

D2.2 - REWARDHeat planning guidelines



Renewable and Waste Heat Recovery for Competitive District Heating and Cooling Networks

REWARDHeat



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1 Introduction

REWARDHeat is a Horizon2020 research project dealing with next-generation district heating and cooling (DHC) networks. The goal of the project is to demonstrate ultra-low and neutral temperature thermal networks and the recovery of available urban waste heat. This deliverable is part of WP2 - Design of low-temperature networks with multiple energy sources which has an objective of developing a database of solutions for next-generation DHC networks and developing the REWARDHeat predesign tool. The project is dealing with next-generation district heating and cooling networks with extremely low network temperatures, sometimes reaching ground temperatures, as shown in Figure 1. The main characteristics of such systems are low thermal network losses, large-scale integration of renewable and waste heat sources, and temperature-boosting devices in substations (usually heat pumps).

This document presents deliverable D2.2 - REWARDHeat planning guidelines. It contains selected information from Deliverable D2.1 - REWARDHeat PLANNING schemes database [1], presented as reliable design rules and recommendations. The planning guidelines are focusing on the most important planning issues of the next-generation district heating and cooling networks: demand balancing, temperature regimes, heat sources selection, network dimensioning, and end-user substation selection. Furthermore, three thermal network types have been selected and discussed: neutral temperature district heating (NTDH), ultra-low temperature district heating (ULTDH), and sub-networks district heating and cooling systems.

In addition to this, for this deliverable online database has been developed, available via this [link](#). The database consists of more than 100 existing case studies, with additional info available such as general description, topology visualization, location, heat source type, end-users, and other data.

The deliverable is divided into several sections. Section 2 proposes energy planning guidelines related to different topics, while Section 3 shows selected thermal networks and provides a short description of each. Finally, Section 0 concludes the report.

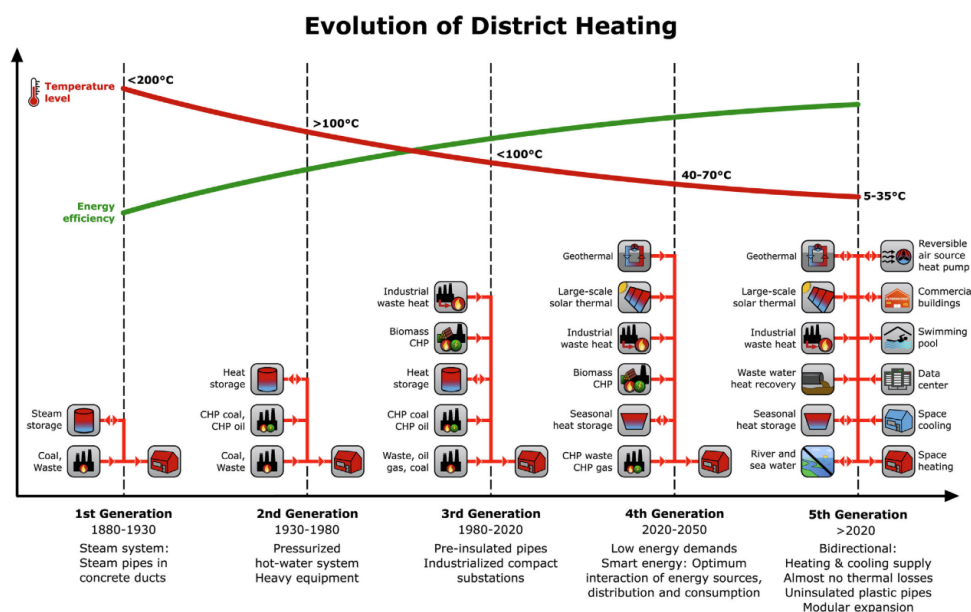


Figure 1 Next-generation district heating systems overview [2]

2 Planning guidelines for next-generation DHC networks

This section shows planning guidelines for next-generation DHC networks from selected topics: demand balancing, temperature regimes, heat source selection, network dimensioning, and end-user substation selection. These topics have been selected according to the literature review carried out in Deliverable D2.1 - REWARDHeat PLANNING schemes database.

According to the literature review and overview of existing next-generation DHC networks, we noticed that almost every system is unique. Due to this, the following guideline should be treated as general recommendations. Each system has unique characteristics, resulting in case-specific substations and network layouts. The technical and economic feasibility of the network should be analysed in detail by using different numerical tools, such as the REWARDHeat predesign tool.

2.1 Thermal demand – heating and cooling should be in balance

In most next-generation DHC networks there are three possible thermal demands: space heating, domestic hot water production, and cooling. It should be noticed that in next-generation networks a single end-user can have all three thermal demands, even simultaneously. If this is the case, the end-user substation should be carefully selected. Heating and cooling demands in the network should ideally be in balance, both in time and volume.

The thermal network should be used both as a heat source and a heat sink

Next-generation DHC networks have the possibility of covering both heating and cooling loads simultaneously by introducing so-called warm and cold pipes. As already mentioned, temperature regimes are extremely low, reaching 5-35°C. Both can serve as supply and/or return. Heating consumers are recovering heat from warm pipes (and returning cooled water in the cold pipe) and use the network as a heat source. Cooling consumers are rejecting heat to cold pipes (and returning warmed water to warm the pipe) and using the network as a heat source. Next-generation DHC network should be used for both heating and cooling, ideally at the same time.

Next-generation DHC networks should be energy bi-directional

Bi-directional thermal energy exchange between final customers and the network is the most important advantage of NTDH systems. It allows thermal energy recycling and minimizes external energy supplied to the network. However, not all NTDH networks are utilizing this possibility. In the ideal case, heating and cooling demands in the network are balanced, thus no additional heating or cooling sources are needed.

Heating and cooling demand should be balanced to recycle thermal energy in the DHC network

Demand balance can be quantified by introducing a demand overlap coefficient (DOC). It has been shown that the higher DOC the higher the exergy efficiency of the system. Moreover, district energy systems with bi-directional networks have lower specific supply costs if a district DOC exceeds 0.45. The better economic and thermodynamic performance of systems with large district DOC is a result of the larger potential for balancing demands in the districts. Higher the demand overlap coefficient the better the system coefficient of performance (COPC) and the specific cost is lower. Furthermore, it can be noticed that networks with higher cooling demand have better system COP.

End-users should be carefully selected according to their thermal demand type and capacity

End-users can have various thermal needs such as heating, domestic hot water, and cooling. Furthermore, they can come from various sectors such as residential (households), tertiary (supermarkets, shopping malls, data centers), or even industrial. They can be different in size (capacity), which means that the network layout could be appropriate for the “largest” end user. Furthermore, end-users usually have different demand temperature regimes. The network operator should try to select the users to increase balancing demands across the network, both in time and energy volume.

Energy balancing could be done at the network and substation level

The main role of a network operator is to provide balancing energy in the system. In other words, if cooling is dominantly used, the balancing operator should serve as a heating sink – i.e. “cool down” the network. And vice versa – if the heating is dominantly used, the network operator should use the central station as the heat source. However, there is an additional option. In some cases, energy balancing can be done at the substation level, since some end-users need cooling and heating energy simultaneously (or also DHW during summertime). This demand overlap can be used locally and enable heat pump-based substations to link the heat source and heat sink. This enables the reduction of the system operating costs. However, in that case, end-user substations should be appropriately selected.

2.2 Temperature regimes – as low as possible, but carefully selected

Next-generation DHC networks have extremely low-temperature regimes, usually reaching ground temperatures around 10-35°C. Furthermore, the temperature difference between warm and cold pipes is relatively low, around 5-10°C. Detailed analysis is needed for the selection of temperature regimes across the whole DHC system (heat source/sink – central unit – thermal network – end-user substation). The goal should be to obtain as high system COP as possible, while at the same time satisfying all end-user needs.

Residential end-user should have low-demand standards, resulting in low heating temperature regimes

Residential end-users are the most common end-user of thermal networks. To enable high efficiency of the overall system, temperature boosting at end-user substations should be as low as possible. This means that space heating temperature regimes should also be as low as possible. This results in well-insulated buildings with floor space heating. Although well-refurbished buildings have low-temperature space heating demands, domestic hot water temperature conditions remain the same. Domestic hot water production calls for high temperature boosting and results in low substation efficiencies. Due to this, DHW production should be treated with care.

In any case, network supply temperature must be selected and adapted along the year for the boosting substation effectiveness to be high enough both from the technical and operation costs perspectives. This allows integrating existing buildings while they are waiting to be renovated.

Tertiary sector end-users should clearly define their temperature needs since they can vary significantly

Tertiary sector end-users such as supermarkets, shopping malls, hospitals, etc. are relatively complex since they usually have specific thermal needs and temperature regimes. Furthermore, they are sometimes representing a high share of the overall demand. Due to this, temperature

regimes of their thermal demands should be studied in detail while focusing on temperature regimes, capacity, and seasonality.

Temperature regimes of the thermal network should be aligned with the central thermal unit and end-user substation types

As already mentioned, temperature regimes of the overall next-generation DHC system should be selected in such a manner that the overall efficiency of the system is the highest. In case that balancing unit is based on a low-temperature renewable energy source such as water, ground, groundwater, or air, a connection via a heat exchanger or heat pump is a possible option. In most next-generation DHC systems, the largest share of temperature boosting is done only once – at the central station or the end-user heat pump-based substation. In case the central unit is providing the boosting, thermal network temperature regimes can be higher than 30°C. However, if the end-user substations are performing most of the temperature boosting, thermal network temperatures can be kept at around ground levels, around 15°C.

Temperature regimes of the network usually have seasonal effect

Thermal demands of end-users are not constant, they have daily, weekly and seasonal changes. Due to this, optimal temperature regimes of the network will also change on the seasonal time scale. There is no “silver bullet” solution for defining optimal temperature regimes since the final choice mainly depends on the end-user structure. For example, If the thermal network is dominantly providing cooling, temperature regimes sometimes could be even kept low during the winter season. However, most next-generation DH networks have ambient-air compensation and usually are increasing supply temperatures in case ambient air is too low.

2.3 Thermal central unit sizing – providing a balance to the system

In next-generation DHC systems, the role of a system operator is to provide a balancing of the thermal demand in the network. This is usually carried out by using renewable energy sources/sinks such as water, ground, groundwater, or air. The selection of the thermal balancing source/sink usually depends on its availability. It should be mentioned that although air is always available it is seldom used since the ambient air temperature does not correlate well with seasonal variations in thermal energy needs. The most often used renewable energy source/sink is ground or groundwater as borehole thermal storage (BTES) or aquifer thermal storage (ATES.)

Thermal balancing unit capacity can be smaller than the total load of the system

The capacity of the thermal balancing unit can be smaller than the peak load of the system due to two crucial reasons. Firstly, if the end-users are appropriately selected, their heating and cooling needs can potentially balance each other. In that case, the balancing unit covers only the imbalance on the system level. Secondly, decentral heat pump-based substations are also covering part of the thermal load via an electrically driven compressor. The central unit in that case must only cover the load at the evaporator side (in case of heating end-user) and load at the condenser (in case of cooling end-user).

Connect with existing DH networks to develop sub-networks where possible

Next-generation DH networks are sometimes developed as a sub-network of a larger traditional high-temperature system. Such thermal and hydraulic separation is possible via shunt or heat exchanger-based connections. In this way, low-temperature areas of the network can be separated from the rest of the system and reduce thermal losses. However, the connection can be done

another way around. Low-temperature DH network can be used as a heat source for a high-temperature network via a heat pump connection.

2.4 Network dimensioning – cost benefit between thermal and pressure losses

Although next-generation DHC systems have network layouts like the traditional systems there are crucial differences in the selection of pipe sizing, insulation, and pressure levels. All these differences are a direct consequence of reduced temperature regimes, which results in lowered temperature difference between a warm and a cold pipe. This has a direct influence on the pressure levels since a higher flow rate is needed to satisfy an equal thermal load. However, reduced temperature regimes also mean smaller thermal network losses, which sometimes result in piping buried in the ground without any insulation. All these aspects should be analyzed in detail and included in the cost-benefit analysis of the network investment and sizing.

Decentral heat production is reducing the thermal network pipe size

Heat production is partially carried out on-spot, in end-user heat pump-based substations. This means that the network can have a capacity lower than peak demand. In other words, the capacity of the network is equal to the peak demand of the heat pump evaporator thermal load. This is crucial information for DHC network developers since thermal network piping size will be reduced. This presents additional savings on the system level which must be considered.

Network dimensioning is directly influenced by temperature regimes

Due to lower DH temperatures, the temperature difference could be reduced. This could mean that flow in the network needs to be increased. That could cause an increase in pipe diameters, but despite that, networks are still designed according to the largest hydraulic load (they need to withstand pressure 1,2 to 1,5 times the nominal value). This is especially important in networks that will not expand any further. Smaller pipe dimensions reduce thermal losses. However, DH networks are typically dimensioned according to a permissible specific pressure drop in the range of 50 Pa to 100 Pa per meter for the coldest day.

Pressure losses in next-generation networks should be treated with care

Due to low supply and return temperatures, the temperature difference is rather low. Such temperature regimes demand an increased mass flow rate to establish the same level of thermal load. An increase in the mass flow leads to a velocity increase. This results in a high specific pressure drop, leading to the higher pumping power needed. Permissible specific pressure losses vary in the literature. However, all agree that the permissible specific pressure drop is around 50 Pa/m and 150 Pa/m.

Substations configurations allowing to keep temperature difference between supply and return as high as possible, in the range of at least 20°C, help reaching this objective.

Although thermal losses are extremely low, they still need to be considered

Thermal losses of next-generation DHC networks are smaller than traditional networks. For the network operating at 10°C, they are about 2% of the supplied energy. This is substantially lower when compared to 60°C and 90°C DH temperature regimes which have losses of 19% and 25% respectively. An additional advantage is that next-generation DHC networks require lower piping insulation, which additionally reduces investment costs. In the case of neutral-temperature district heating network temperature levels which are similar to ground, thermal insulation can even be

avoided. This enables the reduction of operational costs and enables savings which could be used for additional investments needed in the network

2.5 End-user substations – different solutions for different end-users

According to the carried-out review of existing next-generation DHC systems, most end-user substations are heat pump-based. Such equipment is relatively complex both from the design and operational point of view. Some researchers are sometimes emphasizing that end-user substation is the core of the next-generation DHC networks. If designed and operated well, it can boost the efficiency of the overall system. However, if operated poorly, the COP of the heat pump can be reduced, thus diminishing the performance of a network. The highest potential in the development of next-generation DHC systems is correlated to the development of novel end-user substation layouts which demonstrates the importance of this topic.

Single next-generation DHC network can have multiple substation types

Next-generation DHC systems usually involve a large number of different end users, coming from different sectors with different thermal needs, temperature regimes, and capacities. Due to this, it is common that different end-users to have different layouts of substations. This is the most challenging part of the successful development of next-generation DHC networks since each end-user must be individually analysed and finally operated on in an optimal manner.

Domestic hot water production is a major issue for end-users substations in next-generation DHC

Next-generation DHC networks operate at extremely low network temperature regimes. If the end-user demands a high-temperature thermal load, this results in high-temperature boosting. Therefore, the COP of the heat pump-based substation can be significantly reduced. This is the case if domestic hot water production is carried out in end-user substations. To prevent *Legionella* growth in the system, temperatures should be boosted up to ~60°C. With the network temperature regimes of around 20°C, this means ~40°C temperature lift, resulting in COP around 2. This is a relatively low COP and could present an issue if the domestic hot water production share in the overall network is relatively large. To avoid heat pump efficiency degradation, DHW production can be carried out by using additional stand-alone technology such as electric or natural gas boiler. However, this approach does not represent an excellent solution since primary energy consumption is increased and additional CO₂ emissions are emitted with the use of fossil fuel sources. Once again, a system-based cost-benefit analysis is needed to obtain a system-optimal solution.

Heat pump-based substations could affect the quality of the power distribution network

Power-to-heat technologies, such as heat pumps, are an excellent solution for efficient heating and cooling. Heat pumps are also a key part of next-generation DHC networks. However, they could represent an issue for the power distribution system if the overall capacity is increased in the local power network. DHC planners should consider this threat and analyse if there are potential distribution problems that could arise. Although this currently does not represent an issue, researchers agree that the quality of the distribution networks will have to be assessed in case large power-to-heat capacities are distributed in a small area (neighbourhood).

3 Selected next-generation thermal networks

3.1 Ultra-low temperature district heating

3.1.1 Temperatures

ULTDH networks are DH networks with a low-temperature regime that varies from 35-55 °C in the supply line and 30-40 °C in the return line. Low supply/return temperatures result in relatively small temperature differences in the network of 15-20 °C. The use of low-temperature regimes in the network usually results in larger pipe diameters for the same level of peak capacity, but at the same time, the insulation class can be reduced due to a smaller temperature difference concerning the environment. However, defining optimal supply temperature depends on numerous boundary conditions such as ambient temperature, thermal source temperature, supply technology, linear heat demand density, etc. It can be stated that supply temperature varies during the season, and it should be defined on the case study level by using detailed analysis.

ULTDH networks are mostly based on solar thermal, as expected for such temperature regimes. Sources for ULTDH networks could also be existing high-temperature DH networks or geothermal heat sources. ULTDH can use existing DH for heat source if they are connected with the supply/return line via shunt or heat exchanger.

3.1.2 Layout

There are two most common ULTDH network layouts:

- ring layout
- tree (mesh) layout.

Both layouts have some specific features. The most widespread network layout is a tree structure network where it is necessary to install balancing valves to equalize the flow and pressure at the entrance to consumer substations. Tree layout also uses network street circulation bypasses to keep network temperature above the minimum temperature setpoint. They simply mix water from the supply line into the return line. The result of them has increased return temperature which then causes increased heat losses.

To avoid valve installation and hydraulic imbalances when they are applied, a ring structure is used. To achieve hydraulic balance each consumer, have an equal length of pipes. The supply line begins with the heat source and ends with the last consumer in the network. The return line, in this network topology, begins with the first consumer and ends with a heat source. In this network typology, both supply and return flow have the same direction. Ring layout can achieve significant energy savings when supply water can flow through the whole network. On the other side, negative effects are higher pumping power (because of the increase of differential pressure), longer pipes, and installation of additional valves and pumps to balance flow in the network. Despite all that, heat savings are significant compared to tree layout.

3.1.3 Thermal and pressure losses

Losses of the thermal network losses depend on many factors, such as commissioning year, heat demand density, and temperature regimes. Furthermore, it depends on the pipe type and diameter, as well as insulation thickness and the temperature gradient between the pipe and the

surrounding ground. Considering all the above, it is estimated that heat losses in ULTDH networks are usually lower than 10%. On the other side, pressure losses are higher.

Due to low supply and return temperatures, the temperature difference is rather low. Such temperature regimes demand an increased mass flow rate to establish the same level of thermal load. An increase in the mass flow leads to a velocity increase. This results in a high specific pressure drop, leading to the higher pumping power needed which causes higher operational costs.

3.1.4 Substations

ULTDH networks are suitable for low-temperature space heating, such as floor heating. However, they are too low for domestic hot water production. Due to this, the ULTDH substation always includes a direct heat exchanger for space heating purposes and a booster heater unit to provide temperature regimes that are suitable for preventing *Legionella* bacteria occurrence in the DHW system of the building.

The development of ULTDH substations is the topic of many research studies. There are numerous reports dealing with the analysis of the most suitable ULTDH substations and there are many solutions that are proposed. There are four most installed ULTDH substations:

1. Solution based on booster heat pump combined with district heating storage unit
2. Solution based on micro booster heat pump
3. Solution based on booster air-water heat pump
4. Solution based on booster boiler unit (electric, gas, or biomass boiler).

All the proposed solutions have similar common-basic characteristics:

- Space heating can be covered directly by using a direct heat exchanger, while domestic hot water demand should be covered via a booster unit or additional heater
- Substations must use boosting technology such as an electrical heater (simple solution) or booster heat pump (more com)
- Substation design is more complex since it includes DHW booster technology
- Investment is increased due to booster technology
- Bi-directional energy exchange with a thermal network is possible but limited.

3.1.5 Sub-networks

ULTDH have an additional advantage, which is that they can be integrated as sub-networks of the existing traditional district heating networks. In this sub-networks type, the temperature regime of the traditional district heating system is different from the temperature regime of the sub-network. There are different implementations, but in this report, we will focus on ULTDH sub-networks where the traditional district heating system serves as the heat source for the network, as, shown in Figure 2.

ULTDH networks are usually part of a larger DH system and are hydraulically separated using heat exchangers or shunt connections. The advantage of such a system is that there is a constant high-temperature heat source, and no additional technology is required to connect the network and sub-network (there is no BHP). Also, the use of sub-networks enables the separation of consumers who do not need a high temperature for heating, and thus primary and final energy savings are

achieved. The disadvantage of such systems is the complex control and operating system and the case when a shunt connection is used due to the potential occurrence of significant pressure drops.

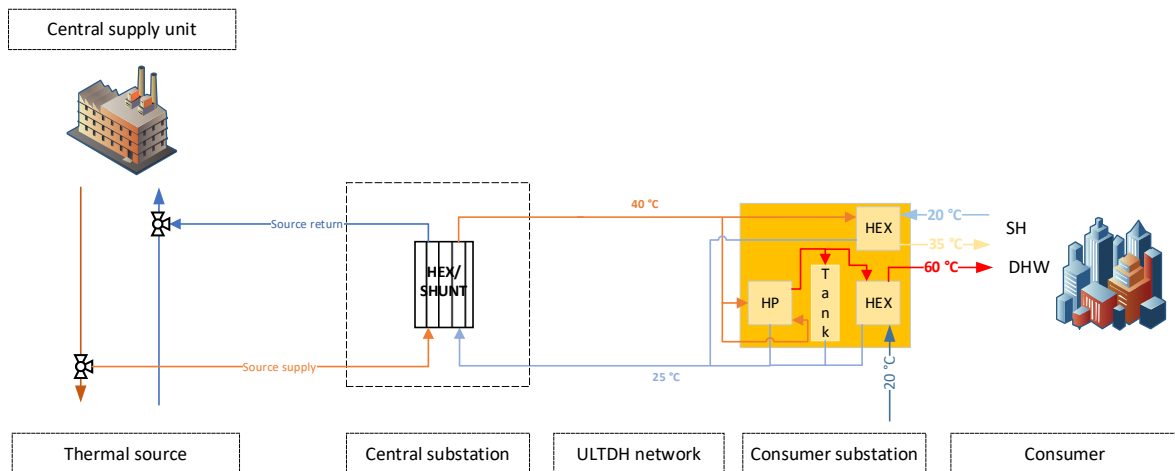


Figure 2 ULTDH thermal sub-network - traditional DH system serves as a heat source for the ULTDH network

3.1.6 Overview

Table 1 provides an overview of the definitions and configurations of the ULTDH network.

Table 1 ULTDH - General Overview

	ULTDH
Definition	Ultra-low temperature district heating system which needs booster heater in consumer substation to deliver DHW with suitable temperature level (55-60 °C).
Temperature	Network supply temperature up to 50°C with the return of 20-35 °C
Heat carrier	Water-based brine in closed loop
Space heating production	Floor heating or low-temperature radiator in a secondary loop (30-40°C). Network temperatures are high enough to provide low-temperature heating.
Domestic hot water production	Domestic hot water temperature should be increased up to 55-60 °C to prevent Legionella growth. To achieve this temperature, booster heating units are needed.
Cooling production	Not possible
Bidirectional energy exchange	Not possible

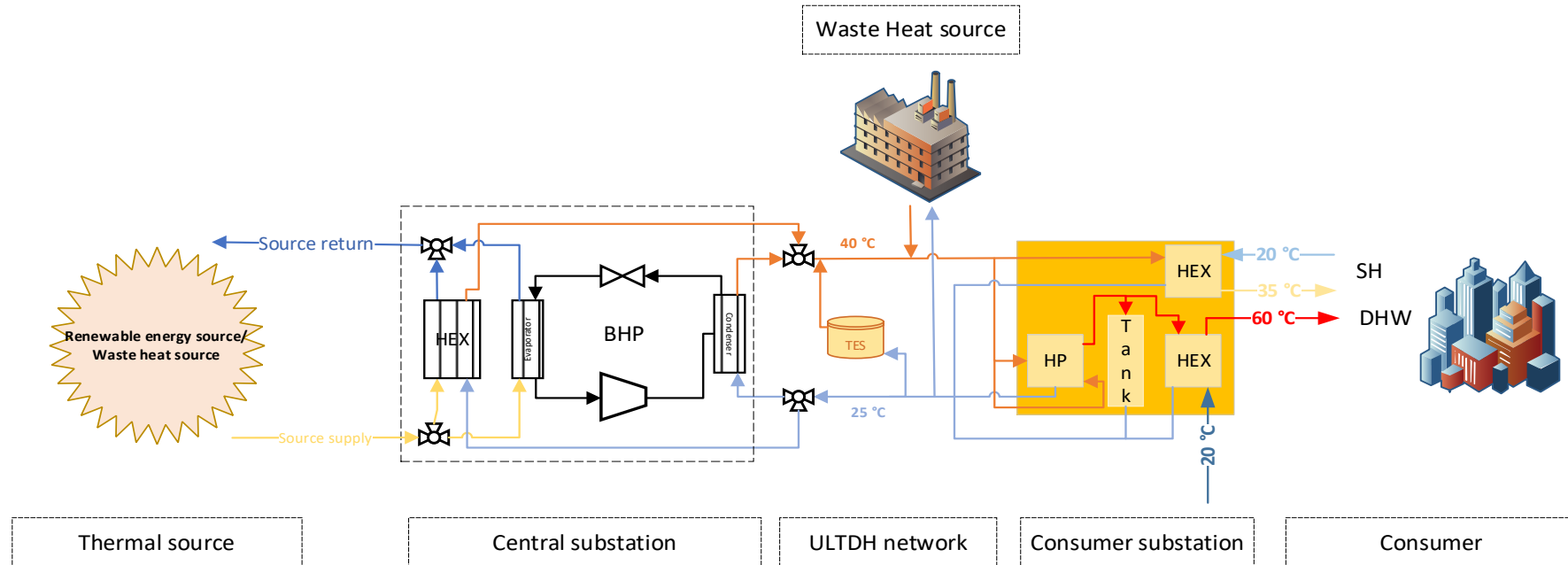


Figure 3 ULTDH - Network Configuration example

Table 2 ULTDH – examples of practice

Location	Country	Heat source	Central substation	Thermal Energy storage	Consumer substation	DHW production
Drake Landing Solar Community, Okotoks, Alberta	Canada	Solar	BHP/HEX	Yes	HEX for SH, HP for DHW	Sollar collectors
Geding	Denmark	Solar	BHP/HEX	Yes	HEX for SH, HP for DHW	-
Mieres (Barredo), Asturias	Spain	Ground	BHP	No	HEX for SH	Natural Gas
Kassel	Germany	Ground/Solar	BHP	Yes	HEX for SH	Sollar collectors
Albertslund South	Denmark	Existing DH	Shunt	No	HEX for SH, HP for DHW	-

Figure 3 shows an example of a ULTDH network configuration. The heat source in the ULTDH network can be a renewable source (ground, groundwater, sea, river, etc.) or a waste heat source (wastewater treatment plants, data centers, etc.). The heat from the source is transferred to the network via a HEX or BHP depending on the network temperature. The HEX and BHP form a central heat substation between the source and the network. In the case when the temperature of the source is higher than the temperature in the network, the heat is transferred through the HEX, while in the opposite case, the BHP is used. The ULTDH network can contain thermal energy storage (TES) or another waste heat source that enables to keep the flexibility and balance of the system. The consumer substation has a simple design and can be divided into a part for heating and a part for DHW preparation. The part of the substation that serves for heating consists of a HEX since the temperature in the network is usually higher than the temperature needed for low-temperature heating systems (underfloor heating and fan convectors). For DHW preparation HP raises the temperature level required for the DHW (55 to 60 °C). A hot water tank can be placed between the HP and HEX circuit in the DHW preparation circuit to reduce the usage of the HP. Also, in some versions, it is possible to connect the hot water tank via HEX to the heating circuit, which can preheat the water for DHW and thus improve the HP performance. Consumer substations can be simpler as well as complex in design, which may require a more complex design. In that case, the substation control system is conducted from the central system.

Table 2 provides examples of ULTDH networks and a short overview of them.

3.2 Neutral temperature district heating

3.2.1 Temperatures

NTDH networks are DH networks with a low-temperature regime that varies from 12-20 °C in the warm pipe and 8-16 °C in the cold pipe. Due to this, NTDH can satisfy both the heating and cooling demand of the final customer. In the case of heating demand, the circulation pump of the building withdraws water from the warm line, uses it in a heat pump to reach temperatures suitable for space heating and domestic hot water, and then discharges the cooled water to the cold line. In the case of cooling demand, the system works in the other direction. It takes water from the cold line, heats it, and discharges it in a warm pipe. Due to this, the control of the system is rather complex. It is important to notice that booster heating devices are needed both for space heating and domestic hot water production. NTDH network is used as a heat pump source (in the evaporator) for heating and DHW or heat pump sink (condenser) for cooling. In case of low temperatures in the network, cooling can be used directly, thus increasing the efficiency of the system. NTDH networks are mostly based on the ground, groundwater, and waste heat as the thermal source, as expected for such temperature regimes.

3.2.2 Layout

The NTDH network is divided into primary and secondary circuits to avoid direct heat exchange between the heat source and end-users. NTDH network can handle the different thermal loads of users at the same time:

- When a consumer uses a network for cooling purposes
- When a consumer uses a network for heating purposes
- When a consumer uses a network for both cooling and heating purpose.

Furthermore, the secondary circuit in the NTDH network offers pre-heating, e.g., during the winter season when the thermal source temperature is too low. In this case, it is assumed that heating and cooling loads are in equilibrium. If this is not the case, it is necessary to integrate the loop with a heat rejecter (i.e., cooling tower or geothermal heat exchanger), heat supplier (i.e., boiler or geothermal heat exchanger), or energy storage. The important aspect to be considered is the number of final customers. The higher the number of simultaneous requests for heat and cold the greater the possibility to limit the temperature variation of cold ring water.

3.2.3 Thermal and pressure losses

Thermal losses of NTDH are smaller than in ULTDH networks. For the network operating at 10 °C, they are about 2% of the supplied energy. The additional advantage is that NTDH networks require lower piping insulation, which reduces investment costs. Reduced thermal losses are one of the most important aspects of using NTDH networks. This enables the reduction of operational costs and enables savings which could be used for additional investments needed in the network.

3.2.4 Bidirectionality

Bi-directional thermal energy exchange between final customers and the network is the most important advantage of NTDH systems. It allows thermal energy recycling and minimizes external energy supplied to the network. Bi-directional NTDH networks provide a cost reduction (investment and operational cost) and could cause less CO₂ emission compared to the individual HVAC systems. Bi-directional NTDH networks have complex and challenging control which finally enables lower electricity consumption due to the higher COP values. The important aspect to model control systems for bi-directional NTDH is the ratio of heating and cooling demand. The ratio of heating and cooling demand is important for the planning of the network.

Bi-directional NTDH networks are excellent for networks with similar heating and cooling demands. In that case, the network can be used for demand balancing. Also, it is worth mentioning that the utilization of all available waste heat sometimes is not profitable since it raises network temperature and diminishes the cooling capacity of the network. It has been shown that cooling towers are an economically feasible option since they increase the flexibility of the system.

3.2.5 Reservoir network

Another specificity that NTDH networks can offer is that they use only one pipe in their network, such networks are also called reservoir networks, which enable simultaneous heating and cooling. The biggest advantage of reservoir networks is that they need only 50% of the pipe length. For this reason, it is economically feasible to increase pipe diameter. Although there will be an increase in the diameter of the pipe, the reduction in the length of the pipeline will still have an economic advantage and the targeted effect will be achieved.

3.2.6 Potential issue

The physical and chemical water properties of the NTDH network are a crucial issue, especially when the thermal source is circulating directly in the network. For this reason, secondary and primary circuits in NTDH networks should be used. High levels of hardness and/or contaminant concentration may result in a high risk of clogging and/or damage to the pipeline components, like valves or heat exchangers.

One of the challenges in bidirectional networks is managing complicated hydraulics. Bi-directional networks have specific control challenges such as pump-to-pump interaction. The problem also

occurs in the case of prosumers of different sizes – large prosumers affect mass flow through small circulate pumps of other prosumers. This can sometimes reverse flow, freezing damage in heat pumps, or even cavitation in the circulation pumps.

3.2.7 Substations

Neutral temperature district heating substations must be capable of providing temperature boost both for domestic hot water and space heating. The most common technology used is a water-to-water booster heat pump in different configurations. Besides space heating and domestic hot water, NTDH networks can also supply space cooling and substations should also be designed in that manner. Space cooling can be covered directly via a heat exchanger from a cold pipe or by using a booster heat pump and NTDH network as a heat sink.

There are three most used NTDH substations:

1. Solution – water-to-water booster heat pump is connected to the thermal network to provide heating and cooling.
2. Solution – redundant heat exchanger used between thermal network and booster heat pump.
3. Solution – the most complex solution and involved two diverter 3-way valves on the primary loop. This enables to rejection of separately hot water in the warm pipeline and cold water in the cold pipeline, avoiding thermal mixing within the network.

All the proposed solutions have similar common-basic characteristics:

- Both space heating and domestic hot water demand cannot be covered directly due to low-temperature regimes in the thermal network. Boosting technology, such as a heat pump is needed
- Substations are usually based on water-water heat pumps with relatively high COP due to small temperature differences between the heat source and heat sink
- Substations are relatively complex, resulting in high investment.
- Operation is relatively complex, and the thermal network operator usually must be responsible and is the owner of the equipment
- Low operational cost due to high COP of heat pump
- Possible to cover the cooling demand
- Bi-directional energy exchange with the thermal network is possible.

NTDH substations are more complex and bigger than traditional DH systems. First, they require booster technology, usually a heat pump. Secondly, due to low-temperature regimes, the temperature drop across heat exchangers is relatively low which requires a high heat exchange surface area for the same level of heat demand. Thirdly, these systems usually need cold and/or hot water thermal storage. All of this can become a crucial issue since additional space in the building should be reserved. This is quite problematic for existing buildings that are connecting to the NTDH network.

3.2.8 Sub-networks

Looking from the perspective of NTDH networks, there are two types of sub-networks that NTDH can support:

- traditional DH system that serves as a heat source for the NTDH network,
- NTDH serves as a heat source for the ULTDH network.

The first sub-network type is explained in Chapter 3.1.5. In this chapter, the focus will be on the second type of NTDH sub-networks, shown in Figure 4.

In the case when the NTDH network serves as a heat source for the ULTDH network, it is necessary to use a BHP in the central substation. Then the NTDH network is the source and the ULTDH network is the sink for the BHP. This sub-network type enables the minimization of thermal losses while users with different thermal loads (heating, cooling, or simultaneous heating and cooling) can be simultaneously supplied. The advantages of this type of sub-networks are low thermal losses and a higher BHP COP. On the other side, the disadvantage of this sub-network type is the challenging planning and complex expansion of the network. Also, the control system and balancing of these sub-networks are more complex since the capacities of the networks need to be in balance.

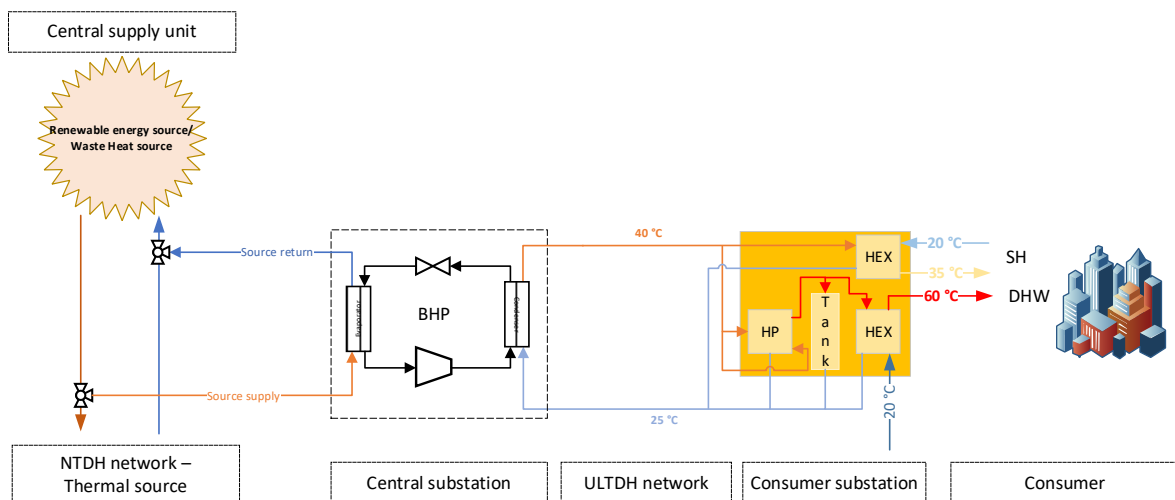


Figure 4 NTDH thermal sub-network – NTDH serves as a heat source for the ULTDH network

3.2.9 Overview

Table 3 provides an overview of the definitions and configurations of the NTDH network.

Table 3 NTDH - General Overview

	NTDH
Definition	Neutral temperature district heating system which needs booster heaters in consumer substation to deliver space heating and DHW with suitable temperature levels.
Temperature	Network supply temperature up to 20°C with the return of 8-15 °C
Heat carrier	Water-based brine in closed loop
Space heating production	Floor heating or low-temperature radiator in a secondary loop (30-40 °C). Network temperatures are not high enough to provide low-temperature heating, i.e., booster heating units in the customer's substation are needed.

Domestic hot water production	Domestic hot water temperature should be increased up to 60-65 °C to prevent Legionella growth. To achieve this temperature, booster heating units are needed.
Cooling production	Supply network temperatures enable cooling for end customers.
Bidirectional energy exchange	Customers and NTDH network suppliers can exchange thermal energy, thus achieving a bidirectional thermal network. In the ideal case, heating and cooling demands in the network are balanced, thus no additional heating or cooling sources are needed.

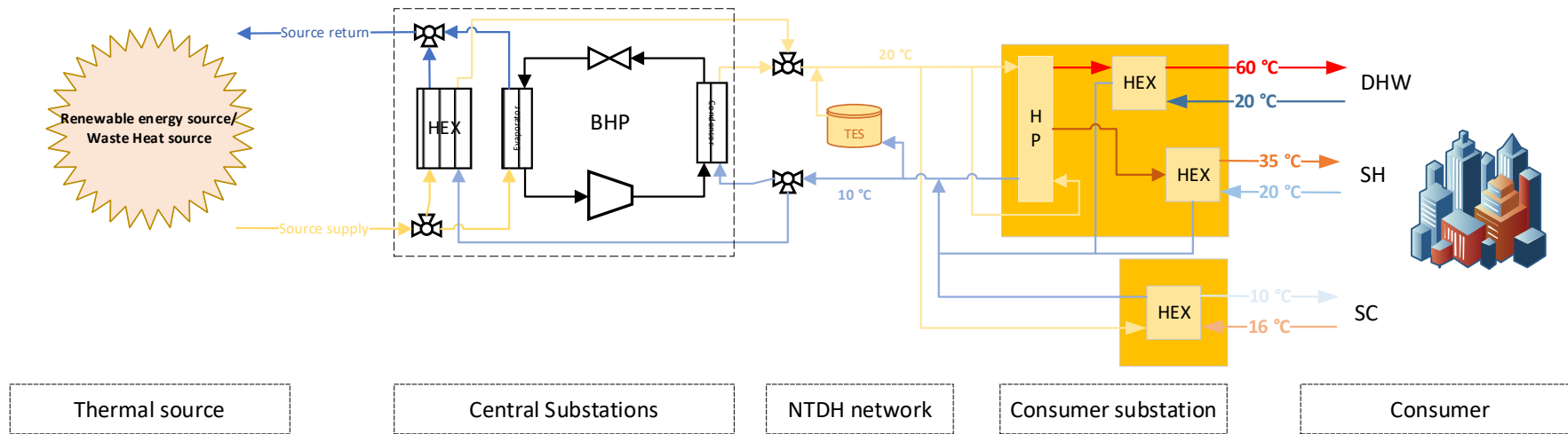


Figure 5 NTDH - Network Configuration example

Table 4 NTDH – examples of practice

Location	Country	Heat source	Central substation	Thermal Energy storage	Consumer substation
Hochvogelstraße, Biberach	Germany	Ground	BHP	Yes	HP for SH and DHW, HEX for SC
Karl-May-Weg, Fischerbach	Germany	Ground	HEX	Yes	HP for SH and DHW, HEX for SC
Broke Street, Derby	England	Ground	HEX	Yes	HP for SH and DHW, HEX for SC
Jonzac	France	Ground	HEX	Yes	HP for SH and DHW, HEX for SC
Eco district "Fort-Issy-les-Moulineaux", Paris	France	Ground	BHP	No	HP for SH and DHW, HEX for SC
Troisdorf	Germany	Groundwater	HEX	No	HP for SH and DHW, HEX for SC
Brig-Glis	Switzerland	Groundwater	BHP	No	HP for SH and DHW, HEX for SC
Sattleweg, Herford	Germany	Excess heat	HEX	No	HP for SH and DHW, HEX for SC
Visp-West	Switzerland	Excess heat	HEX	No	HP for SH and DHW, HEX for SC
Eco district "Velodrome", Marseille	France	Excess heat	HEX	No	HP for SH and DHW, HEX for SC
Schallstadt Weiermatten	Germany	Excess heat	HEX	No	HP for SH and DHW, HEX for SC

Figure 5 shows an example of an NTDH network configuration. The heat source in the NTDH network can be a renewable source (ground, groundwater, sea, river, etc.) or a waste heat source (wastewater treatment plants, data center, etc.) that transfers heat to the network via a HEX or BHP depending on the network temperature. The HEX and BHP form a central substation between the source and the network. In the case when the temperature of the source is higher than the temperature in the network, the heat is transferred through the heat exchanger, while in the opposite case, the BHP is used. The NTDH network contains thermal energy storage (TES) that enables the flexibility and balance of the system. The consumer substation has a more complex design and can be divided into a part for heating and preparation of DHW and a part for cooling. The part of the substation that serves for heating and preparation of DHW consists of HP and a HEX. The HP raises the temperature level required for the heating system and DHW. The consumer heating system is mainly a low-temperature heating system such as underfloor heating or heating with a fan convector. The NTDH network can also simultaneously cover the consumer's need for cooling. In the case of cooling, the temperature of the consumer is usually higher than in the network, therefore the water circuit of the NTDH network can be directly connected to the consumer via a HEX and thus enable the cooling. Due to the simultaneous heating and cooling, such substations require complex regulation and control that cannot be controlled by the consumer itself. Therefore, in NTDH networks, system control is conducted from the central system.

There are also versions of NTDH Consumer substations in which the preparation of DHW is separated from the heating system, and therefore an additional unit is added for the preparation of DHW usually an electric, gas, or biomass boiler.

Table 4 provides examples of NTDH networks and a short overview of them.

4 Conclusions

This document represents deliverable D2.2 – REWARDHeat planning guidelines. Deliverable D2.1 – REWARDHeat planning schemes database provided a literature review of next-generation DHC networks, categorized existing systems, and supplied best practice examples. This deliverable goes one step further and filters existing information into easy-to-use planning guidelines for network operators and investors of ultra-low and neutral temperature district heating and cooling networks. Firstly, the document provides the guidelines related to thermal demand balancing, while focusing on the importance of providing heating and cooling services simultaneously, thus reducing system operating costs and increasing the energy efficiency of the system. Secondly, the topic of temperature regime selection has been analysed. Temperature regimes across the whole system should be selected in such a manner that system efficiency is the highest. This usually results in a deep analysis of the end-user type and their thermal needs. The central balancing unit should provide temperature regimes so that central and decentral heat pump-based substations have the highest possible COP. Then, the topic of heat source selection has been tackled. According to the previously carried out literature review, temperature boosting is usually carried out only once in the network – at the central balancing unit or the substations at the end-users location. Following this, network dimensioning was discussed while mentioning important best practice examples in network layout development. Last, but not least, the selection of end-user substation types was briefly discussed, while the most common solutions have been proposed.

In addition to this, the three most used next-generation DHC network layouts have been proposed. The first one is an ultra-low temperature district heating network with temperature boosting for domestic hot water. The second one is a neutral-temperature DHC network that can provide simultaneous heating and cooling. The last layout is based on sub-networks which is utilising an existing DH network as a heating source or sink for other DHC networks.

5 References

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