the used district heating and the system increases the capacity of the main pipes in the grid and reduces the grid losses.

When considering the u-LTDH system, the lower operational temperatures reduce the heat loss from the DH network. Therefore, a whole system evaluation is advisable. Figure 7 shows the booster heat pump located in the basement of Xplorion.

Figure 7. Booster HP at Xplorion

Table 3 shows the design data of the heat pump:

Table 3. Design data of the booster HP

Heat pump	
Booster Heat Pump	Qvantum Q32P
Heat pump capacity	20.4 $kW_{nominal\ heat}$ -> 35.6 $kW_{heat\ actual}$
Buffer tank volume (for peak shaving)	2 x 1 m^3
Condenser temperature	60°C
Evaporator temperature	20°C (up to 35°C)
COP design	4.5
Expected full load operation hours	2500 h/year

It should be mentioned that the return temperature from the flats and within the 3-pipe system is a crucial factor for the HP operation. The HP had a short operation period of 32 days in September-October 2021. It was then stopped since the return temperature was found to be too high in the building and it was not efficient to operate. After fixing this issue in March 2021 (which will be discussed in Section 3.2.3) the HP was put in operation again.

3.1.2 Heat Interface Unit (HIU)

Figure 8 presents a principal sketch of the 3-pipe system implemented at Xplorion.

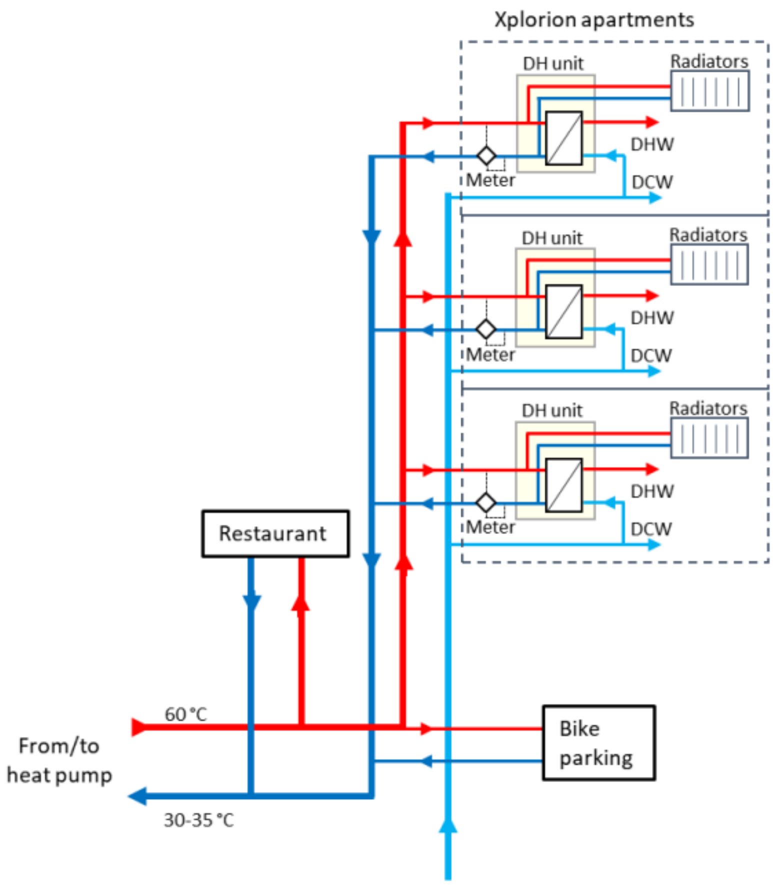

Figure 8. Simplified principal sketch of the 3-pipe system in Xplorion.

Each flat in Xplorion has its own district heating substation including a heat exchanger, as shown in **Error! Reference source not found.**9 and 10, to provide and regulate domestic hot water and space heating use. Such substations can be placed in every flat or single-family dwelling, and it can be implemented with or without a central substation. The units are insulated with a removable cover, which ensures lower heat losses. The units are P-certificated from the Swedenergy (Energiföretagen Sverige) department.

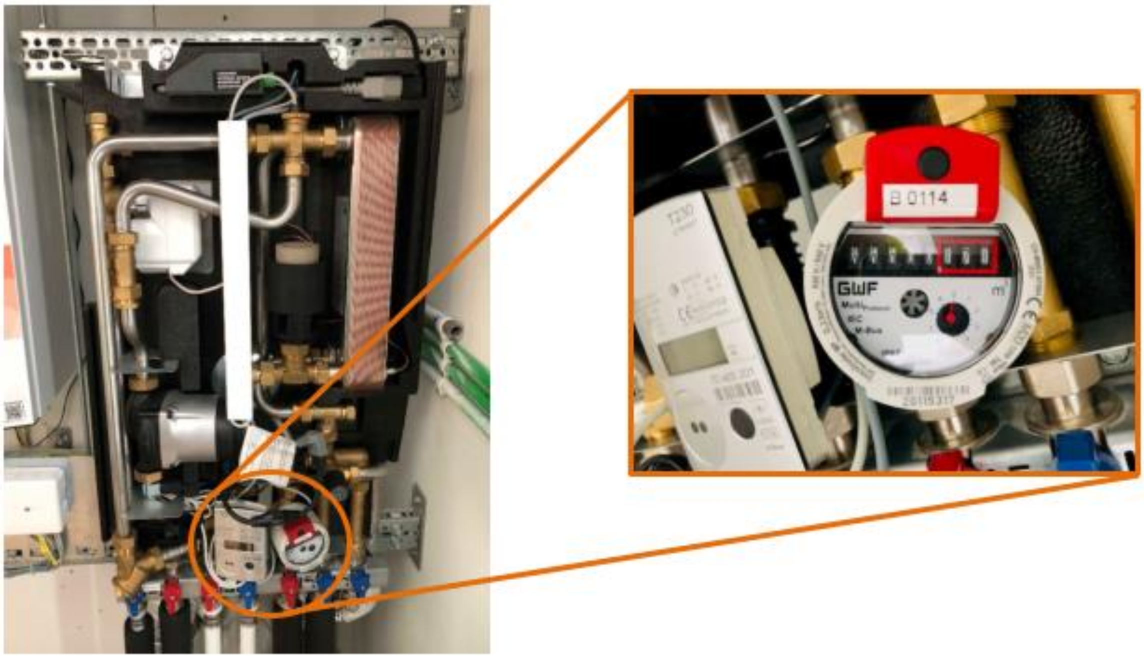

Figure 9. HIU installed in Xplorion with energy meter and DHW volume meter

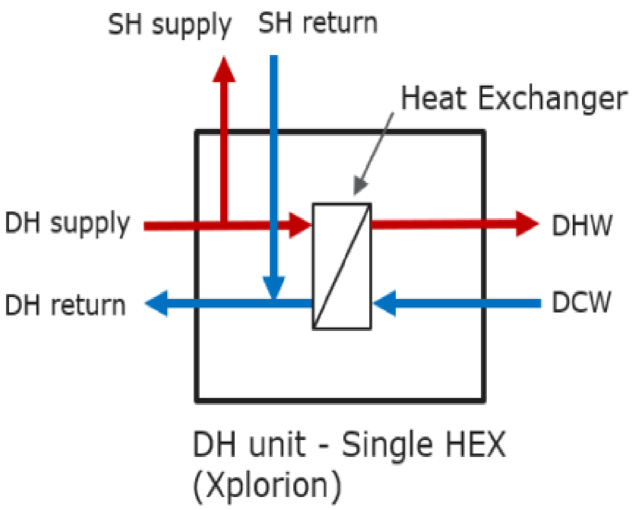

Figure 10. Simplified scheme of the HIU solution

By producing the hot water close to each flat, it is possible to supply the radiators with lower temperatures than before and subsequently lower supplied heat. The low heat usage of the building opens the possibility of being connected to a u-LTDH network, without compromising the thermal comfort of the occupants. However, the minimum supply temperature for the DHW system sets some requirements to avoid the possible proliferation of Legionella bacteria due to the low temperature supply.

3.1.3 Three-pipe solution

Instead of a solution with hot water circulation that normally requires five pipes, an innovative three-pipe system is used in the building as shown in Figure 11. It includes only one pipe for the supply of hot water and one for the return (partly as a twin pipe). The third pipe is for cold tap water that is heated to hot tap water in the HUIs in each flat – thereby avoiding the installation of separate hot tap water pipes and circulation pipes. The three-pipe system allows to deliver both DHW and SH with the same pipes, where a traditional 5-pipe system uses two separate piping systems to supply DHW and SH, including installing a DHW circulation pipe. All energy that goes up in the technical shaft is measured with energy meters.

Figure 11. Three-pipe system

3.2 Energy performance

3.2.1 Three-pipe system & HIUs

The energy supplied to the building for a certain time period can be calculated by using the values from the energy meter located just after booster HP. On the other hand, there are energy meters to measure consumed energy in the building including flats, laundry, bike parking, and restaurant. Then, the total heat loss from the piping system at Xplorion can be calculated by subtracting used energy from supplied energy to the building according to Equation 5:$Q_{loss} = Q_{sup} - Q_{use}$

$$Q_{loss} = Q_{sup} - \sum Q_{use} = Q_{sup} - (\sum Q_{Flats} + Q_{Laundry} + Q_{Vent.} + Q_{Parking} + Q_{room}) \qquad (5)$$

Where Q_{Flats}, $Q_{Laundry}$, $Q_{vent.}$, $Q_{Parking}$, Q_{room} are heat use in different parts of the building including individual flats, laundry room, ventilation system, bike parking, and a common room for meetings and celebrations, respectively. Not surprisingly, the larger part of the energy is used in the flats.

During the project and in Deliverable 2.10, an excel tool was developed to calculate heat losses within the 3-pipe system installed in Xplorion. The theoretical heat loss from this 3-pipe system was calculated to be 10.2 kWh/m^2 with this tool using design conditions of 60°C on the supply side and 30°C on the return side. The monthly pipe losses in the piping system have been monitored since 2021, these values were compared annually with the calculated pipe losses as a reference. This comparison is done to check the size of the pipe losses if the losses are high or low in relation to the computational calculations.

Different heating parameters for the 3-pipe system in Xplorion can be found in Table 4. As it can be seen, energy performance including heat losses in the pipes, and annual specific heat demand in 2022 is better compared to 2021. The annual pipe losses are seen to be close to the reference value that had been calculated earlier (10.8 kWh/m^2 vs. 10.2 kWh/m^2). There are some reasons for higher pipe losses in 2021 such as high return temperature, and the fact that one heater was out of service and that the pipes are not fully

insulated. The issue with high return temperatures was solved in March 2022 but average return temperatures were still higher than the designed one. This resulted in higher pipe losses than calculated.

Table 4. KPIs for 3-pipe system

KPI	2021	2022 (7 Months)	Potential 2022
Heat supply	237,560 kWh	117,180 kWh	187,066 kWh
Annual specific heat demand	65.9 kWh/m^2	55.9 kWh/m^2	**51.9 kWh/m^2**
Heat usage	187,444 kWh	94,011 kWh	148,211 kWh
Pipe losses	50,116 kWh (21.1%) Min. in Dec. 12.6% Max. in July 47.3%	23,169 kWh (19.8%) Min. in Feb. 13.4% Max. in July 49.0%	38,817 kWh (20.7%)
Daily average heat loss	137.3 kWh	109.3 kWh	106.3 kWh
Annual heat loss per area	13.9 kWh/m^2 (*Ref. = 10.2 kWh/m^2*), High return temperature Not 100% insulation in pipes 1 not working heat meter	11.1 kWh/m^2, Not 100% insulation Fixing other issues	**10.8 kWh/m^2**
Flats usage	173,454 kWh (92.5%)	86,335 kWh (91.8%)	137,220 kWh
Bike garage	8,367 kWh (4.5%)	4,088 kWh (4.3%)	5,668 kWh
Laundry	2,895 kWh (1.5%)	2,260 kWh (2.4%)	3,597 kWh
Common room	1,705 kWh (0.9%)	974 kWh (1.0%)	1,380 kWh
Ventilation	1,023 kWh (0.5%)	354 kWh (0.4%)	511 kWh

A Sankey diagram for the heat supplied and used in Xplorion can be seen in Figure 12.

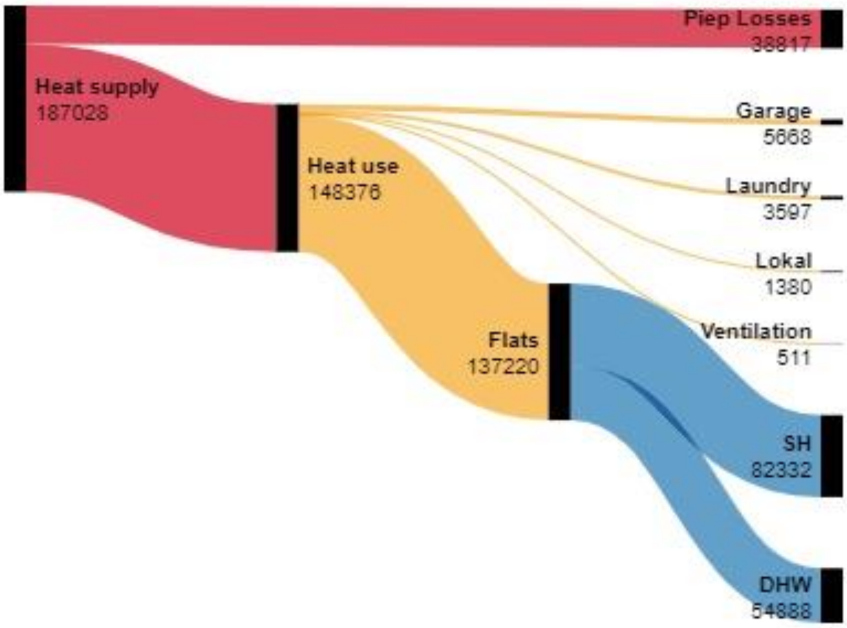

Figure 12. Energy flow(kWh) in Xplorion

A comparison between degree-days in 2022, 2021 and the reference year is shown in Figure 13. It serves as a base for estimations in Table 4 to show that both 2021 and 2022 are to be considered close to normal years.

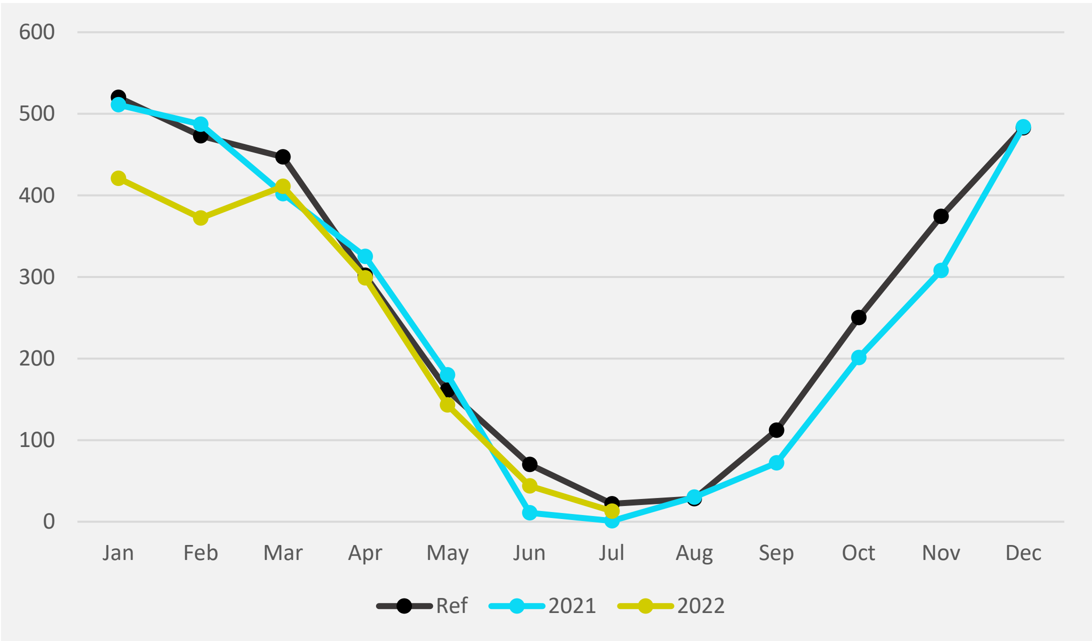

Figure 13. Comparison of degree-days in 2021, 2022, and the reference year

Figure 14 shows heat use for different parts in Xplorion including apartments, bike garage, laundry, common room, and ventilation system. As was expected, the flats are using the largest share of energy (more than 90%) compared to the other parts of Xplorion After the flats, the bike garage has the highest heat use. The heat consumption by the flats is measured by secondary vertical axis on the right to scale the graph since the flats use much more energy than the other parts. The other parts including bike garage, laundry, ventilation, and common room are measured by primary vertical axis as usual.

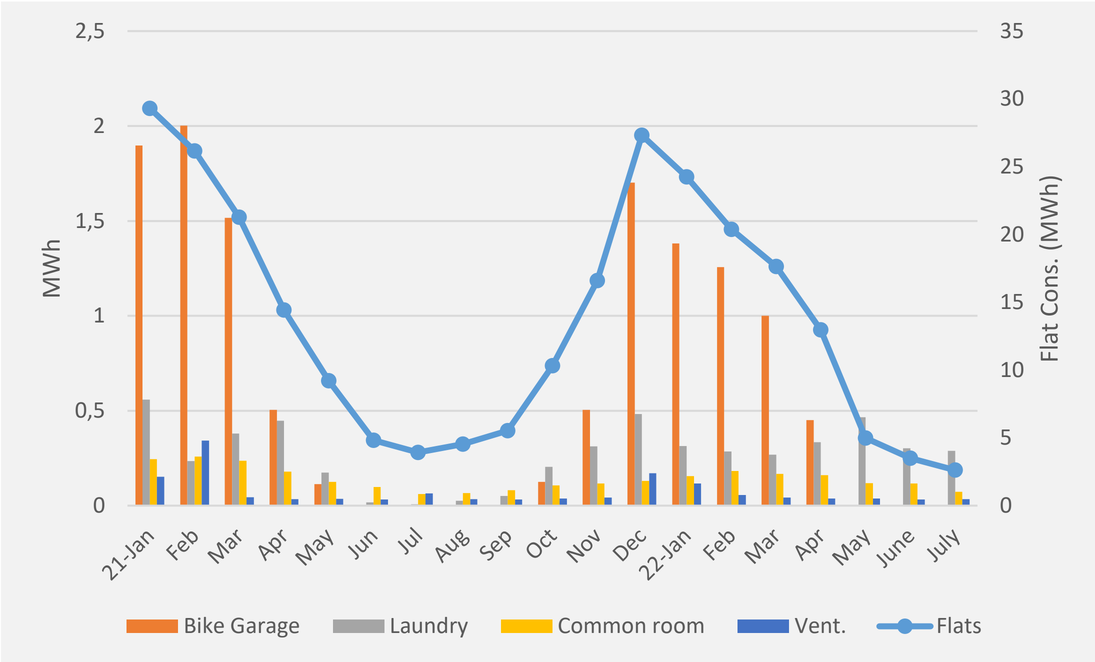

Figure 14. Heat use of each section in Xplorion

A temperature difference of 42°C between the hot water and the surroundings is assumed for DHW consumption. This is used in the formula $Q_{DHW} = \rho CV\Delta T$ where Q_{DHW} is the DHW consumption share, ρ and C are the density and the specific heat capacity of the water respectively and ΔT is the assumed temperature difference.

This estimated share of DHW consumption of the total energy consumption for heat can be seen in Figure 15. Although it varies between 4 to 9 MWh DHW consumption can be considered as a fixed amount of 6 MWh per month. The lowest share was 19% in Dec. 2021 and average share was around 40% in 2021. This is an estimation since there is no separate measurements between hot water tap in the flats and whole flow, which is measured altogether, and it is the reason that the total heat use, which is seen in Figure 15, is less than the DHW use in the summer months.

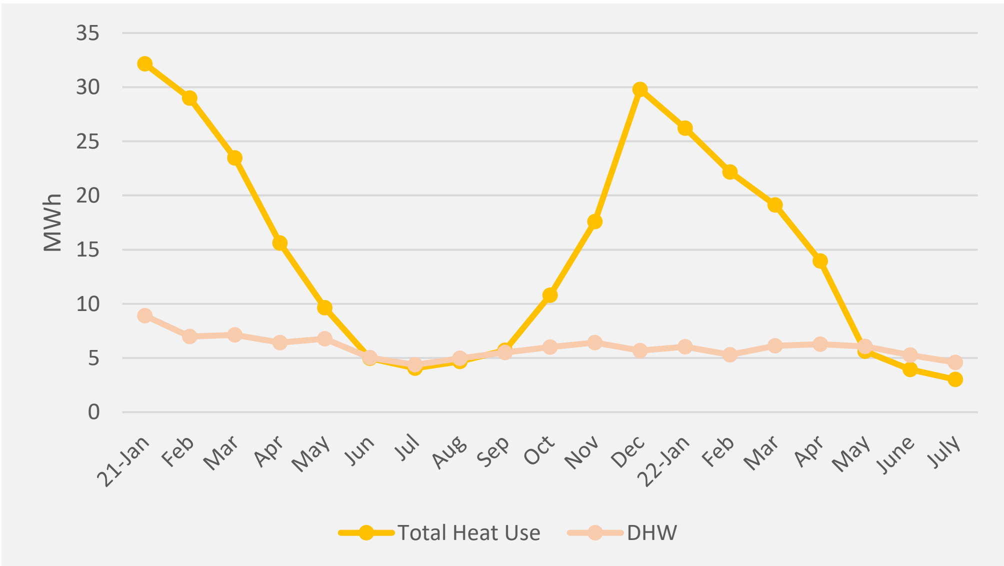

Figure 15. Share of DHW in Xplorion

Then, an approximation of space heating profile can be seen in Figure 16.

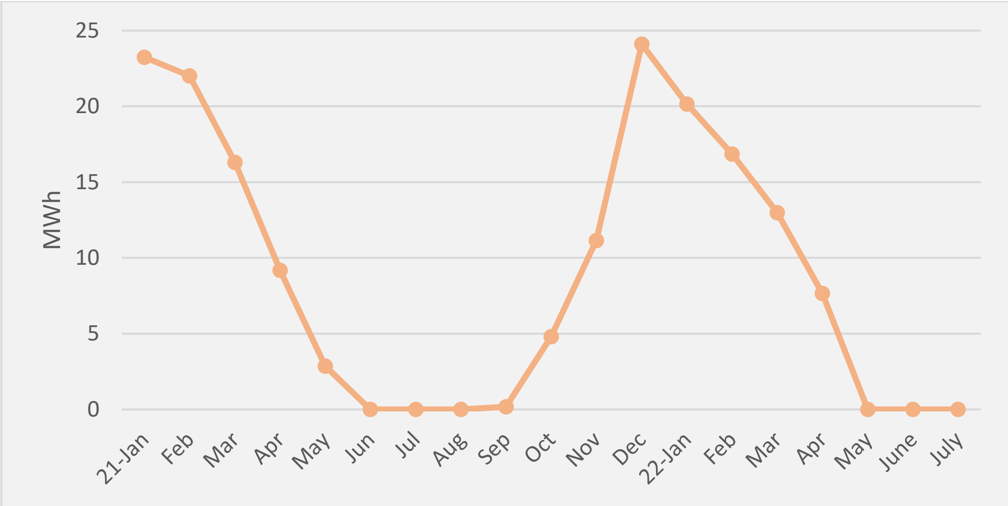

Figure 16. SH profile in Xplorion

Supply and return temperatures from the 3-pipe system to the flats are shown in Figure 17. As can be seen, the return temperatures were high in 2021 indicating problems on the secondary side. After many technical discussions and investigations, it was detected that the hot water sensors were badly adjusted in about half of the HIUs. The main difficulty to solve this issue was that the HUIs were located inside of the flats. Therefore, permission to enter the flats was needed by the tenants before the sensors could be accessed and adjusted. Most problems were finally solved in February and March 2022. The outcome of this corrective action can be seen in Figure 17 which shows that a very low return temperature was achieved, indicating that the heating installations is now working well in the building. It should be mentioned that the expected theoretically calculated temperatures of 60-65°C in supply and 30°C in return temperatures are now very close to the actual measured values.

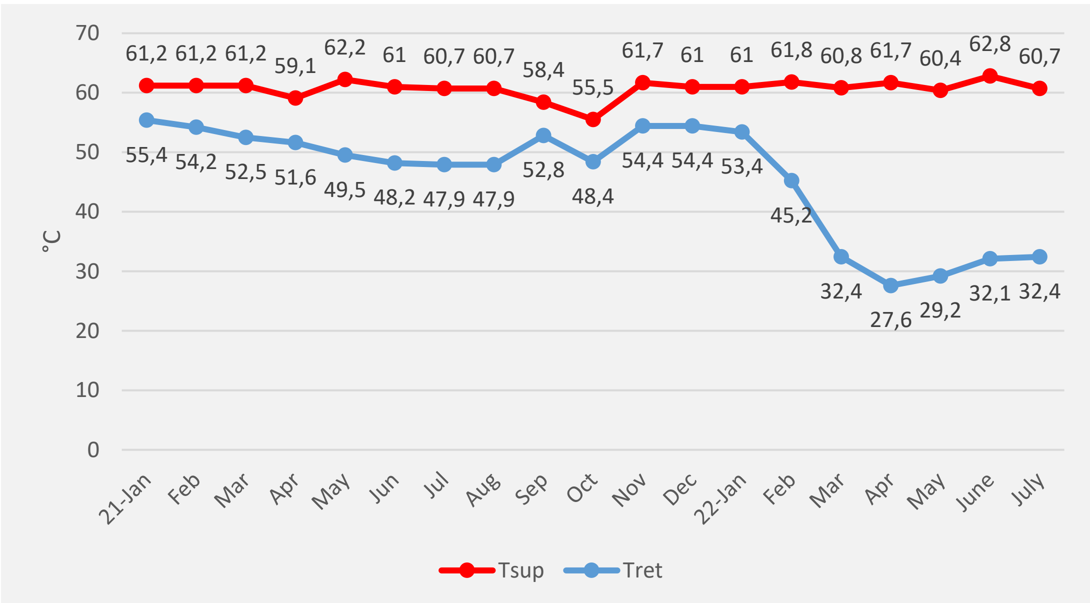

Figure 17. Supply and return temperatures in 3-pipe system to the flats

In addition, heat supply, and pipe losses can be seen in Figure 18. The annual heat loss in the pipes at Xplorion was 13.9 kWh/m² in 2021 and it is estimated to decrease to 10.8 kWh/m² in 2022 after fixing the high return temperature issue in March 2022. This value can be compared with the theoretically calculated value of 10.2 kWh/m².

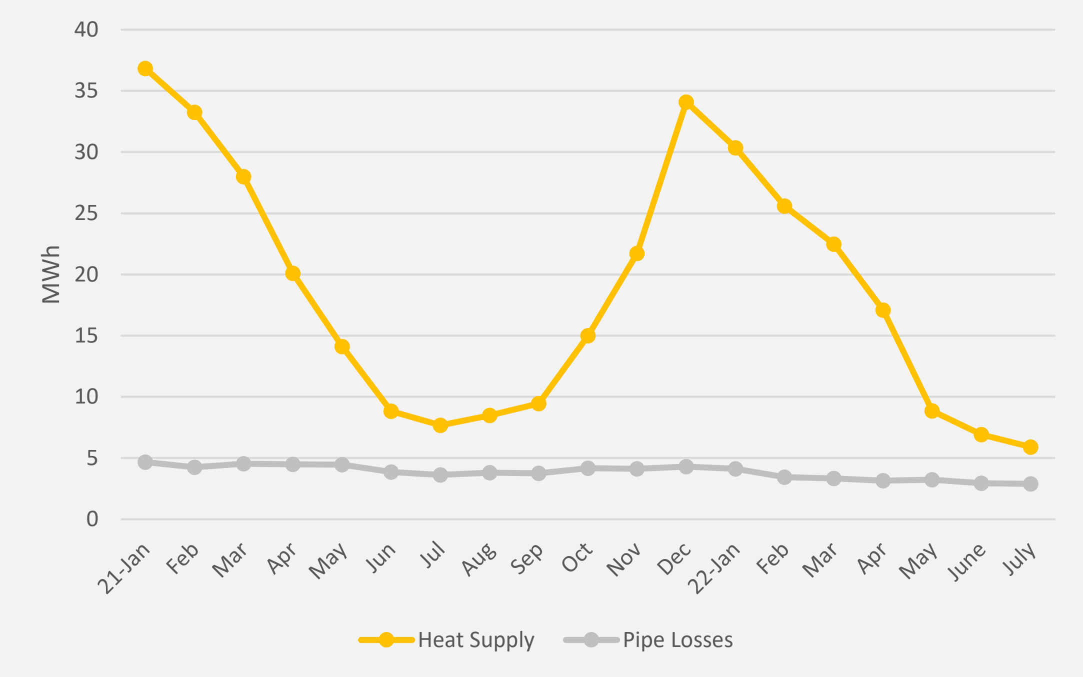

Figure 18. Heating profile at Xplorion

Figure 19 illustrates that Xplorion's heat supply profile roughly corresponds to the degree-days profile. This figure shows that when the weather is colder with more degree-days per month, more heat is required. The heat almost supplied for only DHW in summer with practically zero degree-days.

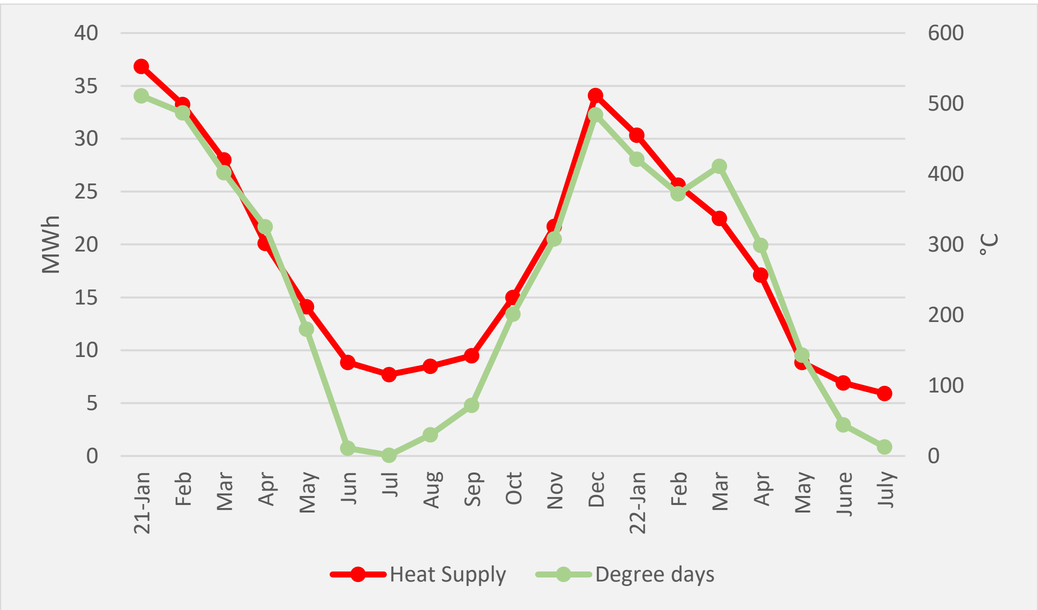

Figure 19. Heat supply and degree-days profile at Xplorion

3.2.2 Booster Heat Pump

A booster HP is installed in the substation of Xplorion to provide u-LTDH demo. The comparison of the performance of the HP in 2021 and 2022 can be seen in Table 5. The last column shows the potential of the HP if it would have worked full time during 2022.

Table 5. HP performance

KPI	Initial estimation per year	Sep-Oct 2021 (32 days)	March 2022 (10 days)	April 2022	May 2022	June 2022	July 2022	2022 (Until Aug.)	Potential 2022
$Q_{hp,out}$ (kWh)	89,000	10,720	6,390	17,250	8,910	6,960	6,000	45,510	187,000
Electricity consumption (kWh)	19,700	3,833	628	1,966	1,222	1,020	940	5,776	24,000
T_{ret} of flats (°C)	-	55	37	39	41	43	44	41	-
Increased temperature (°C)	-	40 to 59	48 to 58	49 to 59	49 to 59	50 to 59	51 to 60	50 to 59	-
COP	4.1	2.8	10.2	8.8	7.3	6.8	6.4	7.6	6~10
COP_{PE}	2	1.3	4.9	4.2	3.5	3.2	3.0	3,6	3~5

As it can be seen in Figure 20, the HP performance is decreased by increasing return temperature of the flats. This makes it extra important to maintain a good cooling in the installations in the flats.

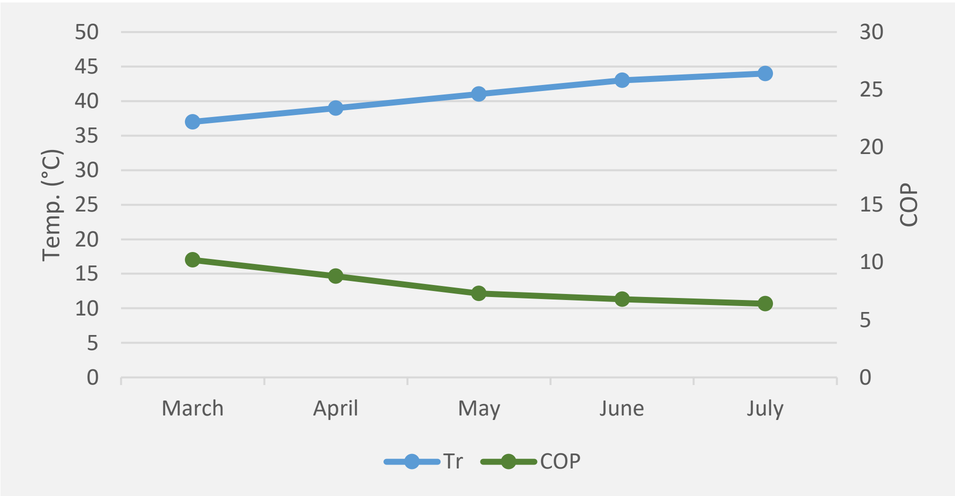

Figure 20. HP performance vs. return temperature from the flats in 2021

3.2.3 DHW sensor adjustment

The DWH sensors in the flats were adjusted during the project, since the badly adjusted sensors gave rise to high return temperatures, as previously mentioned. In the first phase, HUIs in 18 flats were checked and adjusted. As can be seen in Figure 21, the return temperatures were reduced after this adjustment. For example, as shown by the red arrow in flat number 11, the return temperature decreased from 58°C in the top right of the figure (orange point), to 22°C in the middle bottom of the figure (blue point). The same thing happened for the other 17 flats. As can be seen, the return temperatures in the flats decreased, especially in the flats with the highest return temperatures.

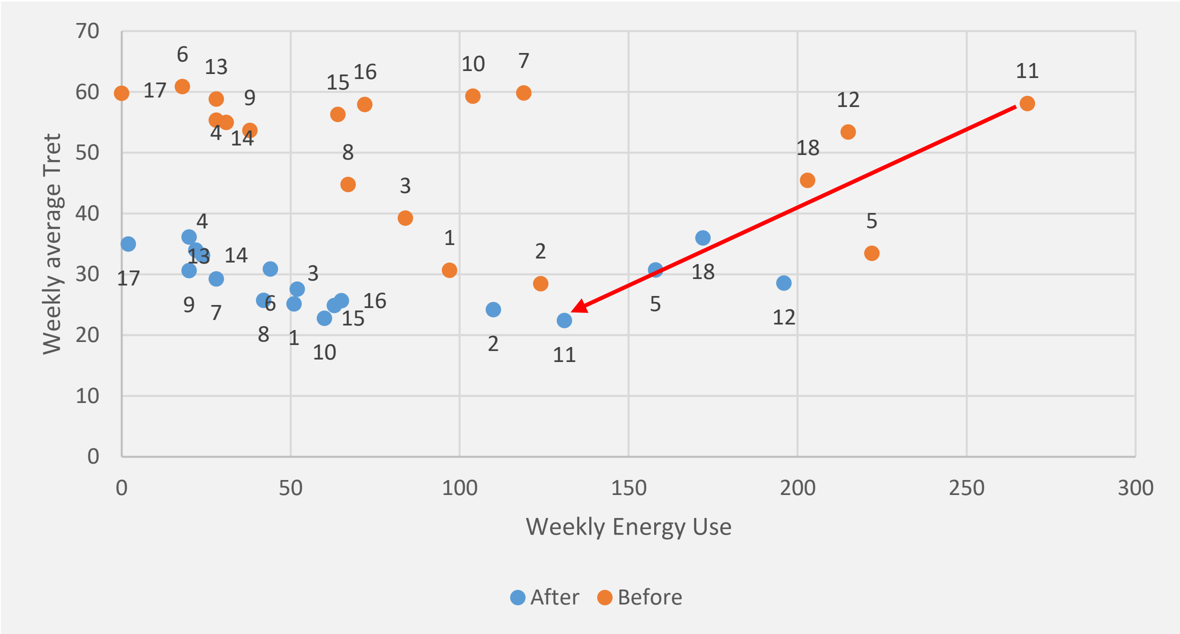

Figure 21. Return temperature and energy usage in 18 flats before and after sensor adjustment

In a general manner, the lowest return temperature occurs in a certain heat usage as can be seen in the hypothetical red line in Figure 22. For example, the minimum return temperature would be around 22°C if heat use is about 130 kWh per month in a flat of Xplorion. The return temperature increases by using less or more heat in the flat as the red line shows there is an optimum.

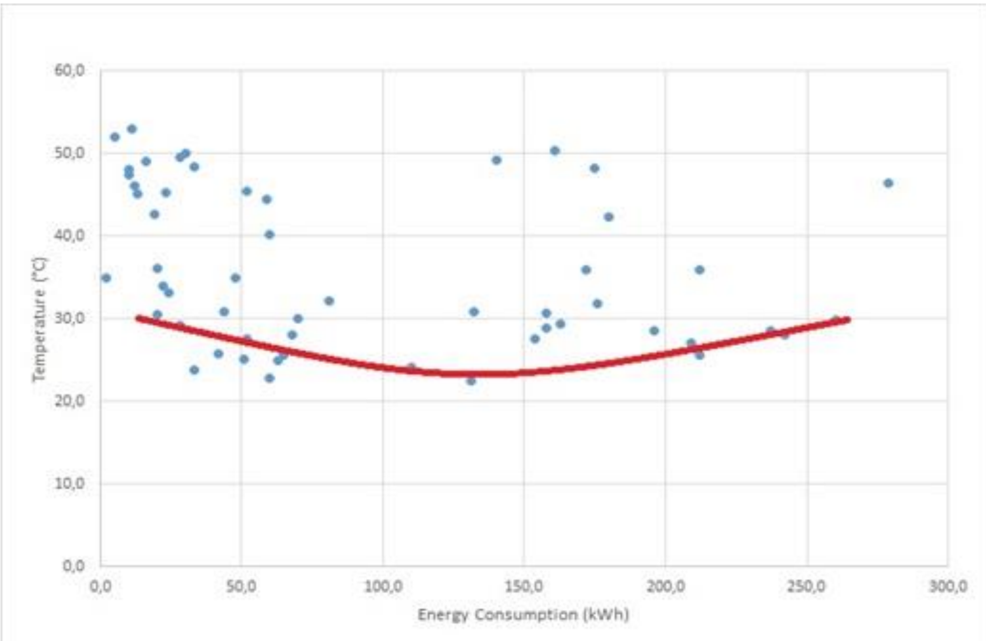

Figure 22. Lowest possible return temperature: return temperature vs. heat use

3.3 Environmental impacts

3.3.1 CO_2

As described in Section 2.2.1 and considering Tables 2 and 5, the reduction in CO_2 emissions from March to July 2022 can be calculated as below:

$$[(0.628 \cdot 42.9) + (1.966 \cdot 40.0) + (1.222 \cdot 41.8) + (1.020 \cdot 39.1) + (0.940 \cdot 42.9)] - (45.510 \cdot 10.0)$$
$$= \mathbf{-218\ kg\ CO_2\ equivalents}$$

For whole of 2022, a reduction in CO_2 emissions is estimated to be more than 1 ton. On the other hand, since Kraftringen has a green certificate for renewable electricity production, a higher reduction in CO_2 emissions of 455 kg can be claimed.

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:

$$(45.510 \cdot 202) - (45.510 \cdot 10.0) = +8{,}738\ \text{kg}$$

It shows that if natural gas was used to produce the heating in Xplorion, it would give rise to 8.7 tons of CO_2 emissions (the carbon dioxide coefficient is 202 kg/MWh for natural gas [7]).

3.3.2 Primary energy savings

As described in Section 2.2.2 and considering Table 5, savings in primary energy in Xplorion from March to July 2022 by using the booster HP can be calculated as below:

$$\text{PES} = \text{Q}_{\text{HP}} - (2.1 \cdot \text{P}_{\text{el}}) = 45.510 - (2.1 \cdot 5.776) = \mathbf{33.380\ MWh}$$

For the whole of 2022, 137 MWh is estimated to be saved in PE consumption.

3.4 Economic analyses

Main economic parameters of implementation of Low and ultra-Low Temperature DH system in Xplorion are shown in Table 6:

Table 6. Xplorion costs

Capital	Cost (€)	Remark
HIUs	60,000	56 Heat Interface Units in the flats
Baseline Scenario	93,733	LTDH sys. without HP including HIUs, Piping and smart metering
Booster HP Scenario	142,961	u-LTDH system by Adding booster HP
Increased Investment	**49,228**	Cost of adding booster HP
Total Demo	547,170	All spent costs in Xplorion

The price model for district heating in the low temperature district heating grid is shown below (although the Xplorion building is outside the general low temperature district heating grid, they are charged as if they were in it):

- Cost of district heating at 65/35°C: 550 SEK -> 51.87 €/MWh
- Cost of district heating at 45/25°C: 500 SEK -> 47.16 €/MWh
- Cost of electricity from grid: 77 €/MWh
- Cost of electricity feed-in to grid: 51 €/MWh

It should be mentioned that there is not enough data to evaluate annual savings and payback time by using the booster HP to provide u-LTDH system since the booster HP was not in operation in a full year period and its operation had some fluctuations. However, an estimation of payback time can be calculated according to estimated data of 2022 in Table 5 and abovementioned price model:

Cost in case of connection to LTDH system:

$$187 \cdot 51.87 = € \, 9{,}700$$

Cost in case of connection to u-LTDH system:

$$[163 \cdot 47.16] + [24 \cdot (77 - 51)] = € \, 8{,}311$$

$$\mathrm{PB} = \frac{49{,}228}{9{,}700 - 8{,}311} = 35 \text{ years}$$

It should be mentioned that this result is uncertain since the HP only had a stable operation during the last period of the monitoring phase.

3.5 Survey study with tenants in Xplorion

A survey study was made to investigate the tenant's experiences of their heating system and what they thought of the individual metering and billing of the heat and domestic hot water use. A questionnaire was sent out in November 2021. The outreach to the tenants was done by e-mail through the real estate company LKF' active email addresses that were included into the company's customer system (56 addresses). The questionnaire was made in Google Forms, with structured questions, but with possibilities to comment on the questions in free text comments as well. The rate of answers landed on 52%.

By the time the survey was sent out, most of the tenants had lived in the building since the building was ready for move in in November 2020, which makes about a year. This means that the tenants have experienced only one heating season (and one summer season).

The survey and the answers from the respondents were written in Swedish, so a translation to English has been made of questions and answers in this report.

The study of user satisfaction in Xplorion was made in collaboration with engineering students in the project course at the Department of Energy Sciences at Lund university [8].

3.5.1 Reactions to Xplorion and the neighbourhood

The first question in the survey was about the reasons that the tenants had chosen to move to the Xplorion building. The question was raised as an open question were the respondents answered in free text answers. A compilation of the most frequently given reasons is shown in Figure 23.

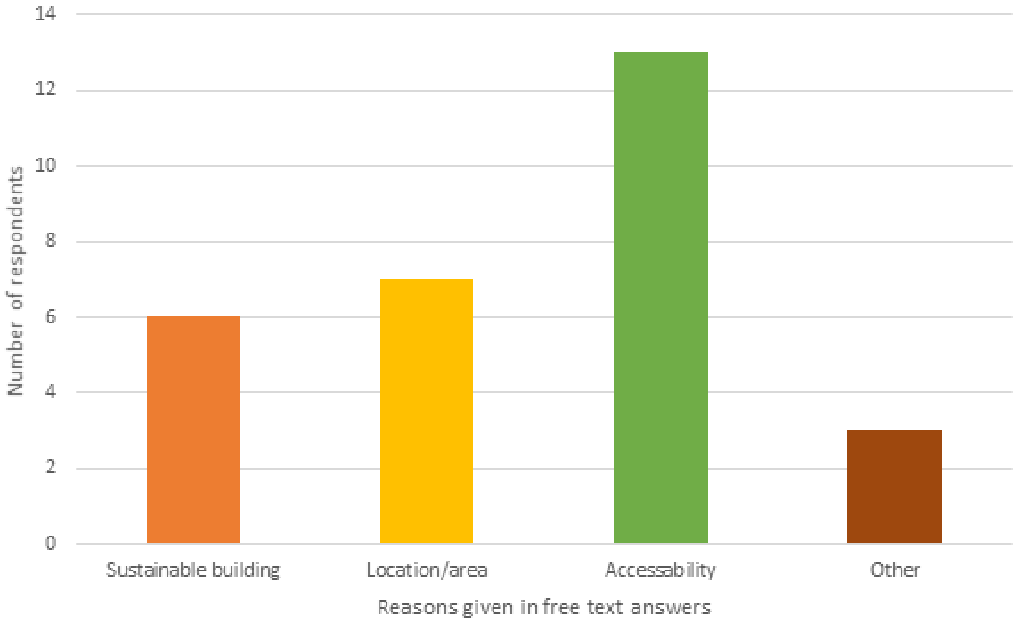

Figure 23. The reasons stated by the tenants in Xplorion of why they choose to move there.

The reason that most of the respondent's state, for moving to Xplorion specifically, was that flats in this multifamily building were available, meaning a shorter queue time in the municipal housing queue. Other respondents stated that it was because they were interested in living in the new city area of Brunnshög, while about a fifth of the respondents said that they choose Xplorion because it was marketed as a sustainable and smart building. The bar called 'Other' in the diagram contains answers about security and services.

With that first question as a background, the next question raised to the tenants was if the accommodation has met their expectations. The question was asked as an open question, but the overall attitudes can be summarized in the pie chart in Figure 24 in terms of meeting the expectations or not.

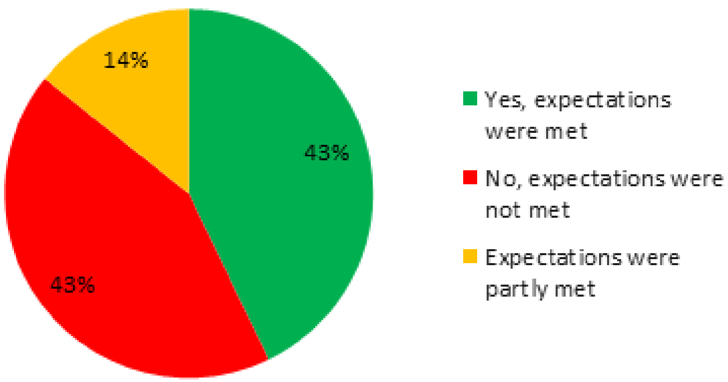

Figure 24. Tenants answer to the question if the accommodation has met their expectation.

The free text answers of the respondents are reported down below:

YES – Expectations were met

- "I think the accommodation is as I expected it to be. I live in a studio flat and have not had any problems with my flat. "
- "Yes. The rent, location and bike garage are good."
- "Yes, I would say so. Especially the focus on sustainable mobility "
- "Pretty much, yes."
- "Yes, as good as the description."
- "Yes, it is. No big difference from other accommodations, more than that we have access to a car and bike pool - it's great! "
- "Noisy but with the potential for many pleasant years."
- "Yes, high comfort, good flat and an area that feels innovative."

PARTLY – Expectations were partly met

- "Having lived here for almost a year, we are satisfied with some and dissatisfied with some. I suspect you are most curious about what we are unhappy with. The criticism mainly concerns (1) has been too hot in summer and too cold in winter, (2) the laundry room is unwieldy to use, both the physical room (crowded) and the booking system (very non-intuitive) which has led to conflicts, (3) the lack of doors inside the flat turned out not to be a good idea, (4) that we "live in a car-free area" feels more and more like a promotion thing that was said to avoid having to accommodate the need for parking spaces, (5) many tenants, including us, have had and have problems with the front door not holding tight, which is a problem as there is no "barrier" between outside and inside.'
- "Both, the environmental profile is correct but the floor plan in the flat is poor. Placement of the front door facing the outdoor environment without delimiters is bad. It's a little disgusting with the toilet so close to the fridge too. Otherwise, lovely, good air, high ceilings, non-smoking and good storage of bicycles but bad that there is no storage for the things one has that are not suitable to store inside the flat."
- "Well, as I said, we like the area, but the fact that the flat does not have doors makes everyday life difficult" (Comment: The flats have an open floor plan; room divisions must be made by the tenants themselves.)
- "The laundry room and car were not expected but I expected a little more comfort in the flat: a heated bathroom, a full shower, door separating the bedroom from the living room."
- "No, maybe partially. A lot of things that have been wrong that are not fixed or that it takes a long time before it is fixed. Some matters we have informed LKF about several times and by several different people but still nothing is done."
- "Yes mostly. Had wished more common areas. And… is tired of the eternal construction work in the area!"

NO – Expectations were not met

- "No. Marketed in a misleading way"
- "Much worse than expected"
- "No not really, there have been many errors and there are really thin walls so you can hear everything."

- "When I moved into a newly built flat, I figured everything would work smoothly because it was brand new. But there have been some troubles and things that have needed to be fixed over time. Some things work poorly but still haven't been fixed because it's being bounced between LKF and contracting."
- "Not really, various environmental initiatives were marketed heavily, but it feels like these were mostly a way to make it sound good. You don't notice them in everyday life. Then the start-up has not gone smoothly. Small things that have not worked like EC2B and thermometer and hot water. "
- "No, the quality is beneath contempt. The flat is freezing cold when it's cold outside and like a sauna when it's hot outside. The heating cost per square meter is three times higher than in a villa built in the 60s."
- "No, it's less well thought out and nice than I thought and many of the solutions to save money are really irritating. Has no walls, has a lot of air draft so the rooms feel colder than what the meter says. The electrical cabinet is located on one of two walls, so we cannot put up cabinets or shelves there. The bathroom is cold, and the shower cabinet has only one wall. The laundry room is small and there is no drying space outside. Really lacks common areas in an accommodation that has the slogan "sharing is caring"."
- "So-so. Expected higher quality and standard of accommodation. Unfortunately, environmental thinking fails a little when the appliances need to be repaired time and time again despite minimal wear and tear and that we do not have the opportunity to sort waste to the extent that we want. Even the general arrangement with the laundry room with limited times and smaller washing machines leads to us having to wash more often and thus use more energy and water than we might have done in another accommodation."
- "No, negative:
    - The climate-smart solutions that were marketed turned out not to be quite what we expected. Some solutions are artificial and sound better on paper, than in reality. It is cold in the flat in winter and hot in summer. The heat and water bills were much higher than what was written of the LKF website. And when complaints were made to LKF, the "solution" was to adjust the taps so that it was no longer possible to open the taps to the maximum position, which limits our use of water, but not in a "smart" way, but rather forced. We stay in the flat with knitted sweaters and pants and blankets so as not to freeze.
    - The floor plan was marketed as smart and flexible. But the open design is most annoying when you have guests over.
    - Bicycle and carpools are appreciated. But LKF is not keen on solving the problems that arise in connection to these, such as the charging post for the electric car, which at the time of writing has been out of order for two weeks. Since this is a car-free accommodation, I see it as a big problem.
    - I personally was very interested in a climate-smart accommodation and spent many years of queuing time at LKF for this flat. And I feel disappointed as I could have had a much better accommodation with the queue time if I wouldn't have been fooled by LKF's marketing of Xplorion. The property has won many awards where it seems that they have been awarded rather for the marketing than for the actual execution. For a long time, us tenants had problems with the front door as a thermal bridge, which brings us to the next point:

- The architecture is ill-conceived: The lack of a heated/insulated stairwell means that higher demands are placed on the front door, or that a hall space should have been designed to serve as a buffer zone for the cold air. Many of the loft aisles "leak" in when it rains, causing tenants to get wet as soon as they walk out of their flat. The parking space for the pool car is (insert of confusednick.gif), as it partly blocks a staircase and partly is difficult to park due to cramped and inclined space.
- The accommodation portal is not as developed as promised.
- The laundry room is designed to create conflicts as you can only book a washer and dryer but not the drying cabinet.

- Positive
  - LKF was responsive to problems regarding heating and hot water costs
  - The flat has proper, soundproofing walls"

So, to summarize the comments from the tenants; perceptions differ from one household to another. The residents emphasize the availability of a car and bicycle pool as attractive. The tenants seem to have problems with the open floor plan and, most important to the COOL DH project – many tenants are complaining about low thermal comfort in the building, where they say that it gets too cold in winter and too hot in summer.

The next question was about the tenants self-perceived knowledge about what 'low temperature district heating is". This is interesting both because LKF had informed about low temperature district heating grid and heating system on the information meeting they had with the tenants at move in, and because the tenants live in a neighbourhood with low temperature district heating. The question was based on self-assessment and hence the question does not measure what knowledge the residents have. Figure 25 shows the tenants answers to the assertion: I have knowledge about what a low temperature district heating system is.

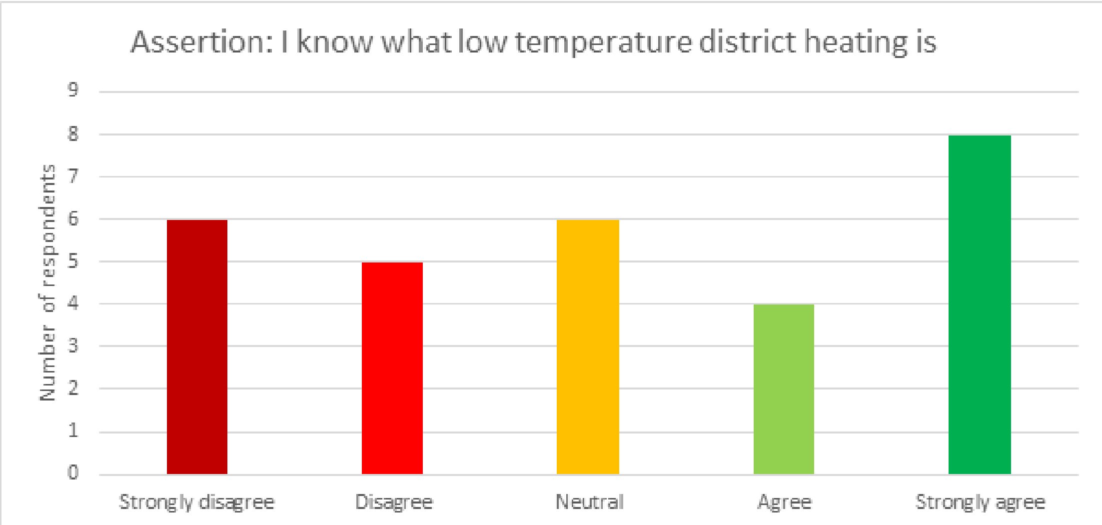

Figure 25. Xplorion households' self-assessment of their knowledge about low temperature district heating.

As can be seen in the diagram, the answers are very scattered, distributed on the whole scale from strongly disagreeing to strongly agreeing. Most of the tenants has stated that they visited the information day that LFK offered (24 of the 29 respondents).

3.5.2 Internal heating systems and thermal comfort

In the flats, the tenants can adjust their indoor temperature in two ways, by setting a temperature centrally on a display that is located near till front door or by regulating the thermostats directly on the radiators. For these installations, see Figure 26.

Figure 26. The picture to the left shows the display (Honeywell 237) that is put up in the flats. The picture to the right shows a thermostat on one of the radiators in a flat in Xplorion.

The tenants were asked if they were satisfied with the thermal comfort in their flat, only 4 out of 29 answered that they were satisfied. All but one of the respondents added a free text comment about the thermal comfort. As in the question above, quite a few commented that the flats were too cold in the heating season, and many thinks it was too hot in summer. Here are the comments:

- “You need to change the entire system for it to be good!”
- “The heat is not working.”
- “No heat in the flat.”
- “It is often cold, especially in the evening.”
- “It often feels cold.”
- “Very unstable.”
- “It is incredibly hot in the summer and very cold in the winter, would have appreciated a more even temperature all year round.”
- “It is very warm and nice when the heating system does not have to run; it is demonstrably well insulated in the flat. But in the winter when I need heat in the radiators, they refuse to provide the needed heat because the sensors on the sunny side think it's warm enough.”
- “In autumn it is difficult to adjust the temperature, the radiators are not running when it is cold outside”.
- “It's cold and I must wear several layers during the day. Our dog is also cold and must wear clothes indoors. Since we don't have a window where sunlight comes in, it's not even that hot during the summer.”
- “It gets cold in the bathroom in winter. In the summer you must air out.”
- “The system should distribute the heat evenly on both levels of the flat. Some rooms are colder, and some rooms are warmer.”

- “The air maintains a temperature, but when the concrete under the floor is cold, it feels colder than it is. Would need some distance between the concrete and the wooden floor.”
- “Gets very cold during the winter months. Is on the lower end of LKF's recommendation. Residents have bought extra electrical radiators which is not sustainable or environmentally friendly.”
- “I have bought a heater and a door for the shower!”
- “I have reported a leaky front door a couple of times. Still not good, but it will be a while until it gets colder before I can do it again.”

Some tenants state that they cannot get the preferred indoor temperature that they set on the display:

- “The control system is unclear, no one understands how the display works and it shows the wrong temperature. We are several tenants who have reported that we have bought external thermometers and placed them in various places in the flat. They show differently than the display on the wall, a consistent difference of 1-2°C. That is, when LKF has set the limits at 19-23°C, in practice it will be 17-21°C in the winter. It's getting cold.”
- “I had wished that what temperature level you set the thermostat to, was the temperature you´d get in the flat and not two degrees below.”
- “The flat is leaking in cold air. The bathroom is like a cold store. And we measure temperature with other thermometers than the one on the wall, they all indicate a lower temperature.”
- “During autumn/winter the flat gets too cold, one gets the feeling that the temperature gauge on the display is not quite correct, hence we adjust upwards to maintain the desired temperature. The radiators are not entirely easy to make friends with and they rarely start - think this may be a combination of low understanding of how the heating system works which makes it difficult. During spring/summer, we think everything has worked without problems.”

A few answers raise the problem that their flat becomes very hot in the summertime.

- “Extremely variable temperature during the summer months.”
- “Extremely hot during the summer, the display was set to 18°C, but it was a constant 27-28°C in the flat, unbearable! Didn't get any help when I reported the errors either.”

And one answer was about it being too hot all around the year.

- “It has been too hot. Even today it is 22°C even though I have a window open.”

Further, questions were asked regarding what information the tenants had received about the heating system in the flat, first through what sources the residents had received the information. This was followed up with a question about whether they were satisfied with the information they had got or if something in the information was missing. As a result, most of the information that the residents stated to have taken part of was via LKF's website and published brochures via email, or during the information day that LKF invited to which was visited by 24 of the 29 respondents. Figure 27 shows the respondents satisfaction with the information.

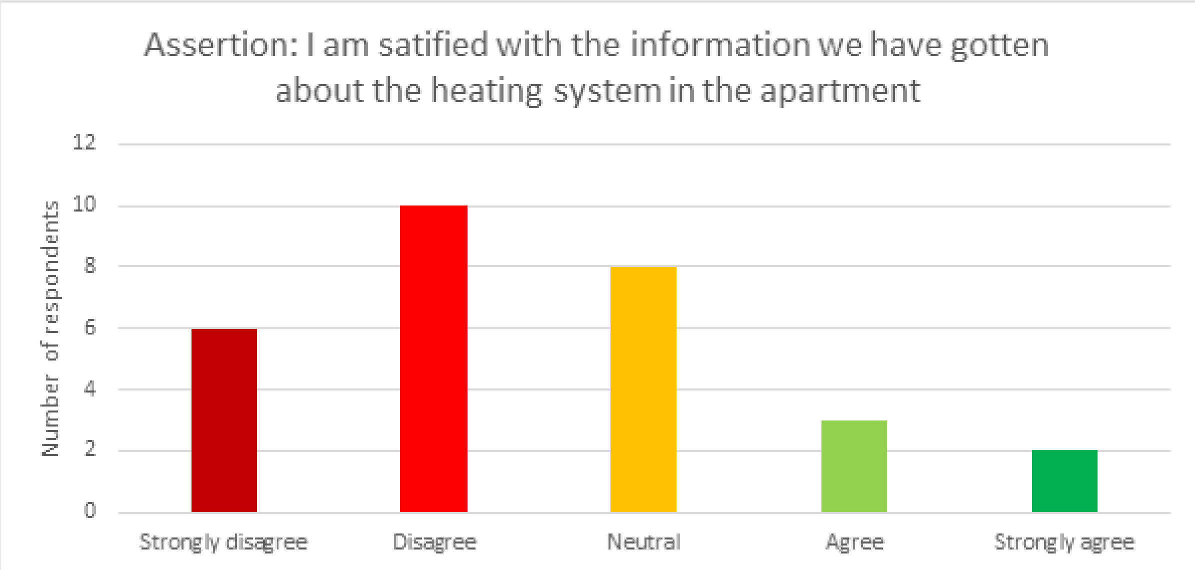

Figure 27. Xplorion households 'satisfaction about information about heating system.

The result show that the there is a large spread, although there are more tenants that are dissatisfied than satisfied. Down below, the free text answers about what information the tenants feel is lacking, are reported:

- "How to regulate the heat yourself"
- "I don't know how the system works"
- "Yes, how to set it up manually so that it actually works the way you want without being scientists.'
- "Why it doesn't work."
- "How to increase the temperature?"
- "I would have liked to have had a one-pager, with the most important information. Preferably in simple words."
- "I feel like I still don't know how the whole system works."
- "Why the sensors for the thermostat are 20 cm apart and not in different rooms so you can get heat in the cold room even though the sun is on the other side."
- "Information on how to manually change the heating."
- "How the thermostat works, where the heat comes from (electricity, district heating, other)."
- "Perhaps how much of the month's consumption was what: what was solar energy, what was residual heat from MAX IV, etc., this would have been good :) and informative so that you know what natural resources you are using."
- "We want to be able to follow our consumption, for example in the accommodation portal or similar. We can't do that now; we never know what we'll consume and how much it might cost before the bill for the rent arrives. Oh, one concrete thing: none of the neighbours we've talked to understand how the thermostat works. Had been kind of... good."
- "None of us were told that there was no cooling of the flat, so all summer we sat with 28-29 degrees in the flat which was unbearable. However, nothing was done about it."
- "Why it doesn't work."
- "Yes, why does the flat feel cold even though it is heated? Very draftee at home. Why did moisture appear in windows on the inside? How do you measure draughtiness?"
- "A manual for the thermostat. Data-generating statistics on heat consumption so that you get perspective over time."

- "Details about how it works, as well as specification of tips and tricks if you want to adjust the temperature in the flat and also how to get an understanding of how the system works locally (in the flat) and in a larger perspective."
- "There was no information day? Instead, we had presentation slides sent by email. At the 'information day´ we got some information but not so systematically. We (and other neighbours) didn't know how to use the temperature controls at all and had to figure it out on our own. What happens inside the technology cabinet?"
- "A proper thermostat."

To summarize the free text answers, it can be concluded that many households would like to have information about how the heating system works in the flat (written in a simple way), and they want to know how to set and get the temperature in their flat that they desire. They also want answers to why the heating comfort has been bad. A few of the tenants would like to have frequent information on the consumption of heat and hot water, and they want to know how the heat is produced.

To get more knowledge about the tenants' experiences of thermal comfort, the tenants were asked what indoor temperature they prefer to have in their flats, and what temperature level they generally have set the display on. The answers are showed in Figure 28.

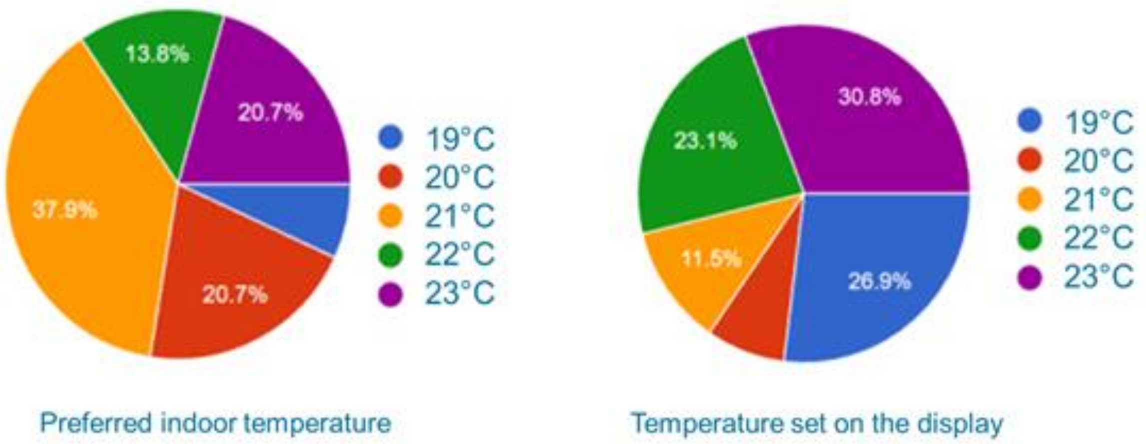

Figure 28. Preferred indoor temperature and temperature set on the display.

As can be seen in Figure 29, there is a divergence between preferred indoor temperature level and the temperature levels set on the display. The level on the display seems to be set higher than the preferred indoor temperature level and lower in some cases. This may be explained by the problem described earlier – that the tenants cannot get the temperature that they want to have by setting the required temperature level on the display. In winter it doesn't get warm enough, and in summer the temperature set on the display doesn't make any sense because the space heating is turned off and there is no cooling system installed.

Domestic hot water comfort

When it comes to domestic hot water comfort, 80% of the respondents said that they were satisfied with this. Nevertheless, many respondents chose to comment on the domestic hot water comfort. Some of the tenants' comment that the domestic hot water system works greatly:

- “It works great, thanks!”
- “Never had a problem with the hot water, but sometimes it sounds a little choked and the pipes hiss a little.”
- “The domestic hot water is working well”.
- “We get very hot water and always quickly.”
- “Raised in a villa so anything under 30 seconds is a luxury.”

The main problems that the tenants bring up seems to be low water pressure and that it takes a while to get hot water to the tap. Others comment that they had had some problems in the beginning, but that the problems were temporary:

- “There have been a few days here and there where is having been no hot water whatsoever. The water pressure in the shower declines the hotter the water is.”
- “Water (shower) has sometimes (very rarely, in the beginning when we moved in) not been hot enough.”
- “It was not good in the beginning as the water was cold. It has been adjusted at the expense of water pressure.”
- “It has happened that there is no hot water for several hours.”
- “Extreme pressure drop, sometimes there is a lack of hot water.”
- “I am most disappointed that LKF went in and "fixed" the water a few months after I moved in and then lowered the water pressure. Now it takes much longer to fill a watering can with cold water.”
- “You notice that the water struggles to reach the right temperature when the shower is on at the same time, someone flushes the toilet or similar. The water pressure is then significantly reduced. But it's not that serious, you can live with it.”

Some tenants state that it takes long time to get hot water:

- “I get hot water slower in my taps than in other homes I've lived in.”
- “It takes a long time to get hot water in the tap.”
- “Difficult to wash hands in hot when it takes a minute for hot water to run.”
- “Hardly possible to get hot water, you must let it run for a long time. It's not exactly environmentally friendly.”

One tenant comment that there is a shortage of hot water after a while:

- “The hot water usually runs out.” (This sounds a bit odd since the hot water is prepared instantly in the heat exchanger in the customer substation).

A few comments were also made about the cost and the feedback for domestic hot water use:

- “It is not possible to separate the cost of the hot water from the heating of the flat during months when both are used at the same time. The landlord should provide the tenants with information on how much hot water costs at least per day. It should be possible to set the flow in the faucet with smarter faucets. The showers should be equipped with low-flush shower heads.”
- “The comfort cost a couple of thousand.”

Individual metering and charging (IMC)

The HUIs in Xplorion enables individual metering and charging of costs for space heating and domestic hot water, since there is an energy meter in each flat station that measures supply and return temperatures and mass flow. The heat exchanger in the station boosts the temperature coming from the central system to provide domestic hot water. There is no way to separate the energy use (and thereby energy costs) from space heating and domestic hot water, since only the total energy consumption is measured.

It should be emphasized that LKF anticipated low energy use in the building for space heating, since the house is built according to passive house standard. Therefore, they wrote on the homepage to the tenants that the energy use for space heating would be very low and so would the costs for this as well; they also gave an estimate approximately what the heating cost should be. LKF and the tenants realized in the winter period of 2020 that the energy use for space heating was not so very small, which led to discussions with the tenants about the higher costs for heating. In some flats the cost for heat was as much as three times higher than anticipated. This led to actions from LKF, and for a while LKF did not charge the tenants based on the metering but used a template instead. The IMC has been reinforced after the problems with the heating system had been attended to. This “incident” could of course affect the tenant’s attitudes to individual metering and charging. But despite this most tenants answered that they were in favour of IMC, as can be seen in Figure 29.

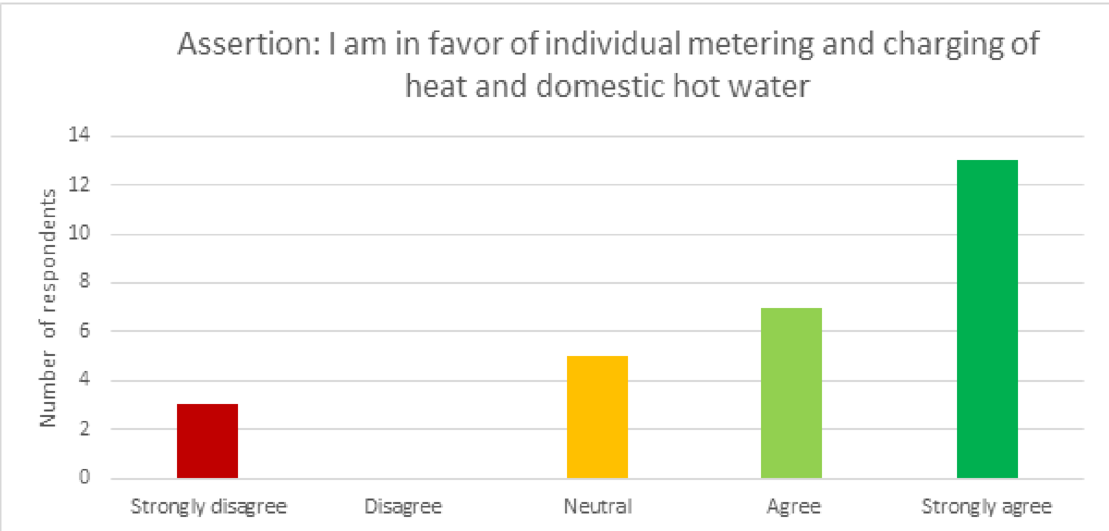

Figure 29. Responses about the attitudes towards IMC.

Over 70 % of the respondents stated that they were positive to individual metering and charging of heat and domestic hot water. A few where neutral and only three of the respondents were against it. Those households that were negative to IMC gave reasons related to high or unevenly spread costs:

- “It costs an indefensible amount. 1500 kWh in heating in a month for a 50 m^2 where the thermostat is set to 19^{o}C, and I live alone (short showers).”
- “It is a very expensive accommodation already. I think you could lower the rent if you ended up below the forecast to encourage lower electricity and heat consumption.”
- “For the first 7 months it didn't work. Will be very different costs in winter/summer. Can differ up to SEK 1000.”

Those who were positive about IMC highlighted advantages such as fair distribution of costs among the tenants, the possibility of being able to influence your own costs and that you get incentives to save energy and money, which is good for the environment and the household finances. But there were also some objections, such as the fact that IMC can create anxiety when you don't know how large your monthly cost will be, and that - if you must pay individually for your heat - you should also be able to get the indoor temperature that you want. See free text answers below:

- “Of course, you should be able to influence and pay yourself for what you consume.”
- “People must pay for the desired temperature”.
- “Very good. Reduces consumption both for our family and other families as the cost ends up on the individual.”
- “Great that you have it.”
- “The idea is great! Then you can follow your consumption and change your behaviour if you feel that the cost is running away.”
- “If LKF had ensured that the door was leaking cold air, I would have chosen the alternative “Agree strongly” instead of “Agree”.
- “If I use less, I want to be able to pay less… and I fully understand the reverse.”
- “Works well, I who don't use much can profit from it.”
- “This means that you think ahead and save on hot water.”
- “I like being able to influence my expenses myself.”
- “Notices one's own environmental impact.”
- “Then there is motivation to consume less, and you can also save costs if you so wish.”
- “No problem for us individually to have a variable cost for heating/electricity. Also good in a larger perspective if it can make residents more aware of their heat/energy/water consumption. However, some risk of negative consequences and dissatisfaction during cold winters?”
- “It's good because it motivates lower consumption of heat and electricity, but it's stressful at the same time because I get stressed by expenses, which makes washing up, cooking, and other things difficult because I think about the electricity and heating costs. Sometimes it feels hard to have turned on the lights in the room I'm sitting in.”
- “It is good if it gives a slightly cheaper rent compared to a rent where it is included. It is also good that you get an overview of the rent. However, it can be difficult as it may be extra expensive if it is cold or if you have many in the family and have a large flat.”
- “It will be my choice. However, I would like clearer statistics for cost and energy consumption so that I could make a more informed choice. As it is now, I just get it in month by month.”
- “Good idea in theory but works poorly when the flat lacks insulation and it leaks in cold from outside, which it does in my flat. Paying a sky-high heating bill but the flat does not get warm.”
- “That's really good. It's just a shame that the heating costs land at around SEK 1,600 per month during the winter when the indoor temperature is between 20-21^{o}C. The radiators in the "bedroom" are cold.”
- “It would have been more reasonable if you were allowed to control your consumption yourself. If LKF is going to limit what you can use, they can cover the cost as well.”

A question was also raised whether the tenants thought that the fact that they must pay for what they use affected their energy behaviour in some way. The results can be seen in Figure 30.

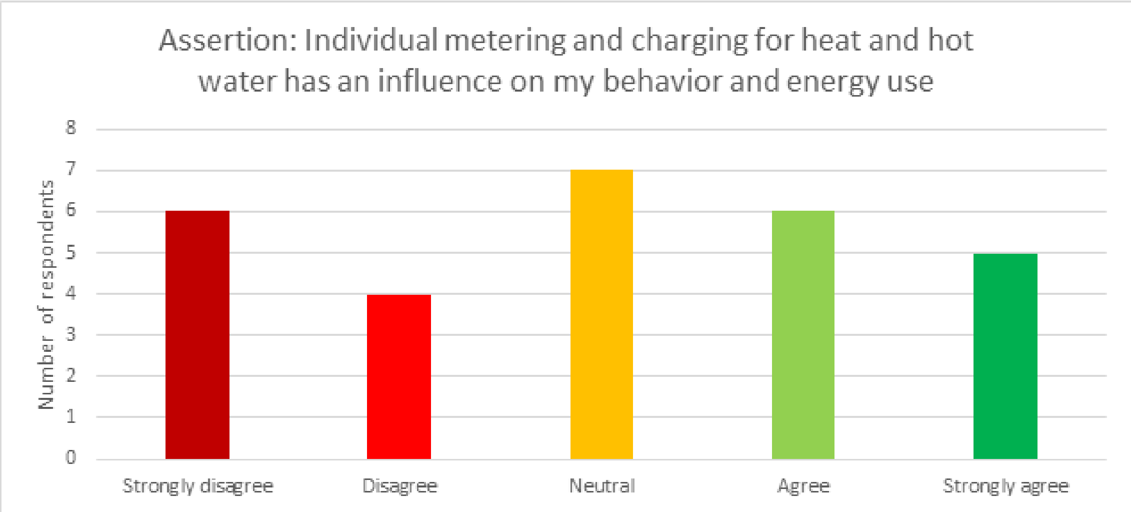

Figure 30: Xplorion households' views on whether IMC affects their behaviour or not.

As can be seen in Figure 30, also in this question the answers from the tenants were very divided. Some tenants say that IMC doesn't affect their behaviour at all, while other say it does.

The tenants that said that IMC affects their behaviour were asked in what ways, and according to the answers, the tenants are trying to reduce their use of hot water by being aware of the usage and take shorter showers, and some tenants said that they are keeping the indoor temperature down:

- "We use less hot water and kept the temperature around 20°C the first winter"
- "Shorter showers, keeping lower indoor temperature settings on the display".
- "I think I have reduced my shower time."
- "Do not use hot water unless absolutely necessary."
- "We try not to shower for too long or run unnecessary dishwashers."
- "Regulates the temperature."
- "Where we lived before (where there was no individual metering) we had radiators running at maximum usually during winter. Here we try to keep track of the temperature. I have started using the dishwasher to consume less hot water. And I remind the kids (and myself) not to let the water run when we wash."
- "If I hadn't had to work from home during the pandemic, I might have set the thermostat to a schedule with a lower temperature during the day on weekdays."
- "We try to use less, but you need it, so you can't reduce as much as you like."
- "Follows LKF's recommendations to keep costs down as much as possible."
- "We usually keep it a bit cold indoors and we dress warmly instead."

Some tenants answered that they don't do anything, because they don't get good feedback on their energy use:

- Nah, since it's not possible to see anything other than sum on the invoice, I don't look at it at all. Have an eye on the thermostat, but just looking to see if it heats up.
- "Again, the system is a great idea. But what does it matter that you are billed individually if the individuals cannot monitor their own consumption on an ongoing basis? Limited practical use."

- “If you don't follow "real-time" consumption, you don't have insight into what affects it. Does it cost more to wash in the washing machine during the day or at night? How much does each degree cost in heat?”

Some tenants stated that the use of energy is out of their control, because the flat is too cold anyway or that the costs are too high anyway:

- “The flat is cold. It leaks cold air from windows and doors. I have no way of influencing it”.
- “I want more heat in the winter than the system allows me, so I set it on the highest temperature level then.”
- “I have no way to influence the indoor temperature because the flat has inadequate insulation and heating system.”
- “It doesn't matter what I do because it costs extremely much anyway.”
- “We thought it mattered but the cost still landed at 1600 per month so it felt pointless to live frugally. I'd rather pay 1800 a month if it gets 2 degrees warmer in the flat...”

3.5.3 Conclusions from the survey study

According to the tenants, it seems that the thermal comfort has not been satisfying in the flats. Many of the respondents complained that it was too cold last winter and that they couldn’t get the indoor temperature that they wanted and that they put on the display. As was shown in the technical evaluation of the heating system, there have been troubles with the radiator systems since they were not correctly adjusted. This has probably affected the thermal comfort to a great extent. Extensive work to address this problem has been done by LKF with the help of Kraftringen in the spring of 2022, as showed in chapter 3.2.3. It would therefore have been good to be able to do another follow-up of the residents' experiences of their thermal comfort during or after the heating season 2022/2023, to see if the residents experience improvements of the thermal comfort, or if there are still problems with getting the temperature they want. Unfortunately, this lies after the COOL DH project is terminated.

LKF has chosen to use displays where the tenants can adjust their indoor temperature in a range between 19-23°C. The survey result indicates that the control through the display has worked poorly. Many of the households have stated that the display shows one or two degrees Celsius too much, and that they cannot get the indoor temperature they want. From the free text answers, it could also be noted that some of the tenants believe that they should be able to regulate the indoor temperature also in summertime when the heating system is not on. Since there is no comfort cooling in the building, this is impossible – this indicates that more information to the tenants is needed about how the heating system works and how the heating in the flats can be regulated.

When it comes to domestic hot water comfort, most tenants have stated that they were satisfied with how it worked. In some flats, however, the tenants have said that it takes long time to get hot water, which is strange since the domestic hot water is produced instantly in the heat exchangers that are situated very close to the tap points. Also, water pressure has been perceived to be poor in some flats. Whether this is due to problems with adjustments or something else is hard to say. Xplorion is a new building and with that comes some initial problems to get the systems working as it should.

From a customer perspective it is gratifying to see that so many of the respondents are positive to individual metering and charging, which is automatically fulfilled by the fact that each flat has their own heating central and that LKF charges each household for their actual use. The tenants however lack possibility to follow their use through feedback with high-resolution data. Therefore, it is hard for the tenants to know how their behaviour reflects on the energy use and the costs for this.

3.6 Experiences from the housing company LKF and the district heating utility Kraftringen

Key persons from Kraftringen and LKF was interviewed to gather experiences from the installations in Xplorion and the tests.

For LKF and Kraftringen the heating installations at Xplorion has been a way to learn more about what could be required in a future with more low or ultra-low temperature systems. There have, however, been some challenges on the way with the installations at Xplorion. The building contractor subcontracted the design of the installations, which turned out to be oversized. The pipes were designed too large as well as the heat power demand, even though it was expected that the building should follow the German passive-house standard. This design would have resulted in too high installation and operational costs, due to high heat losses. A lot of time and effort was put into resizing the installations to a more reasonable and efficient size (as has been stated in the project deliverable 3.1).

The commissioning showed difficulties as the internal return temperature from the building was too high, possibly due to the thermostatic bypasses in the heat exchanger units in the flats. This was tracked by Cetetherm to optimize and enable the heat pump operation.

The installation operations of the HUI was easy thanks to the installation rack in the technical shafts.

Giving the tenants possibility to regulate their indoor temperature both on the thermostats of the radiators and on the control-display was not a good idea, which lead to over-temperatures. LKF has now removed thermostats on radiators located in the same room as the display. In flats with more than one room, the thermostats are left on the radiators to make it possible to withhold different temperatures in different rooms.

As the tenant’s state in the survey study, there has been a difference between the measured temperature in the flats and what temperature is put on the display. LFK has drawn attention to this. Most likely this problem has been fixed by making adjustment on the sensors and by removing the thermostats on some radiators.

LKF states that they measure domestic hot water use and space heating separately, but the tenants are only given a monthly sum of their total heat energy use on the rent bill. Some tenants express a wish to receive better feedback on their energy consumption to get a better overview. This is something that LKF reflects could be improved in the information to the tenants in the future. LKF has also realized that it has been difficult in terms of communication with the tenants that Xplorion has not been connected to the LTDH network, but only has had a test facility where low temp and ultra-low temp. are generated on site. Another lesson that has been learned is that it could have been better to inform the tenants about how the heating system works, not only in the flats but also the test facility with a heat pump to boost the hot water temperature. It would also have been good if the tenants were already made aware of the experimental setting and that they were expected to provide feedback about their experiences.

3.7 Conclusions

The Xplorion demo demonstrates several smart installations at the customer side that enables the use of low or ultra-low supply temperatures in the district heating system. Several benefits can be achieved by HUIs installed at every flat:

1. The domestic hot water is produced close to the user which means that the need for hot water circulation is removed, thus taking away heat losses for this on the customer side.
2. This also means that domestic hot water is produced instantly without storage or circulation, which diminish the risk for Legionella proliferation.
3. It gives the tenants possibility to adjust their indoor temperature themselves.
4. It means that the EU requirements on individual metering and charging can be met.
5. In the 3-pipe system without hot water circulation, there are two pipes less rather than in traditional 5-pipe systems, which reduces the installation costs.

However, with HUI's installed at every flat follows an increased cost compared to if a larger heat exchanger would have been used instead at the ground floor of the property. This limits the cost-effectiveness of the solution.

Individual metering and charging are, so far, not so widely used in Sweden, although EU directives are stating that this is mandatory. The Swedish government has decided that there will be a requirement for individual measurement and charging of heat and hot water in apartment buildings from mid-year 2021. However, the requirement only applies if other energy-saving measures are not implemented so that the energy use falls below the current limit value (In: Regulation on energy measurement in buildings (2014:348)).

For the tenants, the system means that there are some more installations to handle, which Swedish end-users are not so used to yet. There are pedagogical difficulties in explaining to the tenants that the possibility of setting the room temperature is only available during the heating season because the flats are not equipped with comfort cooling. It is also important to consider not to provide the possibility of double control of the heating system for the tenants, as was the case with the customer displays and the thermostats on each radiator in the apartments. This might lead to higher return temperatures in the system. Giving enough and necessary information to the residents is an important point to consider so that they will understand how their heating system is working.

The requirement for low return temperatures in a low temperature system places great demands on the property's installations to be well balanced and adjusted, something that turned out to be a major problem to solve in Xplorion. Improper adjustment of the HIUs and specifically sensors in the flats caused high return temperatures which affected the performance of the heat pump as well as added to the heat losses. Therefore, diagnosis and inspection of radiators, valves, sensors etc. must be performed in order to obtain an efficient heating system before and under operation.

The annual specific heat demand of the flats has been reduced from 66 kWh/m^2 in 2021 to estimated 52 kWh/m^2 in 2022 which is relatively low compared to the average specific heat demand for residential multi-family buildings which was 138 kWh/m^2 in 2014 [9]. Using the 3rd Generation DH concept (3GDH), however, the heat demand should be less than 25 kWh/m^2 for new buildings and between 50-150 kWh/m^2 for the existing ones in the 4th Generation of DH (4GDH) systems [10].

4 New LTDH network in Brunnshög

Traditionally, DH systems are oversized with a large safety margin, causing high system losses of up to 35% where energy density is low. About half of the heat loss is in the connection lines of the consumers. By hydraulic optimization and decentral buffer tanks, the pipe dimensions and thereby the heat losses can be reduced, but the pumping energy and operation pressure of the system raised. COOL DH have been using thermal and hydraulic simulation (using TERMIS and NETSIM) on actual pipes with a potential improvement of 50% reduction in heat losses. Optimizing network design (pipe insulation, pipe technology/sizing, network length optimizations) showed that significant reductions in the heat losses can be achieved.

The new LTDH network in Brunnshög area is based on fossil fuel free surplus heat. UTIL-SE and its partners developed concepts for energy, mobility, and lighting for the infrastructure. The planning of a LTDH grid in Brunnshög started in 2016 and the construction started in 2018 to become Europe's largest LTDH network. In Sept. 2019, right before the inauguration of the LTDH grid in Brunnshög, the first PE-RT pipe was installed.

This network compromising 2,400 m in this current situation and the total development will cover 100 ha over time. In this way, the city can keep growing without increasing the GHG emissions. In addition, 1,418 m of the PE-RT pipes are made of the larger dimensions 110/180 and it was not demonstrated before. However, the total costs and all details are not finalized yet and merely some parts of the network including 872m are finalized which will be discussed in section 4.3.

The main point was the pipes in Nobelparken (The Nobel Park), where a major part of all the pipes in the large dimension were planned.

The project developed new DH pipes offering new characteristics in the following fields:

- Use of PE-RT plastic material instead of PEX and steel
- Improved insulation material
- Integrated oxygen and vapor barrier
- Weldable coupling methods
- Leak detection system and higher flexibility
- Pressure rating 13 bar

The new DH pipes in Brunnshög can be seen in Figure 31. Some of the pipes were preheated before being placed in the ground which resulted in very flexible and effective piping.

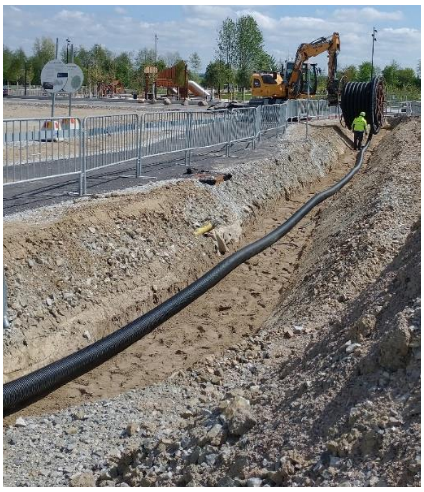

Figure 31. Laying down prefabricated PE-RT pipes in Brunnshög

As can be seen in Figure32, the LTDH network is made by a combination of steel (green lines) and PE-RT pipes (yellow lines). Most of the PE-RT pipes have been installed in Central Brunnshög, Nobel Park with surrounding streets. As seen, the network is not still complete, and it is under development as planned. Contractors are about to start the construction of new buildings and new customers will be connected to the system when heat is required. In addition, MAX IV facility and ESS can be seen in the middle and the top of this figure, respectively. Currently, MAX IV provides heat in the LTDH network and ESS is not in operation yet.

Figure32. Schematic view of LTDH in Brunnshög

4.1 Energy performance

The heat supplied and heat used during 2021 and 2022 are shown in Figure 33. As said before, the Brunnshög area is under exploitation and many more buildings will be built and possibly connected to the network in the next two decades. Currently, the network is oversized and contains mainly of large pipes including bypasses and not so many service pipes. A low number of customers are connected so far which means that the evaluation of the sold heat compared to the heat losses doesn't give a fair picture of the system efficiency. As it can be seen, there are rather high heat losses within the network in today's operating circumstances.

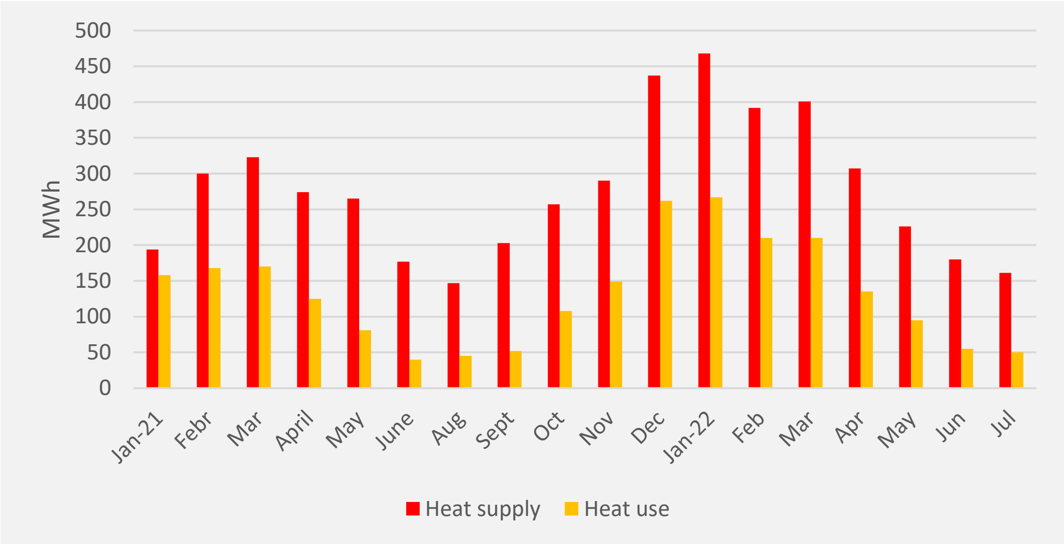

Figure 33. Heating profile of LTDH network in Brunnshög (Data of July 2021 is missed)

As stated above, the relatively high heat losses in the LTDH network Brunnshög is a result of few consumers connected to the network which leads to higher return temperatures and higher losses. However, the calculated heat losses in 'Reduced load in Brunnshög' (please refer to WP2, D2.7), was found to be 1,176 MWh. This was calculated for a temperature set of 55°C/30°C. Considering a temperature increase of 30%, which is the current operating temperature of the LTDH network, as seen in Figure 34, the calculated heat losses are 1,526 MWh. This is very close to the measured yearly heat losses of 1,546 MWh in 2021, indicating that the LTDH network in Brunnshög is operating as expected.

Supplied and returned temperatures in the LTDH network can be seen in Figure 34. The average supply and return temperatures are 66.6°C and 52.8°C, respectively. It shows a high return temperature effecting the heat losses in the network. The heat losses might be reduced by connecting more customers and completing the network. However, fixing probable issues in the customer installations (DH substations as well as internal heating systems) should be considered as well.

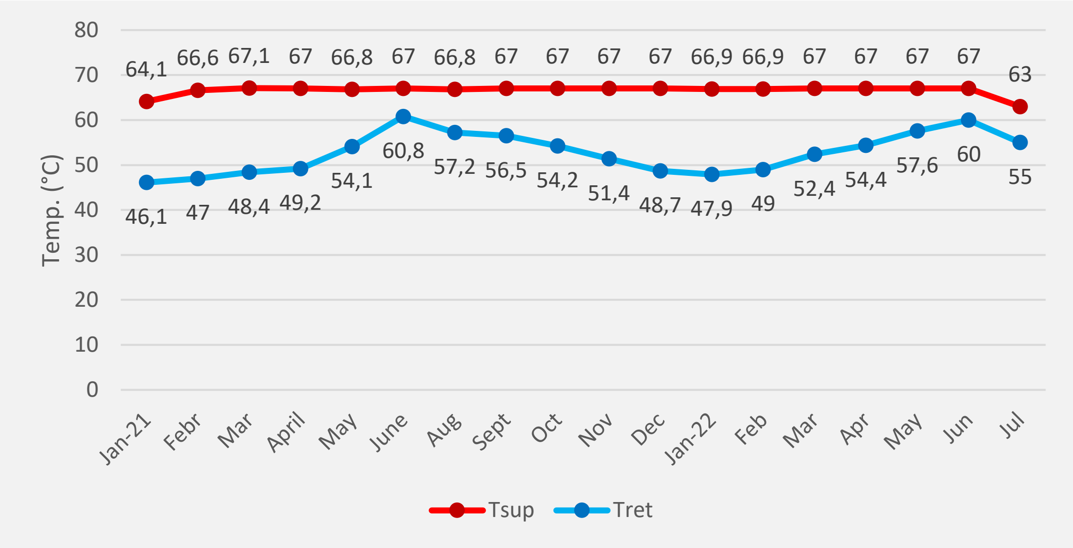

Figure 34. Heating profile of LTDH network in Brunnshög (Data of July 2021 is missed)

4.2 Environmental impacts

A master thesis [11], made within the project, compared the environmental profile of both PE-RT and steel district heating pipes by conducting a life cycle assessment. The study was case-specific but tries nonetheless to reach general conclusions about the considered products.

The result of the main comparison, as is shown in Figure 35, is that the PE-RT system performs slightly worse in the impact categories Acidification Potential, Eutrophication Potential and Photochemical Ozone Creation Potential. It is only regarding Global Warming Potential that the PE-RT system has a less significant impact. The differences are however small, which is satisfying considering the benefits the plastic pipes have shown in the installation process. The similarity between the two studied systems is satisfying since it indicates that both options have been treated equally. Their life cycles are very similar and should therefore logically give rise to similar amounts of emissions.

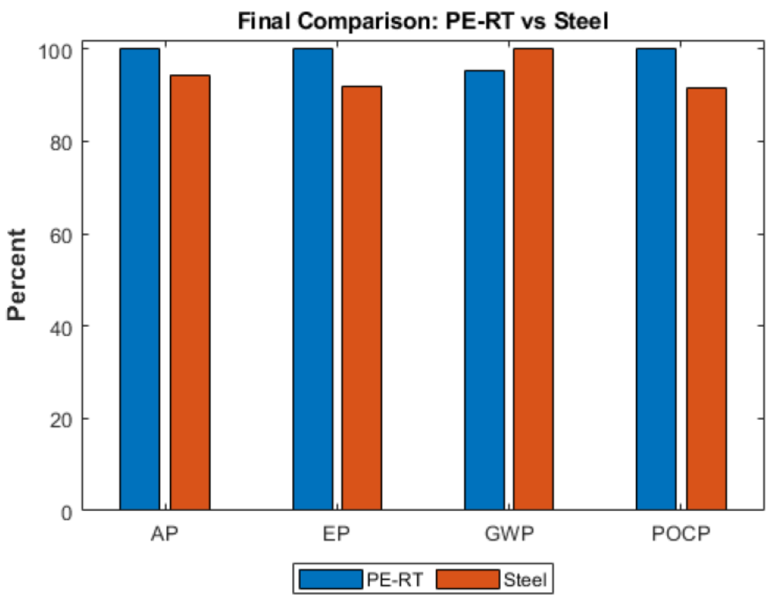

Figure 35. The comparison of the PE-RT and Steel pipe network for each category

Concerning certain areas with a large amount of associated emission or so-called hotspots, the use phase followed by the manufacturing phase are the two most noticeable life cycle phases as shown in Figure 36. More specifically, the most significant activities emission-wise consist of the combustion of fossil fuels to generate heat for the DH network, steel pipe manufacturing, production, and transportation of biofuels as well as PE-RT granulate production. As explained earlier in the report, it should be emphasized that the network at Brunnshög is supplied by surplus heat rather than heat from a CHP plant. This practically eliminates the impact from the use-phase, rendering the PE-RT system the more environmentally friendly option for this specific scenario.

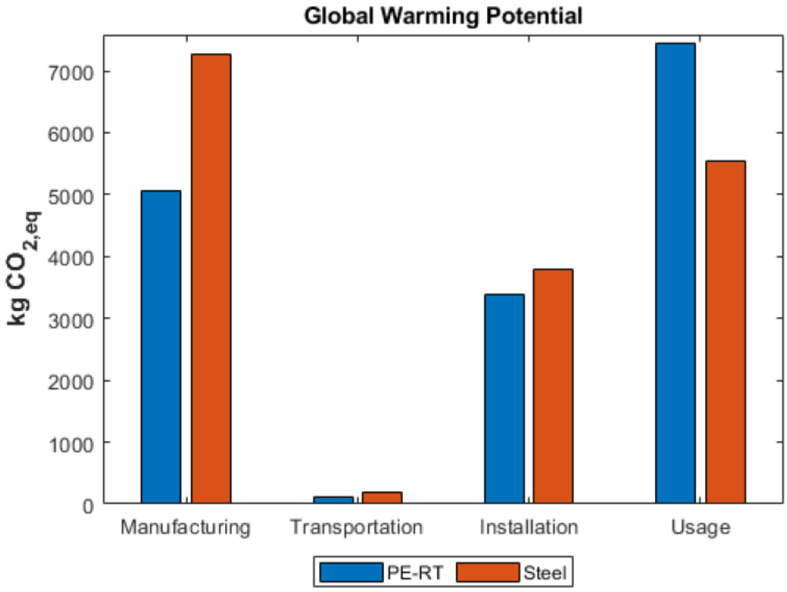

Figure 36. Contributions to GWP divided per life cycle phase and product system

The parameter analysis reveals that reasonable changes to key areas of the two product systems mostly scale their respective impacts linearly and moderately. The large exception is the choice of disregarding biogenic carbon dioxide emissions during heat generation which, if included, completely changes the result on a total and phase specific level.

In addition, it should be mentioned that since a LTDH system is implemented in Brunnshög supplied by a local low-grade heat source, lower losses and emissions are expected. The district heating domain finds itself currently in a transitional period where newly introduced concepts and technologies still need some time to mature.

4.3 Economic analyses

In this section an economic analysis is done on the parts of the LTDH network which the spent costs are finalized and reported so far. When comparing different projects, the circumstances affect the results easily. Preliminary results have indicated that using PE-RT pipes lowers the costs for the laying of the pipes compared to conventional steel pipes. However, part of this can be explained by the fact that the lines were laid within a work area that was already free from traffic and free from other lines, that excavated material in addition to the line bed couldn't only be reused but did not have to be transported away.

The pipe dimensions and the type of pipe also affect the cost of the grid. The larger the pipe, the greater the cost and single-pipe costs more to lay than twin-pipe due to the need for wider trenches. The cost of management contracts also changes with contractors, material suppliers, and type of agreements. Therefore, comparisons can be made between management contracts carried out in different years. In addition, the cost of pipeline contracts is affected by the seasons, mainly due to problems with water in the trenches in the seasons with more precipitation.

For a fair evaluation it would have been desirable to look at several management contracts, under the same conditions, with the same contractors but this data was not available so the evaluation here is made with different types of management. In Nobelparken, a few different pipeline projects have been carried out: Upptäcktsgatan where DN 200/355 mm single-pipe was laid between Brunnshögsgatan and Nobelparken; Sambandet/Nobelparken with single-pipe PE-RT 110/180 mm; southern part of Nobelparken part and Brunnshögsgatan had single-pipe PE-RT 110/180 mm; and twin-pipes DN100/355 mm for Nobelparken in Marie Curie's Allé. In this area, the management contracts took place during the period from late spring 2021 to early winter 2022.

Costs for contracts and materials have been changed so as not to disclose contracts with contractors. It is not certain that all cost items are included, there may be missing costs for some T-piece or sleeves or some transport. However, the largest cost items are included. A few missing sleeves or the similar only give rise to a marginal difference in cost per meter, it makes no significant difference between the contracts. The finalized parts will be described briefly in the following.

Upptäcktsgatan

As was expected, this was the most expensive contract as it has a large dimension (DN200 single pipe). It is large single pipe, which means wider trenches and thus higher excavation costs. The line is mainly in unpaved for pedestrian and bicycle lane. The construction was carried out in good weather conditions.

Figure 37. Upptäcktsgatan pipe

Marie Curies Allé

In Marie Curies Allé, the trenches were excavated during winter and thus in worse weather conditions. The project was put on hold for a while because resources were needed in another project. As a result, costs for materials such as suspension etc. increased. However, if the route would have been laid with PE-RT instead of steel pipes as was the case, the conduit trench could have been refilled immediately saving the costs that was due to suspension.

Figure 38. Marie Curies allé pipe

Sambandet and Nobelparken

PE-RT pipes were used for this line. The work was carried out during a period of good weather conditions. There was no traffic, and the trench was easy to dig. There were only paving at some road crossings in Nobel Park.

Figure 39. Sambandet och Nobelparken pipe

Brunnshögsgatan och Södra Nobelparken

Unlike the other trenches, asphalting in larger quantities was added, as well as a trench with trench monitoring in Brunnshögsgatan, approx. 130 m. Excavation and restoration in the Nobel Park meant excavation and restoration of plant beds, paving of parts of the route, which increased the cost relative to other pipe laying projects in Nobelparken.

Figure 40. Brunnshögsgatan och södra Nobelparken pipe

Kunskapsparken

In Kunskapsparken (Knowledge Park) the works were carried out within a fenced area. Excavated material could be placed to the side of the trench and reused, so called case A. Since the work was carried out in connection with the actual construction of the Knowledge Park, and with small dimensions and Twin-pipes, costs were becoming lower.

Figure 41. Kunskapsparken

Service pipe in North Brunnshög

The work in North Brunnshög was carried out within a fenced area. Excavated material could be placed to the side of the trench and reused, case A. Regardless of the pipe type and material (PE-RT 90/180), the contract was completed quickly at a low cost in relation to other contracts. Thanks to PE-RT pipe on a 100 m roll, the cost of the contract was surprisingly low.

Some specifications of the previously mentioned piping networks can be found in Table 7.

Table 7. Specifications of some parts of LTDH network

Area	Upptäcktsgatan	Marie Curies Allé	Sambandet	Brunnshögsgatan	Kunskapsparken	North Brunnshög
Work completed in	Spring 2021	Winter 2022	2021	2021	Spring 2020	Spring 2020
Material/Dimensions [mm]	Steel/single DN200/355	Steel/Twin DN100/355	PE-RT 110/180	PE-RT 110/180	PE-RT Twin 2x40/120	PE-RT 90/180
Length [m]	73	64	114	377	162	82
Cost Construction [SEK]	831,820	540,310	572,960	2,525,585	281,250	125,980
Cost of Materials [SEK]	258,990	212,220	225,100	827,140	201,180	262,200
Cost per trench length [SEK/m]	14,990	11,740	7,000	8,890	2,994	4,865
Total cost [SEK]	1,090,810	752,530	798,060	3,352,730	484,980	396,450

Specifications of all the mentioned parts are shown in Table 8. Although PE-RT pipes show lower costs per length unit, it is not possible to conclude that they are cheaper since steel pipes are made in larger dimensions in this part of the project. It should be mentioned that the Table 8 includes only some parts of Brunnshög network comprising 872m of total of 2,400m piping.

Table 8. Approximate cost of some parts of LTDH network

Area	Type	Size (mm)	Length (m)	Cost (€)	Cost/Length (€/m)
Upptäcktsgatan	Steel/Single	200/355	73	103,000	1,400
Marie Curies Allé	Steel/Twin	100/355	64	71,000	1,100
Sambandet	PE-RT/Single	110/180	114	75,000	660
Brunnshögsgatan	PE-RT/Single	110/180	377	316,000	840
Kunskapsparken	PE-RT/ Twin	40/120	162	46,000	280
Service Pipe	PE-RT/Single	90/180	82	37,000	460
Total Steel Pipe	-	-	137	174,000	**1270**
Total PE-RT Pipe	-	-	735	474,000	**640**
Total	-	-	**872**	648,000	**740**

4.4 Experiences of the demonstrator from Kraftringen and Logstor (Kingspan)

Interviews have been made with the representatives from Logstor, that have developed and manufactured the pipes and Kraftringen that has put the pipes in use in the new LTDH network.

Experiences from Kraftringen

- The major benefit of PE-RT pipes is that the pipes can be mounted in long sections without joints. In areas where there are many branches or other installations needed, the number of joints will increase, which will reduce the benefits. When the distance between joints is short, the stiffness of the pipes makes them hard to straighten thus hard to join. Short distances also imply the need for working areas in the pipeline pit causing the pipeline pit to be more of the size of an ordinary district heating pit. The PE-RT pipeline trench can be refilled much faster than a conventional steel pipe system. This makes the construction faster.
- The developed pipes are flexible, but the pipes are nevertheless quite stiff and that makes it hard to join the pipes to T-pieces and other pipes. The use of ordinary T-pieces made of steel implies more work with each joint than needed. With that being said, the predicted benefits with less joints as well as a more customizable design have been obvious.
- We realized some difficulties to be handled when laying the pipes. The pipeline trench was refilled too close to the joint, making it hard to flex the pipes thus making the mounting of the joints quite hard. Other experiences were that the pipes must be turned into copper pipes when passing the wall due to the sharp angle close to the wall. Despite these experiences it was evident that there were benefits with the flexible PE-RT pipes which could adapt or flex the pipeline section to obstacles along the way as well as enabling the use of narrower trenches.
- Since the PE-RT pipes are flexible, protective pipes could be mounted when the foundation of the buildings is made, and the PE-RT pipes could be pushed and pulled through the protective pipes. This method is, in fact, common for DH pipes when the dimensions are so small that flexible DH pipes made of copper can be used. Here it can be used for somewhat larger dimensions.
- The flexibility of the pipes is reduced with increasing dimension, thus the dimension 110/180 is quite stiff. Kingspan Logstor does not recommend mounting PE-RT pipes when the temperature is close to 0^{o}C. If the pipes need to be mounted when the temperature is close to zero or below, the pipes will have to be preheated, preferably stored in a warm storage. Sadly, this was not available at the time. The PE-RT pipes were mounted in cold conditions with cold pipes, which was challenging.
- The LTDH plastic pipe system still has some details made in steel, the same as a steel media pipe, such as T-pieces and valves. This might be a risk in the plastic system. It is important that details made of steel are integrated in the leakage detection system. To be able to integrate T-pieces and valves in the leakage system used in the plastic pipes the details must have the same detection cable. Since the production of such details is special, it means higher costs and longer delivery time for the details. This impairs quick changes during the construction of the grid.
- Pipes made of plastic, as for the developed pipes, have both benefits and disadvantages compared to steel pipes. Ordinary steel pipes are rigid; hence the length of steel pipes is limited with regards to transportation - up to 16 meters. This means that in an ordinary District Heating system there are joints with a working area at least every 16 meters. This implies more excavation. Plastic pipes on the other hand are flexible and can be produced as well as delivered with lengths up to 100 meters. This implies that a plastic pipe might reduce the number of joints and thus less excavation is needed.

- In ordinary district heating systems where rigid steel pipes are used, heat expansion must always be considered. Due to lower temperatures in LTDH systems, there is less heat expansion, the heat expansion should nevertheless still be considered. Traditional DH systems are designed with L- or U-shaped bends to manage the heat expansion. The design becomes more complicated and causes more excavation. Plastic pipes in a LTDH system do not need bends for heat expansion, thus the design of the plastic pipe system is more straightforward, and the width of the pipe trench can be reduced.
- Yet again, the harsh work was mounting the pipe ends to the existing pipes. The curved pipe ends need to be straightened to get the two pipes together. Therefore, a new tool has been developed which will be tested when mounting the next section of PE-RT pipes in the LTDH system.

Experiences from Logstor (Kingspan)

- There are some advantages using the new PE-RT pipes. They are flexible and come on coils which implies a faster installation. Another advantage is the independency on steel welders since there is no need for this when laying the PE-RT pipes. It is well known in the business that is 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 degree of insulation. The pipes can be difficult to handle in cold weather below 10°C.
- The PE-RT pipes developed within this project is a good product, 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 that are suitable.
- The mission in COOL DH was to develop media pipes with PE-RT and 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.
- We have realized some work safety issues when manufacturing 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 manufacturer of district heating pipes, we experience an increased interest in low temperature district heating systems. For the specific product of PE-RT pipes, we have experienced an interest in from Swedish and European customers. In Denmark, we feel 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 unlike steel pipes.
- 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.

4.5 Property owners' views on connecting to the low temperature DH grid in Brunnshög

A study about the property owners' views about connecting to the new LTDH network in Brunnshög has been carried out as a master thesis work at the Department of Energy Sciences at Lund University, by the student Jules Hanley, under the supervision of Associated professor Kerstin Sernhed. The text down below is a short summary of the master thesis. More detailed results will be presented in the master's thesis report with the title *Property owners' attitudes to connecting to the low temperature district heating network at Brunnshög* that will be published during October/November 2022.

The COOL DH project has laboured to gather experiences of the different demonstrations from its participants with replicability in mind but has not had a natural forum for the end users of the LTDH network in Brunnshög. The aim of this study was to collect insights from property owners about the success factors and limitations associated with connecting to and operating under the LTDH network. The motivations behind connecting to the network as well as the cases where the property owners decided upon another option, such as heat pumps, have also been of interest.

The scope of the thesis has been limited to gathering the attitudes, opinions and experiences from the property owners who have received a land allocation from Lund Municipality in Brunnshög where a connection to the LTDH network is possible.

Furthermore, the property owners in this study have been anywhere in the process of planning the building project to having completed their building. The goal has been to interview employees responsible for energy planning within each company, or third-party consultants where applicable, to receive as nuanced responses as possible; this has occasionally proven difficult when key persons have been replaced because the construction of buildings has been under way for several years. Out of seventeen property owners relevant to this study, responses have been received from ten. Nine of the respondents had already connected the LTDH network or were going to, and one had decided to use another heating solution.

The research method used in this study has been qualitative, with in-depth semi-structured individual interviews. Six of the ten interviews were conducted in person, one was an online meeting, and three were done by email correspondence. The interviews were recorded and transcribed, and the responses have been thematically analysed using an inductive approach.

4.5.1 Why Do Property Owners Connect to the LTDH Network?

Of the nine connected buildings, six use district heating to supply both hot water and space heating; one building uses electrical heat pumps for producing domestic hot water in some parts and district heating for producing domestic hot water in other parts as well as for space heating everywhere; one building uses geothermal heat pumps as the primary heat source with district heating for peak loads; one building has electrical heat pumps with district heating for peak loads. The tenth, unconnected building uses a combination of geothermal heat pumps and a connection to a different network which distributes excess heat between buildings.

The major findings of the interview study are that there are three factors that determine whether or not the property owners chose to connect to the LTDH network. The three factors are:

- Previous experiences of district heating
- Environmental concerns
- Ambition towards innovation.

4.5.2 Experience of District Heating

All the respondents who had connected to the network reported having previous experiences of district heating in some capacity; among the largest companies it was common that they connected all their new buildings to district heating and cooling networks where these were available. The approach to learning more about LTDH differed between companies, however: the largest had entire divisions devoted to sustainability research, the middle-sized companies enlisted consultants, and the smallest did their own research online.

In a long-term perspective, particularly when the buildings are subsequently sold to a housing cooperative owned by the inhabitants (in Swedish: Bostadsrättsförening), the knowledge of how the building is constructed is dispersed. The companies that have chosen to connect to the LTDH network in Brunnshög relate that the experience has been positive, regardless of what construction stage they are currently in. There have however been isolated issues of too low flow line temperatures, these were however addressed at an early stage and remedied. The property owners with these types of problems also appear to be at the far reaches of the network.

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

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

4.5.3 Environmental concerns

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

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

As a further complication, the municipality has also had different focus areas during the land allocation competitions, the latest of which is carbon neutral construction. This condition is weighed into whether the land allocation is granted, but so far there is no formal definition of what carbon neutral construction entails from Boverket (the Swedish National Board of Housing, Building and Planning). Visionary work like this further exacerbates the problem of providing property developers with clear guidelines while at the same time stimulating environmentally friendly solutions.

In the majority of Brunnshög, connection to the LTDH network is optional, but heavily recommended by the municipality. The price model from the energy supplier Kraftringen is deliberately favourable. However, the area called Science Village in the north of Brunnshög is not owned and allocated by the municipality but by a separate company that has chosen to include a requirement for connection to the district heating network when purchasing land. The developers there accept this condition from an environmental standpoint, as well as from the perspective that being in Science Village means being at the forefront of technological development and innovation. They subsequently recognize the LTDH network as an embodiment of these values.

4.5.4 Ambition towards innovation

From the onset, the Brunnshög area has been conceptualized as an innovative area, both in terms of the kinds of activities that it will contain (research facilities, both academic and commercial) and in terms of the demands that the municipality makes on prospective property buyers. Science Village has similar requirements; property owners sign a sustainability agreement and must incorporate a visible sustainability innovation into their building. This general focus on innovation attracts developers with an interest in doing something new. Connecting to the LTDH network has become a part of the same kind of sustainable solutions as the municipality and Science Village encourage, largely since the existence of the LTDH network is dependent on the research facility MAXIV and therefore closely associated with progress and innovation. Out of the ten respondents in this study, four expressly stated that innovation was their main motivation to construct their building at Brunnshög. Another respondent said that they have prepared their building for even lower supply temperatures, indicating an expectation of changing conditions – with more customers connecting once more buildings have been erected, they see a need to ensure a stable heat supply. These companies draw an implicit parallel between being innovative and connecting to the LTDH network, at the same time as consolidating these factors with their environmental policies.

4.5.5 Limitations of the interview study

The rate of responses from property owners who have decided to use another option than the LTDH network is very low. This affects the quality of the conclusions that can be drawn from the interview material from the unconnected party. However, out of the seventeen property owners who fit the scope of the study, only two have chosen other heating solutions (not counting the three buildings that have hybrid solutions). This is an indicator of the general attitude to the LTDH network. Furthermore, the LTDH price model makes other alternatives less attractive; one respondent suggested that it punishes heat pump solutions when used in conjunction with district heating.

In the process of data collection, it became evident that in some instances, the collective memory within the different companies was rather short, and in others knowledge disappeared when key persons moved on; many of the projects have taken several years to plan, and some of the interviewees had joined the projects in a later stage between the end of the planning to construction already having been completed. Accordingly, they were sometimes unable to answer matter-of-fact questions, and in other cases unable to argue for the decisions made by others. This problem signifies poor or non-existent documentation within organizations which results in poorer quality data. It also hampers future development and innovation efforts, both for those interested in handling the data and for the organizations themselves.

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

4.6 Conclusions

PE-RT pipes have been laid both as distribution and as service lines mixing with steel pipes in a new LTDH network. Plastic pipes with a diameter and size up to 110/180 mm has been designed, manufactured, put in the ground, and put in operation the Brunnshög area in Lund.

The great merit of PE-RT lines lies in a significantly faster installation with fewer joints, which means that large parts of the trench can be quickly refilled and that the pipe installation can be adapted to the surrounding conditions in a completely new way compared to traditional pipe installation. For shorter pipe lengths the PE-RT pipe has no significant benefit. The splicing work requires the same trenches, involves several professional categories, and the flexibility of the pipes serves no larger avail in shorter distances.

The results show that a plastic pipe system can be used in LTDH networks. The functionality is fine and there has not been reported any major concern during the time it has been in operation. It shows the feasibility of using these new plastic pipes in future generations of DH systems. Obviously, the plastic pipes have advantages and disadvantages comparing to ordinary steel pipes that should be considered. The most important advantages are flexibility, easier excavation, and no corrosion. The installation of PE-RT pipes is more convenient to handle in single pipe systems than twin pipes systems because the twin pipes are more rigid, especially in colder outdoor temperatures.

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 pipes in cold seasons. If installed in wintertime, the pipes need to be pre-heated. The pressure limit is 13 bar(o) for the installed plastic pipes which is higher than for other plastic pipes, but not as high as for steel pipes that can withstand 16 bar(o). This weakness is the main reason why plastic pipes are not used in ordinary DH grids nowadays along with diffusion into the media (with the vapour and oxygen barriers diffusion is not an issue for the used PE-RT pipes). 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 evaluation of heat losses shows that the network has quite high heat losses (in percentage of delivered heat). This is due to a somewhat lower insulation degree, but foremost because there are only few customers connected to the network so far resulting bypasses in the network.

Consistently, it can be stated that the total cost of using the PE-RT pipes is lower due to lower costs for laying the pipes, with less joints needed and a faster process. The background to this is the rapid laying of PE-RT pipes on 100 m rolls and that the seamless sections can be refilled almost immediately. This reduces time for renting barrier material etc. and there is also a narrower trench, thus less amount of material to be excavated and transported away.

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 decrease with an increasing number of joints, which means more trenches. Although the installation in Kunskapsparken is quite unique with its twin PE-RT pipes, the line was, however, laid at the same time as the park was constructed. This example denotes that installation of twin- pipes can be even cheaper.

Initial investigations show that PE-RT pipes have lower CO_2-emission impacts than steel pipes specifically in the manufacturing phase. However, the plastic pipes perform slightly worse in the impact categories Acidification, Eutrophication and Photochemical Ozone Creation Potential compared to steel pipes.

Finally, it should be mentioned that the PE-RT pipes are new products developed within the project which led to a long fabrication and test process. Economies of scale and improvements of components such as electro-welding sockets may cut the costs for the material and the installation further. 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 Heat recovery pipes in Lomma

The Swedish demonstration of a heat recovery pipe system is installed at ´Friskis & Svettis´, a local health and fitness centre in Lomma, approximately 6 km outside Lund as shown in Figure 42.

Figure 42. The site location of demo

The demonstration is a relatively long steel service pipe of 105 m as shown in Figure 43. A standard twin pipe and a collector (PEM40) pipe which normally is used for ground heat-pump installation was used.

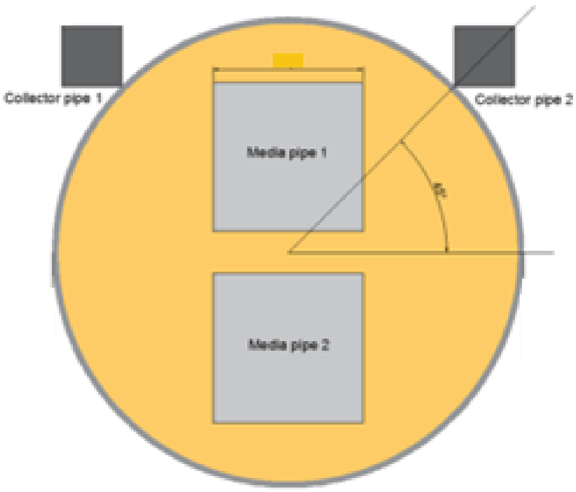

Figure 43. A sketch and photo of the heat recovery pipe with two collectors on top right and left

A drawing of the installation and the heat recovery pipes in orange are shown in Figure 44. The longest part is the service pipe for the street: Twin DN 2*65/225 (2*75 m). Then the service pipe from the street to the house is: Twin pipe DN 2*50/140 (2*22 m), and the last part into the house was: Single pipe DN 50/140 (2*8 m).

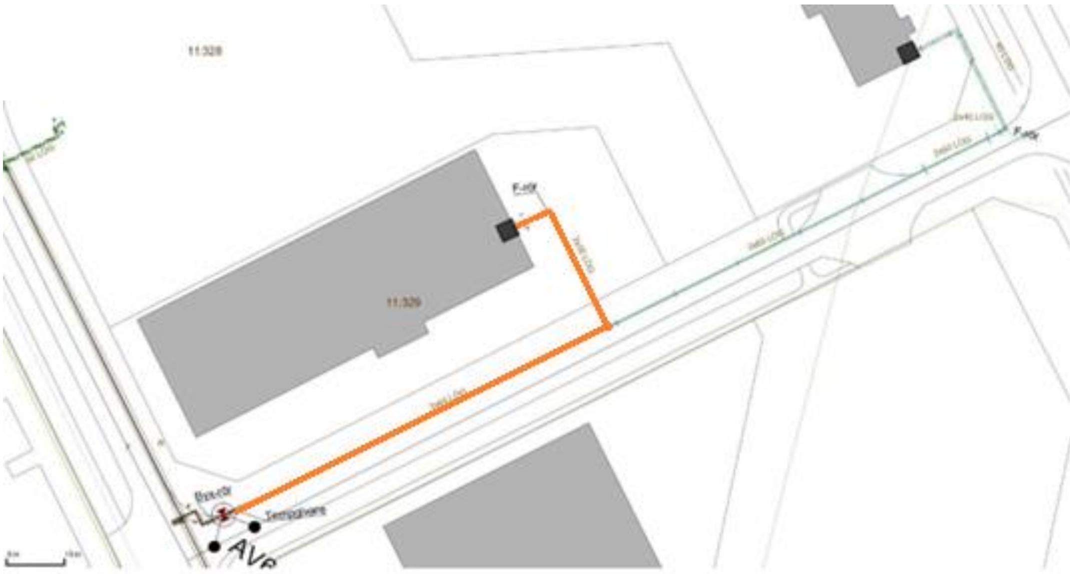

Figure 44. A drawing of the heat recovery pipes (orange lines) connected to the booster HP in the gym

Since the demonstration site is located outside the LTDH network it is connected to a traditional DH network operating at traditional temperatures. Figure 45 shows a principle sketch of the heat recovery installation in Lomma. In this demo, the recovered heat pipes are connected to a 6 kW heat pump in the HP room and substation of the gym to provide hot water for taking a shower etc. It means that the potential for recovered heat is dependent on DHW demand and operational hours and activity in the gym. In principle, these multi-media pipes recover heat from pipe losses and surroundings and then transfer it to the installed HP.

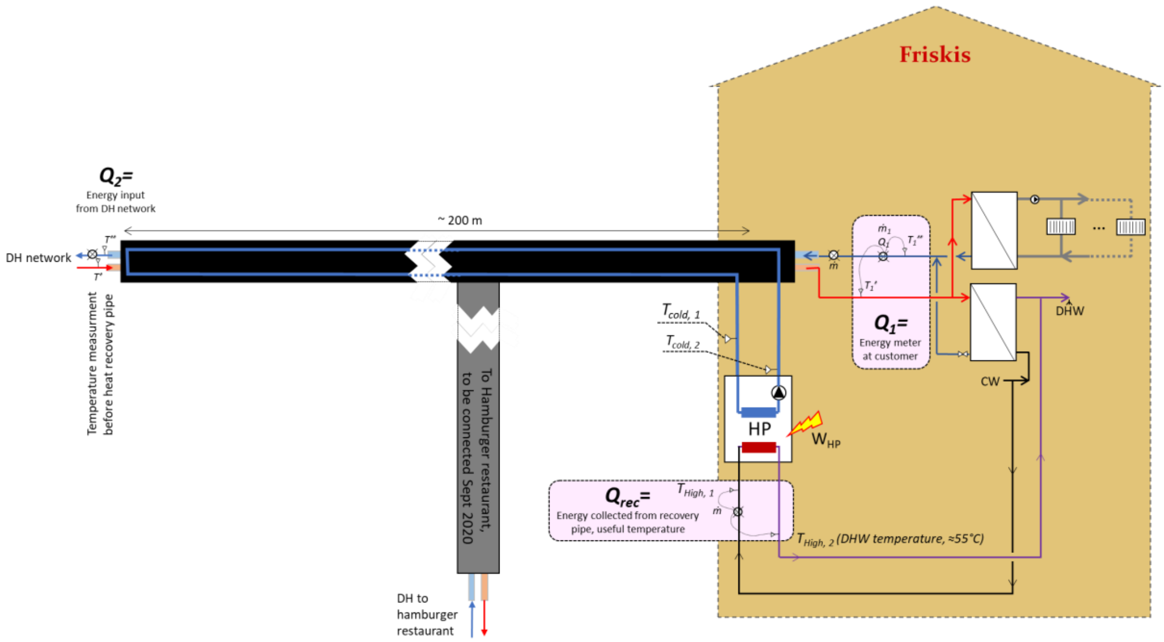

Figure 45. Principle schematic of the heat recovery system

Some special conditions for measuring and evaluating of the heat recovery installation in Lomma is the limited potential for recovered heat due to low DHW demand because of COVID-19 specifically for the first semester of 2021. An additional issue is that parts of the service pipe, that now only was serving the demonstration installation, also started serving an additional costumer since September 2020. Therefore, part of the service pipe works as a distribution pipe serving two installations.

5.1 Energy performance

The heat losses in the service pipe could be calculated from the difference Q_1-Q_2 where Q_2 is the incoming energy into the service pipe and Q_1 is the energy used by the customer according to Figure 45. However, this possibility was destroyed by adding a new costumer to the service pipe. The recovered energy from the recovery pipe can be determined by subtracting the electricity usage for the Heat Pump from the recovered energy on the warm side of the heat pump ($Q_{rec,cold} = Q_{rec} - W_{HP}$). On the cold side of the heat pump, only temperatures are monitored.

Hot water demand in the gym is shown in Figure 46. As it can be seen, Covid-19 restrictions has lifted gradually after July 2021 and more people used gym facilities including showers. Therefore, HP operation was increased resulting in better COP and performance as it is seen in Figure 47. COP is computed as the ratio of DHW consumption and HP electricity usage. The results show a COP of around 3 or even more for the heat pump. The recovered energy from the heat pump was approximately 60% of the heat losses in the service pipe in the period before adding the new costumer.

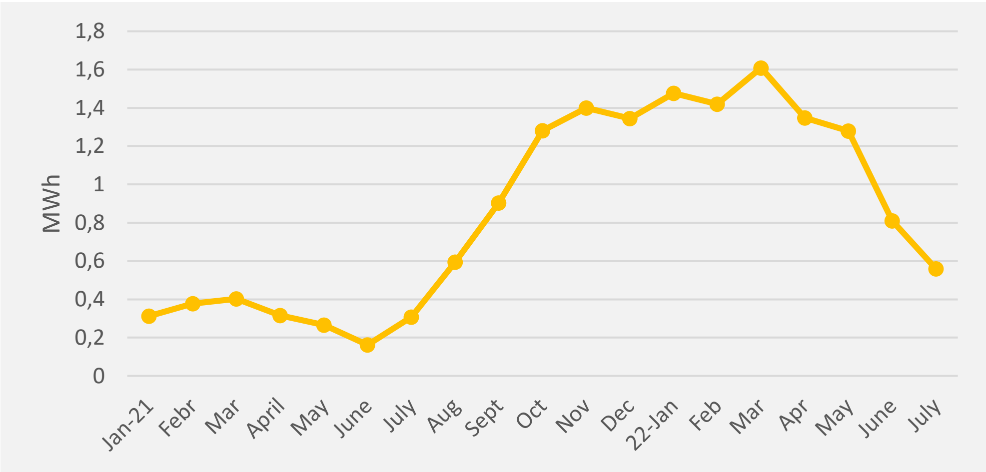

Figure 46. Hot water demand in the gym

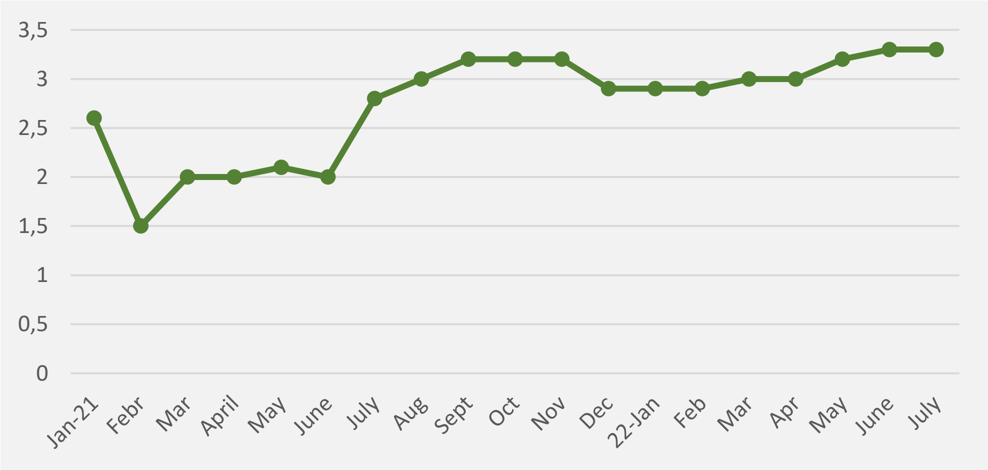

Figure 47. COP of the HP

Operational parameters of the installed HP in the gym are shown in Table 9. As mentioned before, the HP performance is higher in 2022 because of more operational hours and a higher hot water demand in the gym.

Table 9. Operational KPIs of booster HP

KPI	2021	2022 (7 months)	Estimation 2022	Initial Estimation
Recovered heat (kWh)	4,830	5,709	11,700	12,000
Electricity cons. (kWh)	2,837	2,792	5,300	4,000
Delivered heat (kWh)	7,667	8,501	17,000	16,000
COP	2.7	3.0	3.2	4
COP_{PE}	1.3	1.4	1.5	1.9

5.2 Environmental impacts

As described in Section 2.2.1 and considering Tables 2 and 9, there was an increase in CO_2 emissions in 2021 and 2022 by using heat recovery heat pump according to Table 10:

Table 10. Emissions and primary energy savings by using booster HP in the gym

KPI	2021	NG	2022 (7 months)	Potential 2022
CO_2 emissions (kg)	+32	+1,461	+32	+62
PES (MWh)	1.7	-	2.6	6

However, by considering Kraftringen claim to produce zero-emission electricity there would be a reduction in CO_2 emissions of 87 kg in 2021. Again, a comparison to the same system if supplied by natural gas gives an increase of 1.4 tons in CO_2 emissions. On the other hand, the installed system shows savings in primary energy according to the above table.

5.3 Economic analyses

The spent costs to establish booster heat pump to provide hot water in the gym is as Table 11:

Table 11. Costs of Gym demo

Capital	Cost
Booster Heat Pump	€ 6,515
Piping & Heat Exchanger	€ 4,315
Electrical works	€ 838
Total cost	€ 11,668
Cost per length	111 €/m
Cost per capacity	1,945 €/kW
Increased Investment	**€ 7,353**

Price Model is as below:

- Cost of electricity from grid: 77 €/MWh
- Cost of district heating at 65/35 °C: 550 SEK -> 54.02 €/MWh

According to the presented price model and Table 7, the initial payback time was estimated as below:

$$\text{€ 863 (Baseline supply cost)} - \text{€ 308 (HP supply cost)} = \text{€ 556 savings per year}$$

$$\text{Simple payback time} = \frac{7{,}353}{556} = 13 \text{ years}$$

However, the payback time according to 2021 data and a normal operation period of the HP in Aug 2021 – July 2022 is 37.5 years and **18 years**, respectively. The higher payback time for 2021 is due to COVID-19 restrictions resulting in lower operations of the gym and thereby the HP. This time can be increased by considering operational and maintenance costs as well.

5.4 Experiences of the demonstrator from Kraftringen

- Choice of customer: Friskis & Svettis was an ideal customer for this kind of installation, because they have a business that use all the heat collected from the installation all the time. The last two years however has not been a favourable period to test the installation, due to the COVID-19 pandemic which has meant that there has been very little activity at the facility.
- Installation: In hindsight Kraftringen should have taken care of the entire installation, but the customer had already acquired their own heat exchangers and wanted to do it themselves. Then we would have had better control over where the meters were placed. It was very difficult to put on the collector hose. It was much easier to snap it on the outside than to put it inside the insulation of the district heating pipe. The idea from the beginning was to be able to replace the insulation with the pipes.
- Measurements: The measurements have also been affected by the fact that the extra customer, a Burger King restaurant, has been connected to the pipeline. The measurement accuracy was good because there were two meters with the same accuracy. The plumbing contractor had failed to insulate the collector hose. In addition, it condensed a lot.
- Replicability: This is not something we will do in the future.

5.5 Conclusion

This demo shows the possibility of using a conventional heat pump to increase the temperature of working fluid heated by recovered heat to supply hot water in the tap to a health fitness centre. The advantage of this solution is to be able to use waste heat that normally would not be used. On the other hand, it requires a more advanced system with the heat pump as well as more complicated digging and installation works connecting to the district heating pipe. Some issues influenced the monitoring phase which, at first, COVID-19 lock down and limitations reduced operational hours of the gym and the HP. Then, a new customer downstream of the connection to the gym came earlier than expected which affected the monitoring results. In addition, remote controlled meter for monitoring should have been installed from the beginning of the monitoring, to avoid manual readings, which could lead to an error in the measurements. Although the pandemic situation as a rare emergency condition was out of control and inevitable, improved planning and preparation could have helped avoiding the other issues.

The installation is most likely to be considered a ground source heat pump installation. An advantage of the installation is the co-location possibilities. When digging to lay down district heating pipes, you can also lay down collector hoses for heat recovery.

6 Surplus heat recovery at MAX IV facility

In Lund, Kraftringen has installed a heat recovery system at MAX IV laboratory, supplying the new Brunnshög district with LTDH network with heat. Max IV is a large research facility that delivers high-quality X-ray light for research in materials and life sciences, located in the north-eastern part of Lund. The construction of MAX IV started in 2010 and the inauguration was in 2016. The facility uses high-velocity electrons emitting high-energy light to conduct research and studies on materials.

Figure 48. Aerial view of MAX IV facility

The total installed capacity at MAX IV is 5.8 MW for the heating circuit and 5.2 MW for the cooling circuit. The system supplies both the high and low-temperature district heating network. This installation can inspire further developments of LTDH systems and allow for such systems to be replicated in other places. The total designed cooling demand for MAX IV is 29 MW by 2025. The system will be further expanded as the Brunnshög area develops. The total available source of low-grade heat including ESS will grow to 250 GWh/year by 2025 with a maximum capacity of 40 MW [2].

The recycled fossil-free surplus heat system installed at the MAX IV facility recovers the heat produced by the cooling system and supplies low-grade heat to the new LTDH network. An innovative heat exchanger and heat pump coupling was developed and installed to fulfil the cooling demand of the research facility and, at the same time, recover the heat produced in the process to supply the LTDH network connected to the Brunnshög area. In this way, the efficiency of the recovery system was increased. The electricity for the heat pumps is produced by hydropower and then, the LTDH system is entirely supplied by RES. As can be seen in Figure 49, the heat pump system was designed with energy efficiency in mind and includes:

- Division into several temperature levels
- Optimization of the cooling temperatures
- Cascade coupling of the individual units

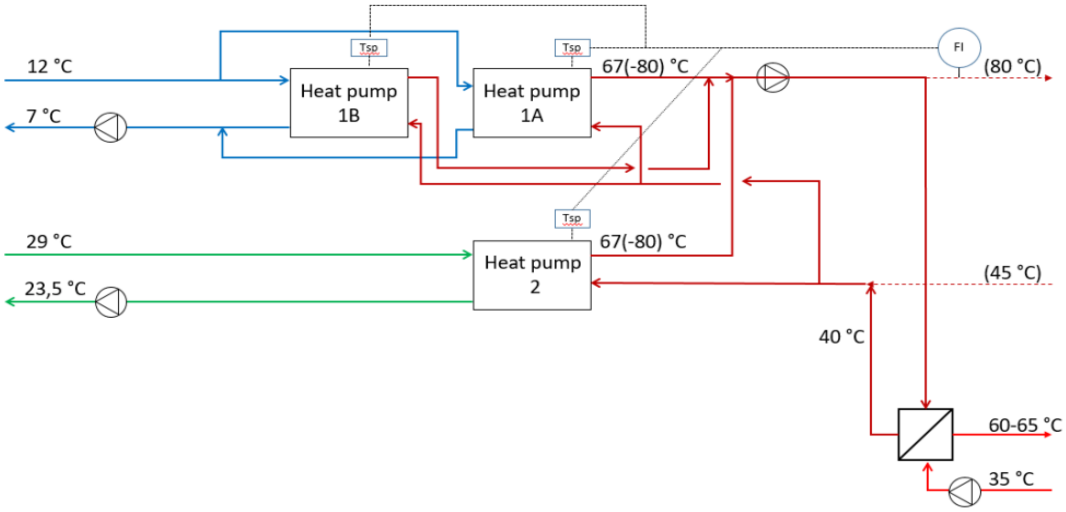

Figure 49. Simplified heat pump coupling system at MAX IV

As it can be seen, the system supplies cooling at two different temperature levels, 7.0°C and 23.5°C. Furthermore, the same system can be used to supply the new LTDH network as well as the network characterized by a higher temperature, respectively at 60-65°C and 80°C.

When producing district heating based on low temperature heat sources the highest overall COP_H is achieved when similar heat pumps are used in cascade coupling and are working under similar conditions. A simplified heat pump system with production of low temperature district heating is shown in Figure 49. The new equipment for production of low temperature district heating is indicated in the bottom right corner of the figure. New control equipment is indicated at the top of the figure. Normal production mode is shown with bold lines. If the heat demand in the low temp district heating network is larger than the heat effect produced at Max IV, it is possible to reverse the flow to the traditional district heating network to provide more heat.

The effect of lowering the heat pump supply temperature is clearly seen in Figure 50, lifting COP_H to about 4. It should be mentioned that the special installations had to be adopted in the system design to limit its vibrations, since they could disturb the operations of the MAX IV installations.

Figure 50. The expected COP variation in relation to the changes in DH supply temperature

The demonstration shows how to gradually increase the amount of low temperature district heating according to the increasing demand and stage of development in Brunnshög. At present the heat pump delivers heat at a higher temperature to utilize the surplus heat also in the normal district heating system, but when the demand in Brunnshög is fully developed then the set point of the heat pump will be reduced to the 60-65 °C needed in the low temperature district heating grid. An overview of the operation modes of MAX IV to supply DH systems is shown in Table 12:

Table 12. Overview of operation modes depending on the stage of development in the served area

	Early development - Winter	**Early development – Summer**	**Fully developed – many consumers in the LTDH grid**
Heat pump supply	80°C	75°C	67°C
LTDH supply/return	65/35°C	65/35°C	65/35°C
DH supply/return	80/45°C	75/45°C	Supply to DH only in case of surplus during summer

6.1 Energy performance

The supply and return temperatures to the network from MAX IV can be seen in Figure 51.

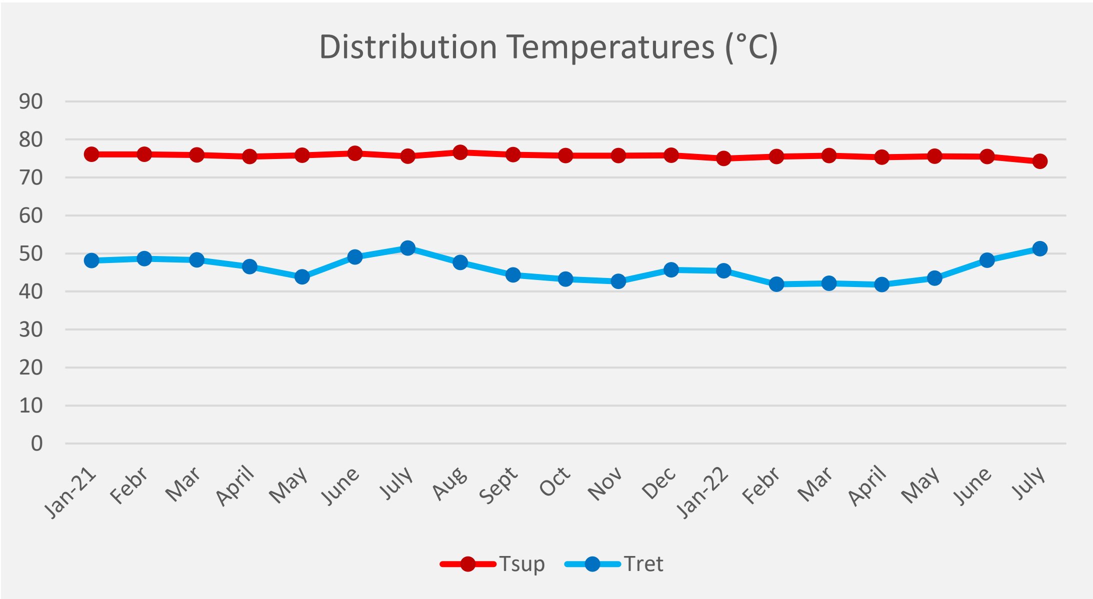

Figure 51. Supply and return temperature to LTDH from MAX IV

Performance of the heat pump coupling system at MAX IV in both the hot and the cold side is shown in Figure 52. As can be seen, the total COP can be considered around 5 roughly (Heating 3 and cooling 2). The COPs are expected to increase after full development of the LTDH network.

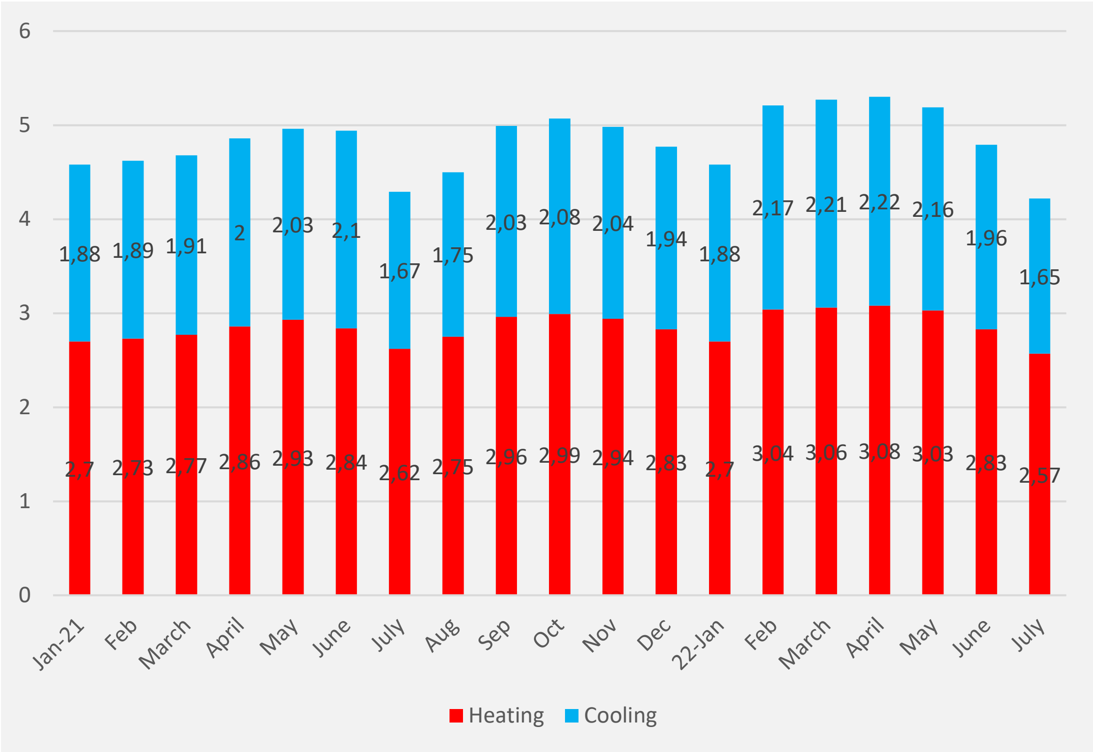

Figure 52. COPs of the HP coupling system in MAX IV

Figure 53 shows energy production in MAX IV since 2021 until July 2022:

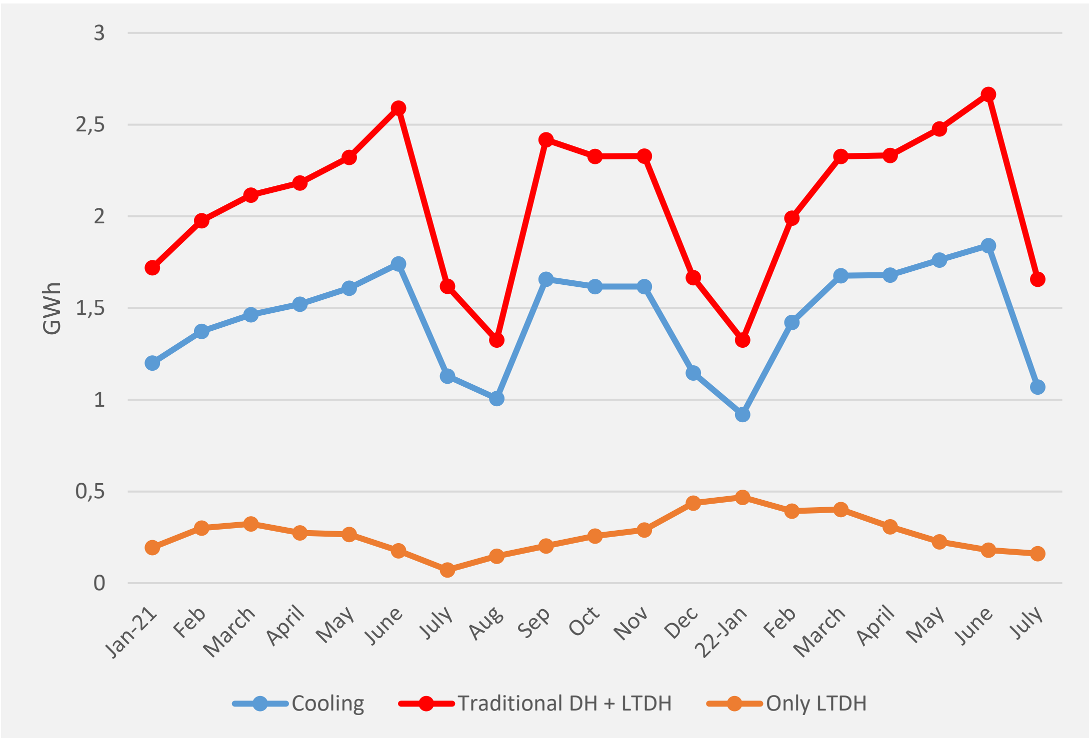

Figure 53. Energy production in MAX IV

Table 13 shows heating and cooling production, electricity consumption and performance of the HP system in MAX IV during 2021 and 2022. The estimated heat production for the LTDH network was 20 GWh per year.

During 2021, the system produced 17.1 GWh of cooling and recovered 24.8 GWh into the district heating network which was higher than the estimation. A bit higher values are estimated for 2022 as well according to Table 13:

Table 13. Energy production and HP performance in MAX IV

KPI	2021	2022 (9 months)	Potential 2022
Total Heat Production (GWh)	24.8	19.0	25.5
Heat for Traditional DH (GWh)	20.6	15.8	20.8
Heat for LTDH (GWh)	2.9	2.5	3.3
Cooling (GWh)	17.1	13.4	18.0
Electricity Cons. (GWh)	8.8	6.6	8.7
COP for Heating	2.9	2.9	2.9
COP for Cooling	1.9	2.0	2.0
Total COP	4.8	4.9	4.9
COP_{PE}	2.3	2.3	2.3

Finally, an energy flow of connection between MAX IV facility and the LTDH network in 2021 can be seen in Figure 54. It should be mentioned that sum of cooling production and electricity consumption is not exactly equal to the heat production of the HP system since the electricity is measured in the switch board room and there are some losses before it reaches to the actual motors. Furthermore, there are losses in the heat pumps as well. Therefore, not all power provided ends up as useful heat.

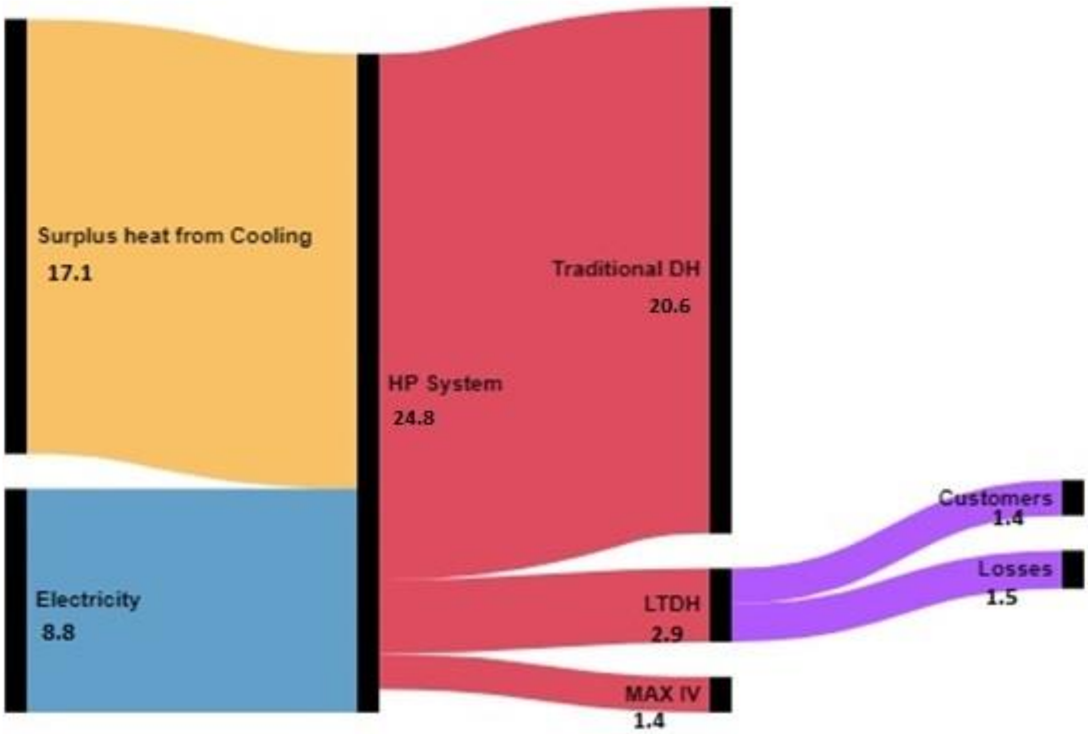

Figure 54. Energy flow (GWh) in MAX IV

6.2 Environmental impacts

6.2.1 CO_2

As described in Section 2.2.1 and considering Tables 2 and 13, there was an increase in CO_2 emissions in 2021 by using heat recovery heat pump:

$$\begin{bmatrix} (638\cdot 48.2)+(725\cdot 51.2)+(765\cdot 42.9)+(762\cdot 40.0)+(793\cdot 41.8)+(913\cdot 39.1)+(673\cdot 36.1) \\ +(560\cdot 39.2)+(818\cdot 40.8)+(779\cdot 36.5)+(793\cdot 39.9)+(590\cdot 47.8) \end{bmatrix}$$
$$-(24{,}800\cdot 10.0)-(17{,}100\cdot 2.75)=+\mathbf{73\ tons}$$

Or briefly in a simpler way which gives almost the same result:

$$(8{,}800\cdot 41.9)-(24{,}800\cdot 10.0)-(17{,}100\cdot 2.75)=+\mathbf{74\ tons}$$

However, by considering Kraftringen's claim to produce zero-emission electricity there would be a reduction in CO_2-emissions of 295 tons.

In the next step a comparison is done with the Danish side of COOL DH to see what would happen if this facility was working in the conditions of the district heating system in Høje Taastrup in Denmark. Regarding local reference, there would be a 794 tons reduction in CO_2-emissions:

$$(8{,}800\cdot 181.5)-(24{,}800\cdot 40.9)-(17{,}100\cdot 81.0)=-\mathbf{802\ tons}$$

This simple comparison shows how local and regional conditions play a vital role for the outcome of an analysis of the emissions of greenhouse gases. Although the demo sites in Sweden and Denmark are situated very close to each other (within about 80 km) the specific prerequisites of the two systems significantly influence the environmental outcome. Finally, it should be regarded that both systems have a high share of renewables in the energy mixes and if instead natural gas would have been used to produce the same amount of heat, which is a common scenario in Europe, the CO_2-emissions would be near to 4,700 tons compared to 73 tons.

6.2.2 PES

As described in Section 2.2.2 and considering Table 13, savings in primary energy in 2021 has been calculated. In addition, an allocation for electricity has been done since electricity is used for both heating and cooling purposes. One approach is to consider the heating system as a bonus to the original system and therefore no extra electricity is allocated for it, i.e. PES is equal to the heat production of the heat pump:

$$\mathrm{PES}=\mathrm{Q_{HP}}=\mathbf{24.8\ GWh}$$

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

$$\mathrm{PES}=\mathrm{Q_{HP}}-(2.1\cdot \mathrm{P_{el}})=24.8-(2.1\cdot 8.8)=\mathbf{6.3\ GWh}$$

Both approaches show significant savings in primary energy usage.

6.3 Economic analyses

The spent costs of energy production in MAX IV are shown in Table 14.

Table 14. Costs of MAX IV

Component	Capital cost (M€)
Heat pumps	1.635
Piping & Heat Exchanger	1.2
Electrical works	1.53
Building works	0.157
Others	0.45
Total cost	5.31
Increased Investment (Costs related to the project)	**0.305**
Project cost per capacity	**52 €/kW**

Price model is given as below:

Cost of electricity on average: *77 €/MWh*

Cost of replaced heat on average: *30 €/MWh*

Therefore, payback time can be calculated as below:

Heat for LTDH cost = 2,900 MWh X 30 €/MWh = *€ 87,000*

El. Cost = 800 (Allocated to LTDH) X 77 = *€ 61,600*

Saving = 87,000 – 61,600 = € 25,400 per year

Payback time = 305,000 / 25,400 = ***12 years***

If heating is considered as bonus: Payback = 305,000 / 87,000 = 3.5 years

Payback period can be considered as 12 years while in initial estimation it was 10 years.

6.4 Conclusions

Developing LTDH networks enables to use surplus heat from local and low-grade heat sources such as MAX IV. Coupling heating and cooling and cogeneration is another promising way to increase thermal efficiency of engineering systems resulting in primary energy savings, mitigation of CO_2-emissions and improved business conditions gaining income from selling the reused energy. This kind of surplus heat sources will play an important role in future DH systems. In this project, the recovered heat from the cooling systems at MAX IV could provide the current demand in the LTDH network as well as contribute to the energy mix of the traditional network. It is also expected that future energy needs in the LTDH system in Brunnshög can be supplied with the residual heat from Max IV. In a near future, the research facility ESS is also planned to be connected to the network as another local heat source. It will increase heat supply capacity of the network significantly.

7 Incorporating a prosumer

As the temperature in the DH grids generally, and LTDH grids specifically, is gradually lowered, it allows for the use of low-grade heat sources. Surplus heat from 'prosumers' has in traditional district heating systems been considered as too low in terms of temperature and volume to be considered a viable heat source, but with LTDH and ULTDH systems that may no longer be the case.

The initial aim in COOL DH was to connect the surplus heat from a cooling system of a planned new supermarket as a prosumer in the LTDH grid. However, the construction of this building was heavily delayed and was not finished within the time frame of the project. Luckily, there was an alternative way of investigating how a prosumer can be connected to the LTDH system in Brunnshög.

Kraftringen has shown a way to incorporate local surplus heat into the LTDH-grid by making two separate connections to a hotel in Southern Brunnshög in Lund. This consumer has become a prosumer by delivering medium grade heat that is recovered and returned to the LTDH system. The hotel is connected to both district heating and district cooling. The cooling and heating needs are 340 kW and 900 kW, respectively.

The use of heat at the hotel is rendering a cooler return flow to the central heat pumps at a steam power plant, and the use of cooling is rendering a warmer return flow to the heat pumps. The cool flow is used to produce new district cooling and the warm flow is used to produce new district heating. For the district cooling, plastic pipes were used instead of steel pipes. This was a better alternative than steel pipes when it comes to both economic and environmental aspects. The hotel is connected to a DN80 (80 mm inner diameter) steel twin pipe for the district heating supply and a PP90 (90 mm outer diameter) plastic pipe for the district cooling supply. The plastic pipes are normally defined by outer diameter and then PP90 fits to DN80. The heating plant is set up with an absorption-cooling machine which recycles excess heat from the district cooling cycle. District heating is then produced using three heat pumps in series.

It should be mentioned that economic and environmental analysis was not possible for this demo since cost data was not shared by the partner and on the other hand, both DH and DC systems are sold to the hotel and they are connected to a central heat pump in a plant, instead of a local heat pump on the site.

7.1 Energy performance

7.1.1 Production of Ångkraftverket

The heat pumps installed at Ångkraftverket for co-generation and heat recovery have a capacity of 9.9 MW and 9.5 MW, respectively. The heat production from this plant is highest in the summer months when the need for cooling is the highest. DH and DC production in this plant can be seen in Figures 55 and 56 for the year 2019. Total DH production, DC production and electricity consumption in 2019 were 52 GWh, 45 GWh and 22 GWh, respectively.

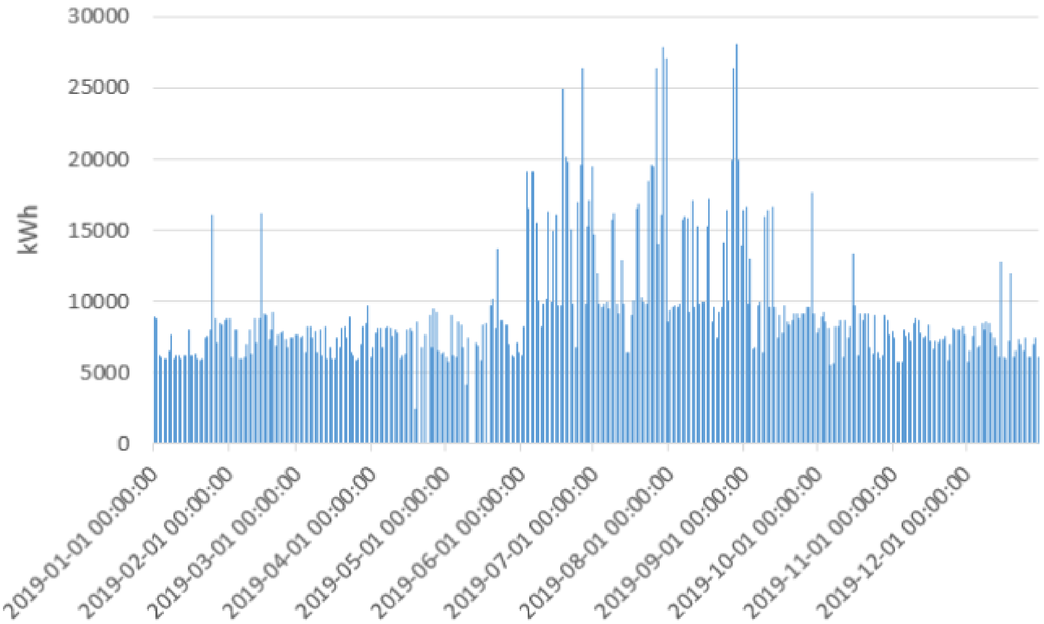

Figure 55. DH production in the central plant

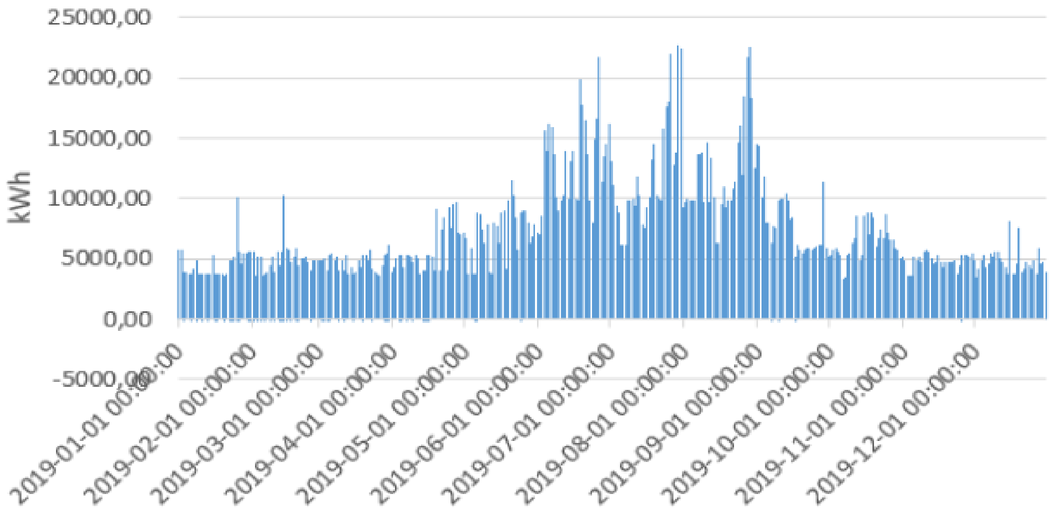

Figure 56. DC production in the central plant

7.1.2 Connection to the Hotel

The COP in the heat pumps was estimated to 1.85 and 2.0 for district cooling and district heating, respectively. The connections to the hotel were estimated to contribute to an increased production of 680 MWh for district heating and 180 MWh for district cooling. This potential of contribution can be seen in Figure 57. In 2021, 603 MWh of heating and 145 MWh of cooling were used in the hotel. The heat use was the same for the first seven months of 2022, but the cooling use was increased by 14%. Set temperature for heating and cooling circuits are 73/40°C and 7/13°C, respectively.

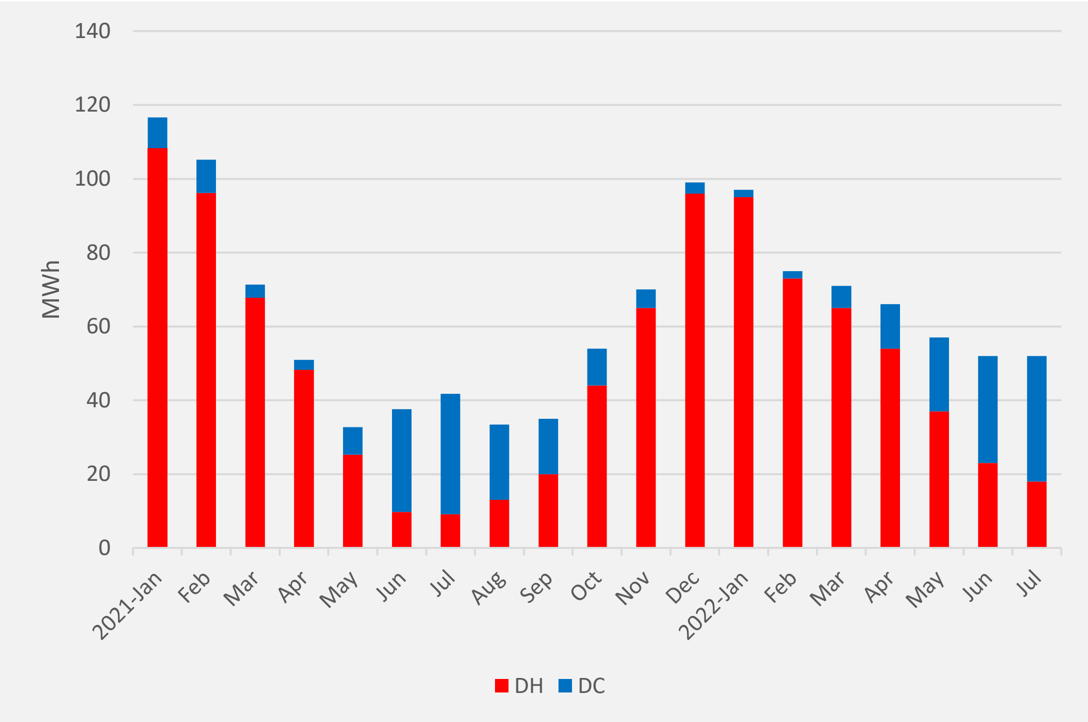

Figure 57. Heating & Cooling use in the hotel

Regarding the connections themselves, the work was easy in terms of getting the pipes in the ground.

7.2 Conclusions

First, the scope of this subproject had to be changed from the original site with an installation in Brunnshög to a neighbouring site, due to the delays at Brunnshög. The energy consumption in the hotel in both the heating and the cooling section shows its potential to be a real prosumer by using recovery heat from cooling machines on site. The hotel can produce significant surplus heat to contribute to the local LTDH network. One drawback, however, is that cooling is mostly demanded during the warm season when the demand for heating is low.

8 Other installations

One aim for the LTDH system in Brunnshög has been to work as a testbed for new and innovative solutions, inviting external actors to try new creative installations. Promoting good cooperation of parties active in the district heating industry may help district heating systems and components to be improved and new utilizations of heat can be discovered, which is especially interesting in Brunnshög that has access to a lot of surplus heat from the research facility Max IV and in the future ESS.

The artistic installations found in Brunnshög and described below aims to increase the awareness of district heating and its good environmental values to visitors.

8.1 Heated benches

In cooperation with Science Village Scandinavia and artist Robert Hais (based in Halmstad), LTDH-heated benches were installed at Möllegården. The idea of Möllegården is that it will be a Visitor Center for Brunnshög, with exhibition of the buildings and installations in the area as well as a café. The heated benches are placed in the garden in the serving area of the café, amongst some trees.

The benches, as shown in Figure 58, are cast in concrete with plastic pipes for the heating system (same as is used for underfloor heating systems). The heating system itself origins from a secondary connection after the primary heat exchanger with its own heat exchanger and expansion vessel. This is because glycol is added to the water in this system to avoid freezing during wintertime. Heat is provided at around 40-45°C to achieve a good temperature at the surface of the benches. The heating system will be in operation at daytime and during the cold period of the year, preliminary when the outdoor temperature is between -4°C and +8°C. All these settings might be subject to changes depending on the potential use of the benches.

Figure 58. Three heated benches

Together with the benches there will be installed a sign with information on how to utilize heat in a good and sustainable way, as a way of educating and raising awareness amongst the visitors of the café and the area.

The heated benches have been in operation since last winter (2021/2022) but there is no individual meter installed for the benches per se, only for the total load of Möllegården. The estimated use is however 10 MWh/year. Total costs spent in this demo is shown in Table 15:

Table 15. Costs of heated benches

	Cost, SEK	**Cost, Euro**
Heat exchanger and installations	38,286.8 SEK	3,735.3 €
Digging and pipes	22,800 SEK	2,236.4 €
Fee for the artist (incl. material)	119,193 SEK	11,691.2 €
Total cost	180,278.8 SEK	17,682.9 €

8.2 Ground heating

There are two tram stations connected to LTDH network in Brunnshög since October 2021. The DH network heats the stations by a ground heating system for snow clearing and passengers' comfort. Figure 59 shows a photo of one of these stations on a snowy day. As can be seen, the snow has melted on the platform.

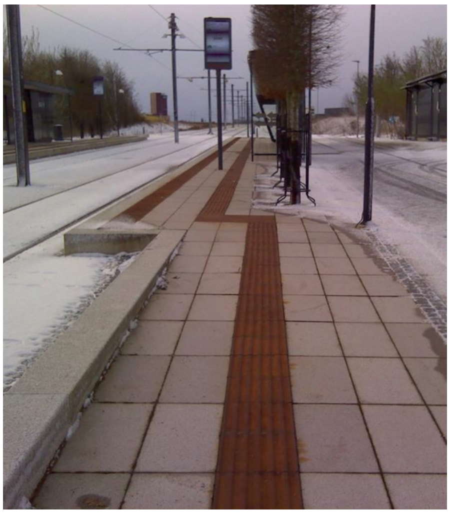

Figure 59. Tram station heated by ground heating

A heating profile for tram stations together in the winter period is shown in Figure 60.

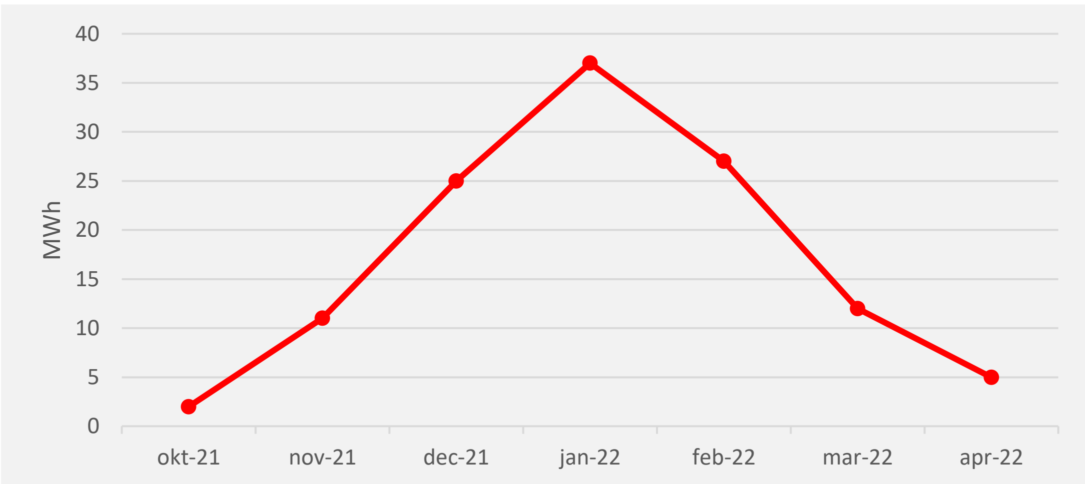

Figure 60. Heating profile for tram stations

9 Final Conclusions

The transition to LTDH networks requires new technologies and new 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 of the key elements in DH systems, in which this project has provided new knowledge and novel designs to all categories, 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 within the COOL DH project in the new-built area in the city of Lund called Brunnshög. The demos have been monitored and evaluated in terms of the overall impact of the low temperature district heating system with regards to energy use and performance of involved plants and buildings, environmental impact, and social impact in terms of economy and user experiences. 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.

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

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

- Implementing the PE-RT plastic pipes, designed and manufactured within the project, showed lower installation costs due to a faster installation with fewer joints since the pipes come on 100 m coils. The flexibility of the pipes showed several benefits; the pipes could be flexed around obstacles and when connecting new buildings, protective pipes could be mounted when the foundation of the building is made and the pipes could then be pushed and pulled through the protective pipes, making the connection simpler to carry out.
- An LCA analysis comparing the PE-RT pipes with conventional steel pipes shows that the plastic pipes have lower CO2-emission impacts than steel pipes specifically in the manufacturing phase. However, the plastic pipes perform slightly worse in the impact categories Acidification, Eutrophication and Photochemical Ozone Creation Potential. The main environmental benefit from the new LTDH system, however, 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 Max IV laboratory:

- Max IV is a large research facility that delivers high-quality X-ray light for research in materials and life sciences. The processes in Max IV needs a lot of cooling. Surplus heat is collected from the cooling machines and the temperatures are lifted in a cascading heat pump system with good operating conditions. The total COP for the installation (both heating and cooling) is about 5. The COP is expected to increase after full development of the LTDH network. The surplus heat from the Max IV laboratory supplies all the heat demand in the LTDH system today and the capacity will be enough to suffice also the estimated coming heat demands of Brunnshög when the area is fully exploited. Today a fair share of the surplus heat from Max IV is used in the conventional district heating system in Lund.

- Comparing the greenhouse gas emissions from the surplus heat in Max IV with heating produced by natural gas, the surplus heat give rise to 4,700 tons CO_{2eq} less in a year than for natural gas for the same amount of heat that is used in the LTDH system in Brunnshög. Comparing it to the energy mix in the conventional heating system in Lund, it would give rise to additionally 73 tons CO_{2eq} if calculating with Swedish electricity emission values. This is due to the need for electricity to operate the heat pumps that adds up to the emissions. If calculating with zero greenhouse gas emissions as Kraftringen claims is true for their electricity production, there would instead be a reduction of CO_2-emissions with 295 tons.

Testing novel customer installations for low and ultra-low supply temperatures in the building Xplorion:

- A new-built residential building with 54 flats was tested in designed supply temperature of 45°C (and higher). The Xplorion building is a low energy building, thus with low space heating demands. The installations installed and tested for space heating and domestic hot water preparation in the Xplorion building includes a booster heat pump that can raise the incoming low supply temperatures from under 60°C to 60°C, a three-pipe system (instead of a conventional five-pipe system that usually includes a hot water circulation circuit to keep the domestic hot water over 50°C) that is connecting the heated water to the flats own HUIs with a heat exchanger for instant hot water preparation.
- Advantages of the system are Legionella safety since there are very short distances between the heat exchanger and the tap points; that the tenants themselves can set the desired temperature; and that the system allows for individual metering and charging of the energy usage. Disadvantages are, above all, the high investment cost for flat-wise HIUs, and that the booster heat pump's COP is greatly affected by the return temperatures from the apartments, which could be seen in operation. The system thus places great demands on good adjustment and troubleshooting of the installations for the system to function well.
- According to several tenants, the thermal comfort was not satisfying in the first heating season. The possibility to control the indoor temperature in the flats was affected by the problems of poor adjustment and sensor problems in the HUIs that have now been dealt with. The tenants would like to have more information about the heating system and how it works. They are positive to the individual metering and charging, making it possible for them to influence their own costs to some extent, however, some of them ask for more frequent feedback on their energy use, to be able to adjust behaviour. Giving enough information to customers is essential since they are an essential part of the system and the last link in the distribution chain of energy in DH systems.

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. This includes 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 development of Brunnshög, which contributed to the fact that certain changes needed to be made against the plan, including for example that the heat recovery pipe needed to be located outside the LTDH system in Lund in the village of Lomma, that the expected grocery store ICA that was to be built and which would constitute a prosumer was not built within project timeframe. The short time frame to include all these steps also had consequences for follow-up and evaluation in the form of relatively short follow-up periods of operation hours of the installations (often one to one and a half years). A longer monitoring and evaluation period would have given the opportunity for comparisons between years, but above all having one more heating season to monitor the installations could have given insight to whether the adjustment made in the heating system of Xplorion really would solve the issues with indoor climate comfort in Xplorion that some of the tenants complained about.

As the low-temperature network in Brunnshög is in an area that is expected to be expanded over 25-30 years, the heat demand in the area will increase for all this period. To meet future heat demands in the area, the current capacity of the LTDH grid is greatly over-dimensioned. This affects the efficiency of the network, for example when looking at the heat losses in the grid as a share of the supplied heat. With a higher heat energy demand in the future the savings in recourses (primary energy) and greenhouse gas emissions compared to conventional district heating and other alternatives like heating based on natural gas will be yet bigger than has been reported in this report.

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 county. This is a very promising feature of the COOL DH project to satisfy overall all involved partners including municipality, utility, and customers. This project can be considered as a step towards low-carbon heating and independency of fossil fuels.

10 References

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11 Monitoring Factsheets

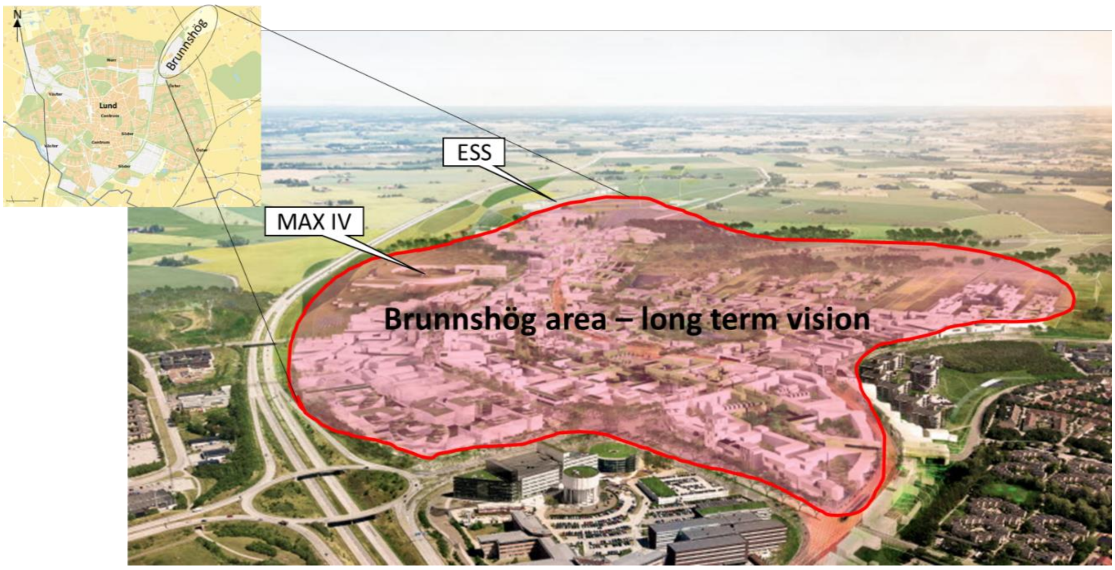
COOL DH - Lund

General Data

55°7029’N 13°1929’E

Country	Sweden
Region	Skåne
City	Lund
Start of COOL DH activities	1st October 2017
End of COOL DH activities	31st October 2022

Demonstration	Xplorion	MAX IV	Lomma	Brunnshög
Type of RES	PV, and RES DH driven hot water booster heat pump and 3-pipe	RES drivenheat pumps for coproduction of cooling and heating	Heat recovery pipes and suplementary heat pump	RES based Low Temperature District Heating network
Installation type	Smart building solutions	Surplus heat recovery	Heat loss recovery PEM40 pipes	PE-RT pipe network
Year of installation	2020	2018	2021	2021
Adress	Brunnshögsgatan 19, Solbjerstorget 1-3, 221 01 Lund	Fotongatan 2, 224 84 Lund	Gustavshemsvägen 1A, 227 64 Lund	Brunnshög District, Lund



COOL DH
COOL DISTRICT HEATING

Xplorion - Innovation and demonstration building

General Data

Solbjer, Southern Brunnshög, Lund

New RES	HW booster, heat pump, three pipe solution
Year installed	2020
Installation type	Smart building solutions
Address	Brunnshögsgatan 19, Solbjerstorget 1-3
Heat pump capacity [MW]	35.6 kW_{heat}
Expected full load hours	2500 h/year
Gross area	4374 m²
Heated area	3606 m²
Number of flats	54
PV system	226 m²
Incoming temperature range	35-65°C

Period	**PV**	**Heat delivered**	**Supply temperature**	**Return temperature**	**Total heat consumption**	**DHW consumption**	**Space Heating**
	MWh	MWh	T_{supply} °C	T_{return} °C	MWh	MWh	MWh
January 2021	n.a.	36.830	61,2	55,4	32.160	8.915	23.245
February 2021	n.a.	33.250	61,2	54,2	29.000	6.983	22.017
March 2021	3,87	28.000	61,2	52,5	23.456	7.139	16.317
April 2021	5,29	20.100	59,1	51,6	15.600	6.423	9.177
May 2021	5,61	14.110	62,2	49,5	9.653	6.788	2.865
June 2021	6,25	8.830	61,0	48,2	4.973	5.047	-
July 2021	5,30	7.690	60,7	47,9	4.055	4.369	-
August 2021	4,48	8.490	60,7	47,9	4.673	4.974	-
September 2021	4,26	9.470	58,4	52,8	5.702	5.520	182
October 2021	2,59	14.990	55,5	48,4	10.803	5.993	4.810
November 2021	1,97	21.710	61,7	54,4	17.577	6.418	11.159
December 2021	2,27	34.090	61,0	54,4	29.792	5.681	24.111
Total	**41,9**	**237.560**	**60,3**	**51,4**	**187.444**	**74.250**	**113.883**
January 2022	2,59	30.340	61,0	53,4	26.205	6.037	20.168
February 2022	2,19	25.600	61,8	45,2	22.159	5.306	16.853
March 2022	5,01	22.470	60,8	32,4	19.119	6.120	12.999
April 2022	6,84	17.100	61,7	27,6	13.953	6.286	7.667
May 2022	8,67	8.850	60,4	29,2	5.610	6.067	-
June 2022	7,96	6.910	62,8	32,1	3.951	5.262	-
July 2022	8,49	5.910	60,7	32,4	3.014	4.599	-
August 2022	14,76	5.620	61,0	33,0	2.854	2.854	-
September 2022	3,50	6.760	60,0	31,0	3.816	3.816	-
October 2022							
November 2022							
December 2022							
Total	**60,0**	**129.560**	**61,1**	**35,1**	**100.681**	**46.347**	**57.687**

Xplorion - Innovation and demonstration building

General Data

Solbjer, Southern Brunnshög, Lund

New RES	HW booster, heat pump, three pipe solution
Year installed	2020
Installation type	Smart building solutions
Address	Brunnshöggatan 19, Solbjergstorget 1-3
Heat pump capacity [MW]	35.6 kW_{heat}
Expected full load hours	2500 h/year
Gross area	4374 m²
Heated area	3606 m²
Number of flats	54
PV system	226 m²
Incoming temperature range	35-65°C

Period	**Heat delivered**	**Flats**	**Bike Garage**	**Laundry**	**Common room**	**Ventilation**
	MWh	MWh	MWh	MWh	MWh	MWh
January 2021	36.830	29.306	1.897	559	245	153
February 2021	33.250	26.163	2.002	235	258	342
March 2021	28.000	21.279	1.517	379	236	45
April 2021	20.100	14.434	505	447	179	35
May 2021	14.110	9.205	113	174	125	36
June 2021	8.830	4.823	-	18	99	33
July 2021	7.690	3.922	1	7	61	64
August 2021	8.490	4.547	-	25	67	34
September 2021	9.470	5.537	-	51	82	32
October 2021	14.990	10.328	126	205	107	37
November 2021	21.710	16.601	505	313	116	42
December 2021	34.090	27.309	1.701	482	130	170
Total	**237.560**	**173.454**	**8.367**	**2.895**	**1.705**	**1.023**
January 2022	30.340	24.239	1.381	314	155	116
February 2022	25.600	20.378	1.256	286	183	56
March 2022	22.470	17.641	1.000	269	167	42
April 2022	17.100	12.971	451	334	160	37
May 2022	8.850	4.988	-	466	119	37
June 2022	6.910	3.499	-	303	117	32
July 2022	5.910	2.619	-	288	73	34
August 2022	5.620	2.834	-	371	66	33
September 2022	6.760	3.388	-	316	79	33
October 2022						
November 2022						
December 2022						
Total	**129.560**	**92.557**	**4.088**	**2.947**	**1.119**	**420**

COOL DH
COOL DISTRICT HEATING

MAX IV - Heat recovery system

General Data

Brunnshög district, Lund, Sweden

New RES	Heat recovery
Year of installation	2018
Installation type	Surplus heat recovery
Address	Fotongatan 2, Lund
Installed capacity - heating circuit	5.8 MW
Installed capacity - cooling circuit	5.2 MW
Tsupply/Treturn, heating loop 1	75-80°C / 45°C
Tsupply/Treturn, heating loop 2	55-65°C / 30°C
Tsupply/Treturn, cooling summer	7°C / 16°C
Tsupply/Treturn, cooling winter	22°C / 27°C
Estimated annual recovered heat	30,000 MWh

Period	**Operating hours**	**Heat delivered**	**Volume**	**Supply tempera-ture**	**Return tempera-ture**	**Heat delivered to LTDH**	**Heat delivered to DH**	**Heat delivered to MAX IV**
	h	MWh	V m^3	T_{supply} °C	T_{return} °C	MWh	MWh	MWh
September 2020	720	2.330	n.a.	76,4	47,0	82	2.170	78
October 2020	744	2.253	n.a.	75,8	43,5	127	2.002	124
November 2020	720	2.105	n.a.	76,2	45,5	125	1.847	133
December 2020	744	1.796	n.a.	76,1	47,3	153	1.461	182
Total	**2.928**	**8.484**	**0**	**76,1**	**45,8**	**487**	**7.480**	**517**
January 2021	744	1.720	52.700	76,1	48,1	194	1.297	229
February 2021	672	1.976	61.600	76,1	48,6	300	1.465	211
March 2021	744	2.116	65.700	75,9	48,3	323	1.641	152
April 2021	720	2.182	64.500	75,5	46,5	274	1.796	112
May 2021	742	2.321	62.200	75,8	43,8	265	2.000	56
June 2021	720	2.591	81.400	76,3	49,00	177	2.387	27
July 2021	737	1.618	57.300	75,6	51,4	72	1.622	65
August 2021	744	1.541	45.500	76,6	47,6	147	1.482	59
September 2021	720	2.417	65.400	76,0	44,3	202	2.215	43
October 2021	744	2.327	61.400	75,7	43,2	257	2.170	79
November 2021	720	2.328	60.300	75,7	42,6	290	1.916	122
December 2021	744	1.666	47.400	75,8	45,7	437	1.002	227
Total	**8.751**	**24.803**	**725.400**	**75,9**	**46,6**	**2.938**	**20.993**	**1.382**
January 2022	744	1.325	38.400	75,0	45,4	468	688	169
February 2022	672	1.991	50.800	75,5	41,9	392	1.448	151
March 2022	743	2.327	59.400	75,7	42,1	401	1.773	153
April 2022	720	2.332	59.700	75,3	41,8	307	1.922	103
May 2022	744	2.476	66.100	75,6	43,5	226	2.209	41
June 2022	720	2.666	83.700	75,5	48,2	180	2.458	28
July 2022	738	1.657	61.800	74,2	51,2	161	1.427	69
August 2022	744	1.864	64.400	74,9	50,5	161	1.669	34
September 2022	720	2.427	69.300	74,7	44,7	187	2.189	51
October 2022								
November 2022								
December 2022								
Total	**6.545**	**19.065**	**553.600**	**75,2**	**45,5**	**2.483**	**15.783**	**799**

*) The supply temperature over time be reduced to 65°C, when Brunnshög is develloped to utilise all the produced heat

MAX IV - Heat recovery system

General Data

Brunnshög district, Lund, Sweden

New RES	Heat recovery
Year of installation	2018
Installation type	Surplus heat recovery
Address	Fotongatan 2, Lund
Installed capacity - heating circuit	5.8 MW
Installed capacity - cooling circuit	5.2 MW
Tsupply/Treturn, heating loop 1	75-80°C / 45°C
Tsupply/Treturn, heating loop 2	55-65°C / 30°C
Tsupply/Treturn, cooling summer	7°C / 16°C
Tsupply/Treturn, cooling winter	22°C / 27°C
Estimated annual recovered heat	30,000 MWh

Period	**Total cooling delivered**	**Low temp cooling**			**Medium temp cooling**		
			T_{supply}	T_{return}		T_{supply}	T_{return}
	MWh	MWh	°C	°C	MWh	°C	°C
September 2020	1.594	857	7,0	15,9	737	22,1	27,2
October 2020	1.581	823	7,0	16,9	758	22,0	27,1
November 2020	1.470	748	7,0	16,8	723	22,1	27,1
December 2020	1.261	666	7,0	15,8	595	22,1	26,8
Total	**5.906**	**3.094**	**7,0**	**16,4**	**2.813**	**22,1**	**27,1**
January 2021	1.200	673	7,0	16,6	527	22,0	26,6
February 2021	1.373	677	7,0	17,2	696	22,0	27,2
March 2021	1.464	748	7,0	17,1	716	22,1	27,1
April 2021	1.522	778	7,0	17,0	745	22,1	27,2
May 2021	1.609	837	7,0	16,4	771	22,1	27,2
June 2021	1.741	978	7,0	15,6	763	22,3	27,2
July 2021	1.129	809	7,0	14,2	320	22,0	25,4
August 2021	1.007	681	7,0	14,8	326	22,0	25,1
September 2021	1.657	892	7,0	15,6	765	22,3	27,1
October 2021	1.617	859	7,0	16,8	758	22,3	27,2
November 2021	1.617	867	7,0	17,9	749	22,4	27,2
December 2021	1.147	656	7,0	15,5	491	22,3	26,2
Total	**17.083**	**9.455**	**7,0**	**16,2**	**7.627**	**22,2**	**26,7**
January 2022	919	531	7,0	13,5	388	22,0	26,2
February 2022	1.422	735	7,0	16,3	687	22,1	27,2
March 2022	1.676	899	7,0	16,6	777	22,0	27,2
April 2022	1.679	914	7,0	16,4	764	22,0	27,2
May 2022	1.762	983	7,0	15,5	779	22,0	27,2
June 2022	1.841	1.062	7,0	16,4	779	22,0	27,2
July 2022	1.069	767	7,0	13,1	302	22,0	24,1
August 2022	1.312	914	7,5	14,5	399	22,3	25,6
September 2022	1.692	920	7,0	15,5	772	22,7	27,3
October 2022							
November 2022							
December 2022							
Total	**13.372**	**7.725**	**7,1**	**15,3**	**5.647**	**22,1**	**26,6**

MAX IV - Heat recovery system

General Data

Brunnshög district, Lund, Sweden

New RES	Heat recovery
Year of installation	2018
Installation type	Surplus heat recovery
Address	Fotongatan 2, Lund
Installed capacity - heating circuit	5.8 MW
Installed capacity - cooling circuit	5.2 MW
Tsupply/Treturn, heating loop 1	75-80°C / 45°C
Tsupply/Treturn, heating loop 2	55-65°C / 30°C
Tsupply/Treturn, cooling summer	7°C / 16°C
Tsupply/Treturn, cooling winter	22°C / 27°C
Estimated annual recovered heat	30,000 MWh

Period	Heat delivered	Total cooling delivered	Electricity consumption	COP		
	MWh	MWh	MWh	COPh	COPc	COPt
September 2020	2.330	1.594	806	2,89	1,98	4,87
October 2020	2.253	1.581	757	2,98	2,09	5,06
November 2020	2.105	1.470	729	2,89	2,02	4,90
December 2020	1.796	1.261	641	2,80	1,97	4,77
Total	**8.484**	**5.906**	**2.933**	**2,89**	**2,01**	**4,91**
January 2021	1.720	1.200	638	2,70	1,88	4,58
February 2021	1.976	1.373	725	2,73	1,89	4,62
March 2021	2.116	1.464	765	2,77	1,91	4,68
April 2021	2.182	1.522	762	2,86	2,00	4,86
May 2021	2.321	1.609	793	2,93	2,03	4,96
June 2021	2.591	1.741	913	2,84	1,91	4,74
July 2021	1.618	1.129	673	2,40	1,68	4,29
August 2021	1.541	1.007	560	2,75	1,80	4,55
September 2021	2.417	1.657	818	2,95	2,03	4,98
October 2021	2.327	1.617	779	2,99	2,08	5,06
November 2021	2.328	1.617	793	2,94	2,04	4,98
December 2021	1.666	1.147	590	2,82	1,94	4,77
Total	**24.803**	**17.083**	**8.809**	**2,82**	**1,94**	**4,75**
January 2022	1.325	919	490	2,70	1,88	4,58
February 2022	1.991	1.422	654	3,04	2,17	5,22
March 2022	2.327	1.676	760	3,06	2,21	5,27
April 2022	2.332	1.679	757	3,08	2,22	5,30
May 2022	2.476	1.762	817	3,03	2,16	5,19
June 2022	2.666	1.841	941	2,83	1,96	4,79
July 2022	1.657	1.069	646	2,57	1,65	4,22
August 2022	1.834	1.312	696	2,68	1,89	4,56
September 2022	2.427	1.692	841	2,89	2,01	4,90
October 2022						
November 2022						
December 2022						
Total	**19.035**	**13.372**	**6.602**	**2,89**	**2,03**	**4,91**

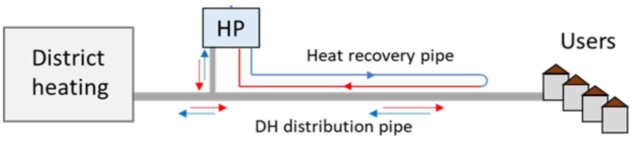
COOL DH
COOL DISTRICT HEATING

Heat recovery pipes and heat pump

General Data

Gustavshemsvägen 1A, 227 64 Lund

New RES	Heat recovery - Heat pump
Year installed	2021
Installation type	PEM40 pipes and heat pump
Address	Gustavshemsvägen 1A, 227 64 Lund
Total pipe section length [m]	100 (double)
Total capacity [kW]	6,0
Est. annual prod.	125
Total Investment cost [€]	11.668



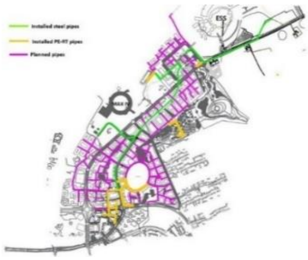
Period	**Operation hours**	**Recovered heat**	**Heat delivered to DHW**	**Brine/Isopropyl alcohol (IPA) 27%**		**Electricity consumption**	**COP**
				T_{supply}	T_{return}		COPh
	h	MWh	MWh	°C	°C	MWh	
January 2021	87	192	313	16,6	9,8	121	2,6
February 2021	183	123	378	12,8	7,4	255	1,5
March 2021	145	198	402	16,4	10,8	204	2,0
April 2021	111	159	316	19,9	15,0	157	2,0
May 2021	90	139	266	22,5	17,4	127	2,1
June 2021	58	82	162	28,4	24,4	80	2,0
July 2021	77	198	308	29,9	25,2	110	2,8
August 2021	127	399	594	26,2	21,6	195	3,0
September 2021	173	623	903	24,3	18,6	280	3,2
October 2021	248	879	1.282	17,4	13,4	403	3,2
November 2021	261	961	1.400	14,3	10,3	439	3,2
December 2021	295	878	1.344	8,9	5,4	466	2,9
Total	**1855**	**4.831**	**7.668**	**19,8**	**14,9**	**2.837**	**2,7**
January 2022	325	966	1.476	9,7	6,1	510	2,9
February 2022	332	936	1.419	9,6	6,1	483	2,9
March 2022	341	1.067	1.609	10,2	6,6	542	3,0
April 2022	273	902	1.348	13,5	9,9	446	3,0
May 2022	235	885	1.279	18,9	15,6	394	3,2
June 2022	150	564	810	25,1	19,9	246	3,3
July 2022	109	389	560	26,4	23,4	171	3,3
August 2022	124	460	651	28,3	24,1	191	3,4
September 2022	200	790	1.122	22,7	18,3	332	3,4
October 2022							
November 2022							
December 2022							
Total	**2.089**	**6.959**	**10.274**	**18,3**	**14,4**	**3.315**	**3,1**

LTDH network in Brunnshög

General Data

Brunnshög, Lund, Sweden

New RES	LTDH network
Year installed	2020-2021
Installation type	PE-RT pipe network
Address	Brunnshög, Lund, Sweden
Total pipe length [m]	2.400
Heat delivered from	MAX IV
Heat planned from	ESS



Period	**Operating hours** h	**Total heat delivered** MWh	**Total heat consumed** MWh	**Heat loss*** MWh	**Supply temperature** T_{supply} °C	**Return temperature** T_{return} °C	**COP** MWh
January 2021	744	194	158	36	64,1	46,1	0,8
February 2021	672	300	168	132	66,6	47,0	0,6
March 2021	744	323	170	153	67,1	48,4	0,5
April 2021	720	274	125	149	67,0	49,2	0,5
May 2021	744	265	81	184	66,8	54,1	0,3
June 2021	720	177	40	137	67,0	60,8	0,2
July 2021	744	72	35	37	66,6	58,7	0,5
August 2021	744	147	45	102	66,8	57,2	0,3
September 2021	720	203	52	151	67,0	56,5	0,3
October 2021	744	257	108	149	67,0	54,2	0,4
November 2021	720	290	149	141	67,0	51,4	0,5
December 2021	744	437	262	175	67,0	48,7	0,6
Total	**8760**	**2.939**	**1.393**	**1.546**	**66,7**	**52,7**	**0,5**
January 2022	744	468	267	201	66,9	47,9	0,6
February 2022	672	392	210	182	66,9	49,0	0,5
March 2022	744	401	210	191	67,0	52,4	0,5
April 2022	720	307	135	172	67,0	54,4	0,4
May 2022	744	226	95	131	67,0	57,6	0,4
June 2022	720	180	55	125	67,0	60,0	0,3
July 2022	744	161	50	111	63,0	55,0	0,3
August 2022	744	161	Missing	Missing	64,0	56,0	n.a.
September 2022	720	187	Missing	Missing	67,0	57,0	n.a.
October 2022							
November 2022							
December 2022							
Total	**6552**	**2.483**	**1.022**	**1.113**	**66,2**	**54,4**	**n.a.**

*) The high heat losses are a result of few consumers. This leads to highger return temperatures and higher heat losses.