Guidelines for Low-Temperature District Heating

A deliverable in the project financially supported by the Danish Energy Agency in the R&D programme EUDP (Energiteknologisk Udviklings- og Demonstration Program):

"EUDP 2010-II: Full-Scale Demonstration of Low-Temperature District Heating in Existing Buildings"

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About the guidelines

The guidelines are a deliverable of the project *"Full-scale demonstration of low temperature district heating in existing buildings"* (In Danish: *"Fuldskala demonstration af lavtemperatur fjernvarme i eksisterende bebyggelser"*) financial supported by the Danish Energy Agency in the R&D programme *EUDP* (Energiteknologisk Udviklings- og Demonstrations Program), EUDP 2010-II project Journal No. 64010-0479.

Project group

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Preface

The purpose of the guidelines is to provide recommendations for the design of the different elements in a district heating system in order to enable low temperature district heating supply aiming at a supply temperature of 50°C at the consumer. The target group is engineers and planners as well as operators of district heating networks.

The guidelines for low temperature district heating are based on a number of demonstration projects carried out in different locations in Denmark in the period 2008-2013. Low temperature district heating has been demonstrated for both, new low energy buildings and existing buildings; mainly in dwellings and in low heat density areas. Based on the lessons learned recommendation are made for the design of the district heating systems, consumer units and requirements for the single elements.

The project group would like to thank all the people that have contributed to the guideline by asking questions about the low temperature district heating concept at international occasions as the:

- 13th International Symposium on District Heating and Cooling in Copenhagen, September 2012
- IEA DHC Annex TS1 Meeting in Finland, September 2013
- DHC+ Conference in Brussels, November 2013.

Also, thanks to those of you that did take your time to comment on the draft version of the guideline

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1 Scope

The guidelines include recommendations for:

- establishment of low temperature district heating systems
- design and operation of low temperature district heating networks
- specifications for consumer connections and low temperature district heating substations
- domestic hot water and heating systems

2 Normative and other references

- DS439 (Danish Standard for domestic water installations)
- Energy Efficiency Directive (2012/27/EU)
- German Guidelines for DHW systems (DVGW, W551)
- Euroheat&Power Euroheat & Power Guidelines for District Heating Substations
- EN 253
- EN 13516

3 Terms and definitions

The basic terms and expressions used in this report are defined here below. They are based on EN 253, EN 13516 and [1]. They offer the basis for a standardized terminology for District Heating practice.

District heating system: the heating system, which supplies hot water or steam to the building thermal system from a heat generation system outside the building. The district heating system transmits heat through networks to a number of remote buildings.

Cogeneration: the simultaneous generation in one process of thermal energy and electrical or mechanical energy. Also known as combined heat and power (CHP).

Final energy consumption: all energy supplied to industry, transport, households, services and agriculture. It excludes deliveries to the energy transformation sector and the energy industries themselves.

Surplus heat: heat from industrial and commercial activities that is a by-product (not technically and/or economically feasible to avoid).

Polyurethane rigid foam (PUR): it is produced by the chemical reaction of polyisocyanates with hydroxyl containing compounds in the presence of catalysts, the foaming being assisted by a blowing agent. These foams have a mainly closed cell structure.

Media pipe: the pipe inside which the heat carrier flows, excluding the surrounding insulation. The typical materials are steel, copper or plastic (polyethylene or polybutylene). Note: in EN 253 it is called "*service pipe*", but this could cause confusion (*see House Service Connection*)

Casing pipe: the plastic pipe surrounding the insulation and the media pipe(s) and in contact with the ambient material (soil or outdoor air). It protects the insulation and the media pipe from ground water, moisture and mechanical damage.

*House Connection Pipe (*alternatively: *House Service Pip*e or *Service Pipe*): the heat distribution pipe, comprehensive of media pipe(s), insulation and casing pipe leading from the main pipeline to the consumer installation.

Branch pipe: the heat distribution pipe, comprehensive of media pipe(s), insulation and casing pipe that is connected to a main distribution pipe and serves only a fraction of the number of buildings served by the main distribution pipe. It is a relative definition, since a branch pipe can be a main distribution pipe for another branch pipe. The term can also be used to indicate a service pipe.

Main distribution pipe: the heat distribution pipe, comprehensive of media pipe(s), insulation and casing pipe that serves more than one building.

Transmission pipe: the pipe that brings the heat carrier from a major heat source (typically a CHP plant) to a distribution network and it is operated at higher pressure and/or temperature than the distribution network.

Single pipe: the single supply or return district heating pipe, comprehensive of media pipe, insulation and casing pipe.

Twin pipe: the pair of equally-sized media pipes, embedded in the same insulation and casing pipe.

Double pipe: the pair of differently-sized media pipes, embedded in the same insulation and casing pipe.

Bonded system: a system consisting of media pipe, insulation material and casing pipe bonded by the insulation material

Centre line deviation: the deviation between the centre line of the media pipe and the centre line of the casing pipe.

Supply temperature [°C]: the temperature of the heat carrier in the media pipe carrying the heat from the heat source to the heat sink.

Return temperature [°C]*:* the temperature of the heat carrier in the media pipe carrying the heat from the heat sink back to the heat source.

Continuous temperature: the temperature at which the hot water network is designed to operate continuously.

Peak temperature: the highest temperature at which a system is designed to operate occasionally.

Linear heat density [MWh/(m·yr)]: the ratio of the annual heat delivered to the consumers (at the interface building/network) and the trench length of the DH network serving that area.

4 Abbreviations

CHP	Combined Heat and Power
DH	District Heating
DHSU	District Heating Storage Unit
DHW	Domestic Hot Water
DN	Diameter, Nominal
IHEU	Instantaneous Heat Exchanger Unit
HE	Heat Exchanger
LTDH	Low Temperature District Heating
PE	Polyethylene
PEX	Cross-linked Polyethylene
PN	Pressure, Nominal
PUR	Polyurethane
RE	Renewable Energy
SH	Space Heating

5 Low temperature district heating system – definition

A number of demonstration projects have proven that the district heating supply temperature at slightly above 50°C can meet the end-user's Space Heating (SH) and Domestic Hot Water (DHW) demands in central-northern European climates, in properly designed and operated district heating networks and in-house installations.

Therefore, in these guidelines, Low Temperature District Heating (LTDH) system is defined as a system of district heat supply network and its elements, consumer connections and in-house installations, which can operate in the range between 50-55°C to 60-70 °C supply and 25-30°C to 40°C return temperatures and meet consumer demands for thermal indoor comfort and domestic hot water. This low temperature definition is pushing temperatures to the limit, see figure 1. Both new low energy buildings and existing buildings can be supplied by low temperature district heating.

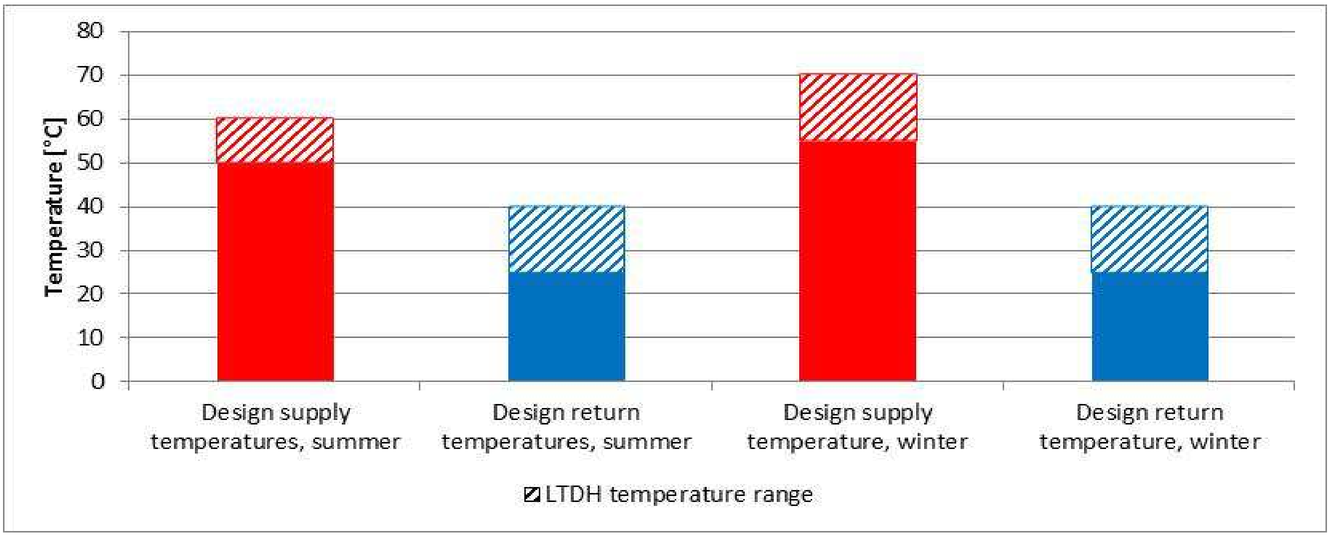

Figure 1: The range of design supply and return temperature of low temperature district heating as defined in the guidelines.

Low temperature district heating supply at temperatures at, for instance, 45°C is also possible, for meting consumers' space heating requirements. However, preparation of domestic hot water at 40-45°C requires an additional energy source. Such 'ultra' low temperature district heating is not within the scope of these guidelines.

6 Why low temperature district heating?

Low temperature district heating system complies with two main requirements for the future district heating and the whole energy sector – high energy efficiency and high share of renewable energy.

- Low temperature district heating supply has several advantages. First of all it ensures efficiency of energy supply: Energy performance requirements of new and renovated buildings set progressively lower limits on energy consumption for heating. Consequently energy efficiency on the consumer side increases considerably. However, the relative heat losses in the traditional district heating supply network increase when heat consumption in buildings decreases. At the same time better energy performance of buildings makes low temperature district heating supply possible. More important, district heating supply losses can be reduced considerably when reducing network temperatures. This increases supply side efficiency and competitiveness of district heating systems to supply also low energy buildings in low energy density areas.

Another important advantage of low temperature district heating is increased utilisation efficiency of renewable energy and low temperature resources:

- *Low temperature RE resources.* District heating supply temperature below 60°C makes geothermal plants more advantageous to satisfy the base load heat demand; similarly, it increases the efficiency of solar thermal collectors, both in case of roof applications and large-scale solar thermal field.
- *Heat pumps* - Regardless of heat source, efficiency of (electric) heat pumps is higher the lower the required district heating supply temperature is. Low DH supply temperature opens up for a broader range of heat pump technologies.
- *Surplus heat.* Utilisation of excess heat from industrial processes or by heat recovery from cooling processes is better and cheaper the lower the required district heating supply temperature is.
- *Flue gas condensation.* The low network return temperature in LTDH systems increases the possibility for flue gas condensation. This is particularly relevant for biomass/waste plants due to the high moisture content in the fuel.

Finally, lower temperatures in district heating network reduce pipeline thermal stress. As the supply temperature becomes lower, the unevenly distributed temperature gradient along the pipeline is decreased. The risk for pipe leakage due to thermal stress and related maintenance costs are therefore reduced. Furthermore, reduced thermal stress also prolongs lifetime of DH network.

The described advantages of the LTDH concept are based on [1] and [4].

Summarising, low temperature district heating brings value to district heating companies and consumers by increasing supply efficiency and to overall energy system by facilitating better utilisation of more renewable energy resources and excess energy.

7 Planning of low temperature district heating

Low temperature district heating can be supplied to both new and existing buildings. Thus LTDH systems can be established in new and existing district heating areas – in the latter case typically over a longer time horizon. Further, by sectioning/dividing into subnets, LTDH can be introduced area by area. Figure 3 shows four different applications of LTDH: a) connecting a new development area to an existing district heating system, b) establishing a small-scale district heating system in a new development area, c) connecting an existing area e.g. by replacing gas boilers with district heating or d) renovation of an existing district heating system e.g. as part of a general strategy to reduce supply temperature.

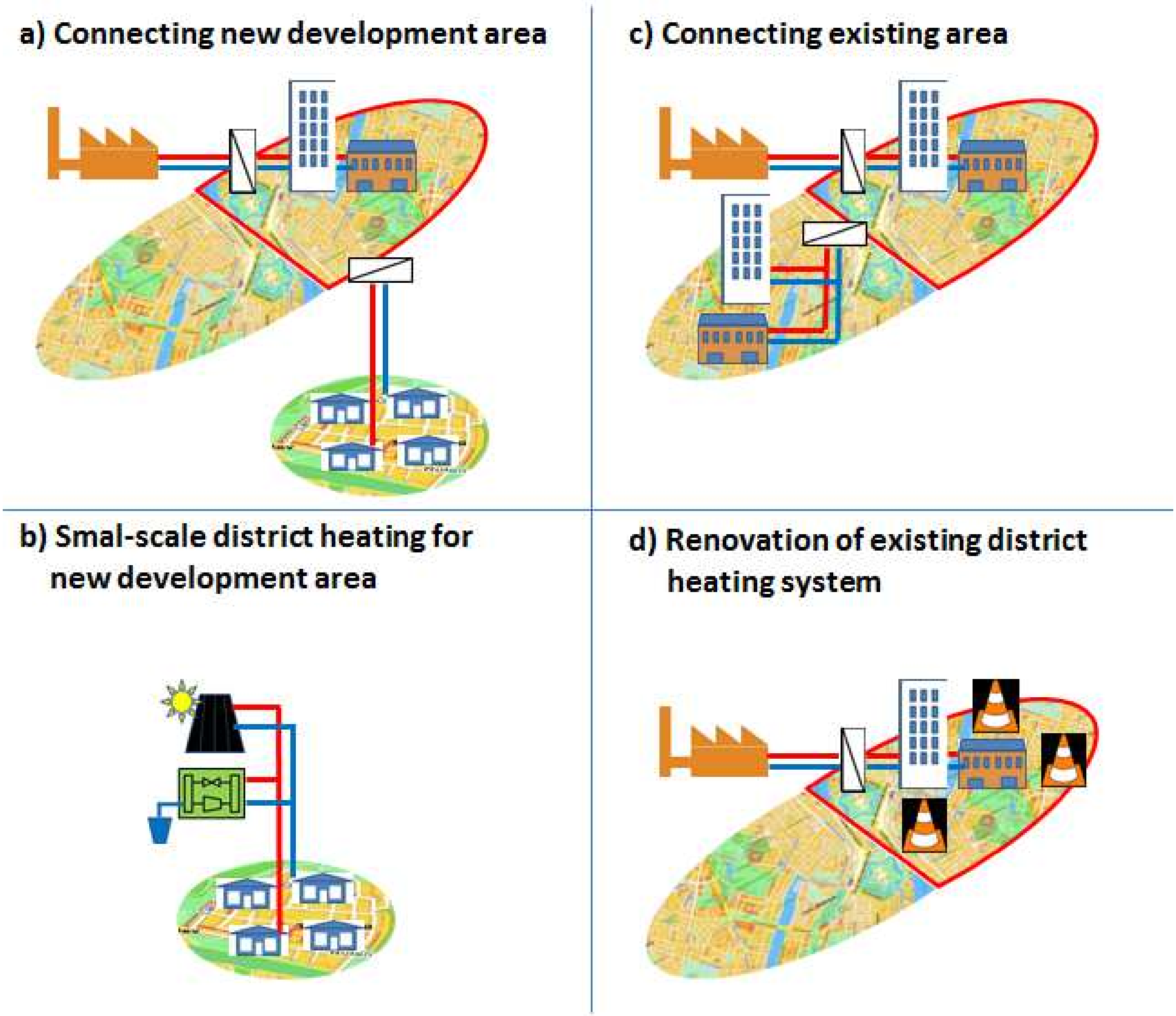

Figure 2 Examples of application of LTDH.

In new areas with new-built low energy houses low temperature district heating systems should always be considered. Low energy demand for space heating in new-constructed buildings combined with low temperature building heating systems (under-floor heating or low temperature radiators) make low temperature district heating supply particularly suitable. At the same time, high consumer energy efficiency puts pressure on supply side efficiency. Thus low temperature district heating supply is both preferred and possible in new low energy buildings.

In the existing district heating areas with existing buildings, which have higher energy consumption, than current energy performance requirements, consumer connections and substations should be prepared for the future low temperature district heat supply. When replacing consumer units in the existing buildings it is recommended to choose new units which comply with LTDH requirements described in the guidelines. Temperature of the existing district heat supply to the current building mass can already today be reduced a part of a year. The number of hours with low temperature operation will in the future increase with gradually increasing energy efficiency of the existing building mass. Many existing networks can operate at low temperatures already today without any major investments.

A well-functioning and efficient low temperature district heating system requires a properly designed and operated district heating networks, consumer connections and in-house installations for space heating and domestic hot water preparation. The next sections include guidelines for implementation of the LTDH.

8 LTDH consumer connections and substations

Consumer DH substations and domestic hot water preparation

LTDH can be applied to both single family houses and to multi-storey (multi-family) buildings. In case of multi-family buildings a decentralised solution with flat stations is used. The different solutions are explained in the following sections.

SINGLE FAMILY HOUSES

Two types of consumer LTDH substations for single family houses are recommended, which differ by the domestic hot water (DHW) preparation systems – the Instantaneous Heat Exchanger Unit (IHEU) and the low temperature District Heating Storage Unit (DHSU).

Heat Exchanger Unit (IHEU)

The IHEU is a substation with instantaneous domestic hot water preparation in a heat exchanger (Figure 3). The heat exchanger is dimensioned for the network supply temperature range considered e.g. 50-55°C. Due to the low temperatures a high efficiency heat exchanger with low operating temperature difference is applied. DHW temperature is controlled by a flow controller with a temperature sensor. The flow controller will close, when there is no tapping of domestic hot water. A thermostatic bypass valve is letting a small amount DH water passing by the heat exchanger.

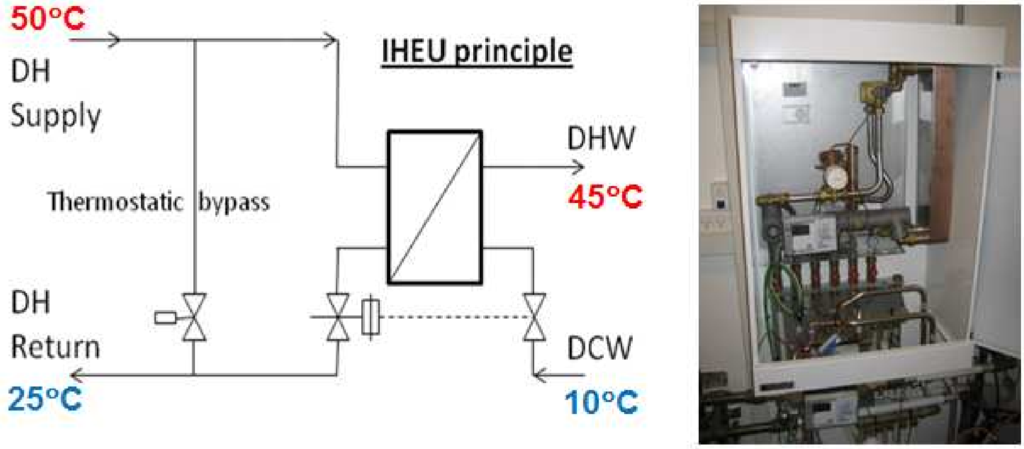

Figure 3 Prototype of the IHEU (right) and sketch diagram (left).

Critical components in IHEU for LTDH connection are:

- *Heat exchanger:* A high efficiency HE is to be applied, due to the low operating temperature differences, with a logarithmic temperature difference, ΔT_{log}, in the range 6°C to 8°C (in common DHW applications the ΔT_{log} is in the range 12°C to 14°C). This means the normally used HE plate area increases significantly, as a rule of thumb by a factor 3-5. The plate corrugation must result in a high turbulence level for assuring a high heat transfer coefficient.
- *DHW HE controller:* an integrated flow compensated, thermostatically operated control valve to control the heat exchanger, see figure 4. The controller has to be very accurate due to the low ΔT_{log}. Assuming that the primary flow is a bit too high, the primary return temperature will increase to a unacceptable high level, e.g. one degree higher DHW temperature, from 45°C level results in 1-2°C higher return temperature in the primary side. Assuming the primary flow is a bit too low, the consequence is a lower DHW temperature. The main factors for obtaining high level of control performance are:
  - The controller should be adapted to the stability requirements for the whole operating range.
  - The integrated flow compensation eliminates the "P" deviation from the thermostatic control valve.
  - The ratio between friction forces and actuation forces should be low.
  - A differential pressure controller should be integrated. That eliminates the decrease in control performance due to variations of the flow which depend on the pump head applied on the valve in primary side.
  - The thermostat also provides a fast "heat up" of the DHW system after idle periods where the piping and HE have been partly cooled off, due to the full opening of the valve until the desired DHW temperature is reached. This cannot be obtained with a controller working solely on the flow proportional principle, for which delays for the lower tapping steps are critical.

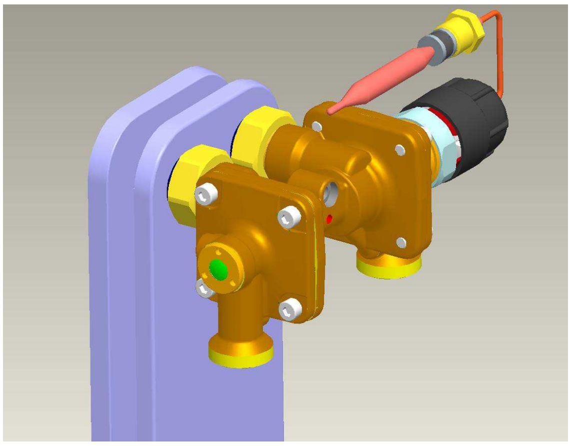

Figure 4 3D CAD model of flow compensated thermostatically operated control valve, mounted directly on the HE

- *Total substation pressure loss*: Low supply temperature requires higher flow than usual which will influence the total pressure loss of the substation, see figure 5. Special care should be taking in designing the substation piping and selecting components in order to reduce total pressure loss. It is recommended to keep the total pressure loss of the unit below 0.3 bar. In this respect, the HE characteristics are crucial.

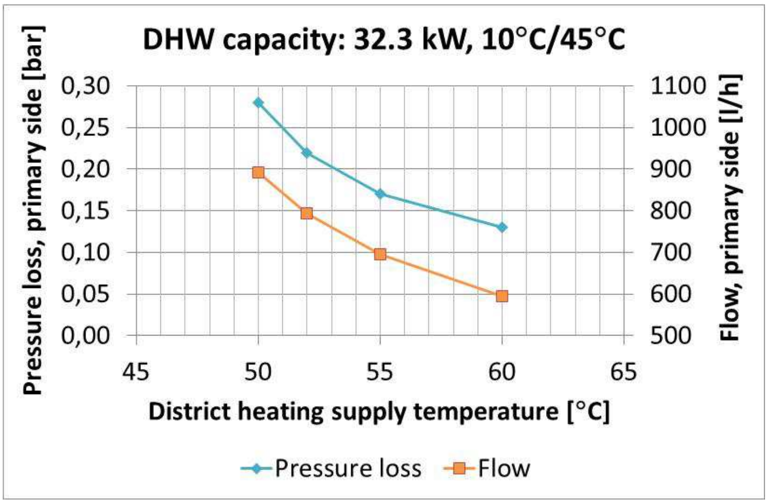

Figure 5 Total pressure loss of a LTDH consumer substation in the DHW design situation.

- *DHW system* – due to the low operating temperatures a DHW circulation should be avoided and the DHW systems in the buildings should be designed with individual connections of DHW pipes between each tap and source of DHW. The DHW pipe diameter should also be reduced as much as possible, complying with noise and pressure drop requirements.

District Heating Storage Unit (DHSU)

The unit includes a storage tank, a heat exchanger (HE), a pump and a flow controller with a temperature sensor (Figure 6). The temperature supplied from the DH network is assumed always to have the same temperature (50-55°C). Heat is stored in the tank with DH fluid as the medium. DHW (45°C) is produced by the HE, with DH water supplied from the storage tank. A flow switch detects a water flow and starts the pump. The DH flow from the storage tank to the heat exchanger is controlled by a flow compensated thermostatically operated control valve.

The storage tank should be sized for the expected total daily draw off based on national standards. The primary water flow can then be adjusted to be constant complying with the actually daily draw off. The tank should be filled from the top and the return connection from the DHW HE then should be connected to the bottom of the tank to secure stratification.

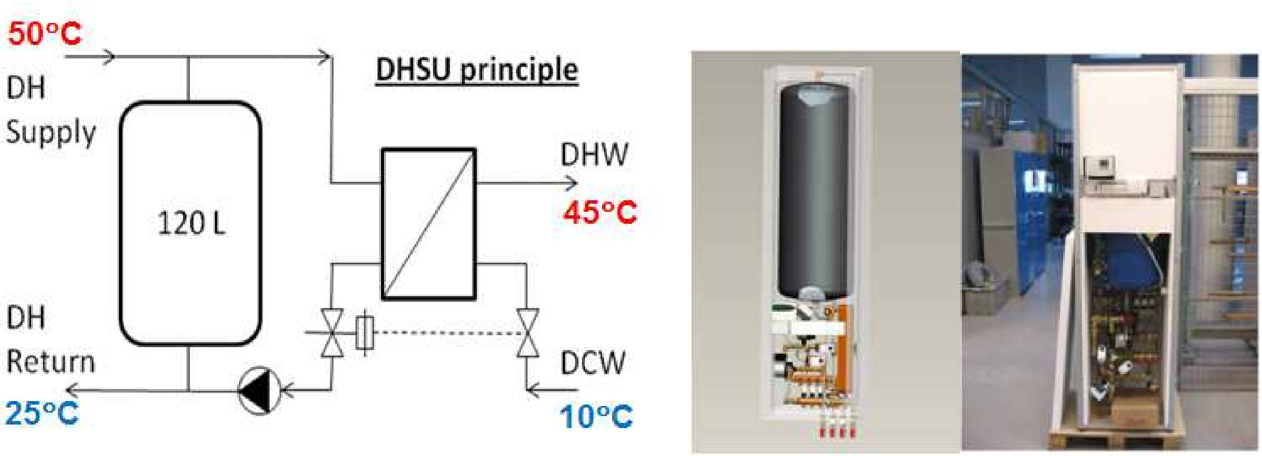

Figure 6 Sketch of the district heating storage unit for LTDH consumer connection (left) and a 3D model and picture of a prototype (right)

The size of the DH storage tank is calculated based on the daily DHW tapping profile, the required DHW temperature and the DH flow rate. Using a higher primary flow reduces the necessary tank size (Figure 7). However, all in all the size of a tank and DH flow rate is a result of an optimisation. For more see [2].

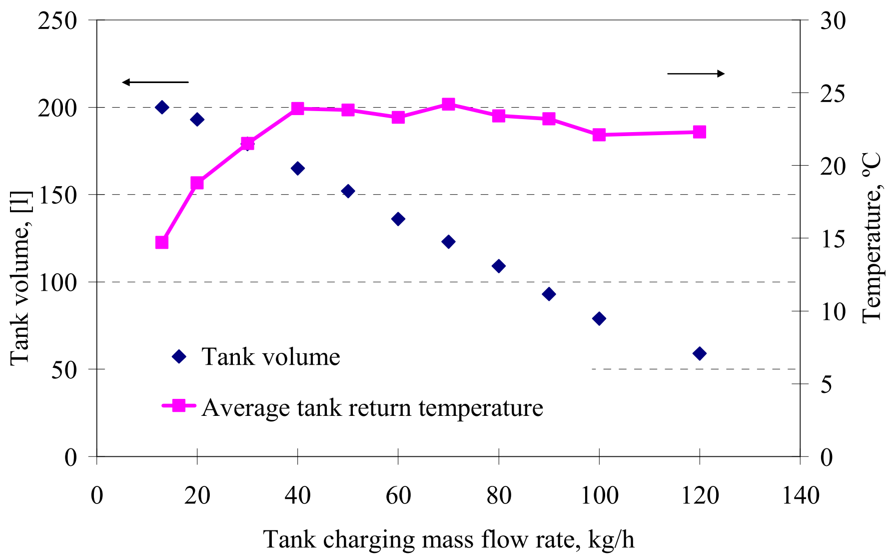

Figure 7 Required storage tank volume and average temperature of the return DH water from the tank as a function of tank charging mass flow rate for a specific tapping programme based on the Danish standard DS 439.

In DHSU concept the charging of the storage tank is controlled by temperature difference between a set temperature (e.g. 50 ˚C) and the water temperature 1/3 from the bottom of the tank. If the water temperature at the sensor is lower than the set temperature, charging of the tank will be activated. The charging is stopped again when the temperature at the sensor reaches the set temperature.

Critical components in DHSU for LTDH connection are:

- *Storage tank.* It is important that hot water inlet/outlet is at the top of the storage tank and cold water inlet/outlet is at the bottom in order to keep good water stratification in the tank. Furthermore, the inlets should be designed in the way to prevent water mixing.
  The storage tank has to be well-insulated – system with small temperature differences is sensitive to even small heat losses.
- *Heat exchanger:* generally the same heat exchanger as is used in the IHEU unit described above is used in the DHSU unit.
- *DHW HE controller:* generally the same DHW HE controller as is used in the IHEU unit described above is used in the DHSU unit. *DHW system* – as with the IHEU unit it is recommended to design the building DHW without DHW circulation and with individual connections of DHW pipes between each tap and source of DHW. The DHW pipe diameter should also be reduced as much as possible, complying with noise and pressure drop requirements.

In case the DHSU is connected in parallel to a direct, under-floor heating system there is a possibility to supply the under-floor heating with the return water from the storage tank. When the return from the under-floor heating system has a lower temperature than the return from the DH storage tank this flow is directed to the under-floor heating system to achieve an extra cooling off. The mixing circuit is controlled by a two way control valve in a traditional way.

Critical points in DHW preparation for LTDH connection

For both systems the critical point is the delivery time of the DHW with the required temperature (40-45 ˚C) to a tap after start of tapping (waiting time or tap delay). According to the Danish standard (DS439) the suggested value is 10 sec. The waiting time depends on the theoretical "DHW transportation time" (length of the pipeline between the DHW unit outlet and the tap water fixture, divided by the average DHW velocity) and the thermal capacity of the components (pipes and substation). The delays arise in three areas: the house-connection pipe (also called service pipe, the pipe connecting the street pipe with the in-house substation), the DH substation, and the DHW supply system in the building. The time delay in the house-connection pipe and in the substation is related to the temperature and flow characteristics in the DH network, and to the substation control strategy and is only a question during summer operation where there is no space heating demand. The time delay in the DHW supply system in buildings without DHW circulation is determined by the length and thermal capacity of pipes, the volume of water in individual pipes, the nominal flow, and to some extent also by the pipe insulation.

The main difference in the time delay between the two proposed units is originating from the house connection pipe. Depending on the control strategy the house connection pipe can be either kept warm by implementing bypasses or it can be allowed to cool down between tapings. In case of the DHSU unit there is a natural bypass due to the operation of the storage tank but in case of the IHEU unit it is an option to add a bypass to keep the supply line warm during the non-heating season. The bypass can be implemented by different methods depending on the comfort requirements. Special analysis on tap delay for IHEU substations using various different bypass options can be found in. Delays that originate inside the substation are common to both the IHEU and the DHSU units.

IHEU LTDH substation with external bypass

Due to an inherent difference between the DHSU and IHEU units an external bypass can be implemented to reduce DHW temperature time delays on the IHEU unit during non-space heating periods. Tap delay and hence water consumption on the consumer side (amount to be estimated) can be reduced if solution with external bypass is used. However, additional energy consumption and insufficient cooling of district heating water might occur. This concept includes the DH water bypass outside the DHW heat exchanger (Figure 8).

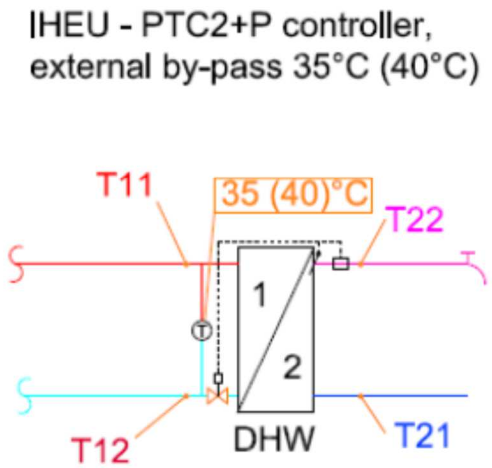

Figure 8 LTDH IHEU substation with external by-pass. The bypass temperature is set at the knob of the thermostatic valve.

The set-point temperature of external bypass is a compromise between insufficient cooling of DH water and additional heat consumed by consumer and reduced waiting time for DHW. During the heating period the function of the external bypass is overtaken by the space heating loop.

Solution without bypass is not suggested due to long waiting time for DHW.

Furthermore, the DHW waiting time can be reduced by insulating the DHW heat exchanger and by specifying higher pressure losses across the heat exchanger. By specifying higher pressure losses across the heat exchanger the number of plates in the heat exchanger can be reduced which leads to reduced water volume and transport delay. The impact on the delay would although only be few seconds.

MULTI-STOREY BUILDINGS

For LTDH in multi-storey buildings consumer substations for each flat (flat stations) is a state of the art solution (Figure 9). In this case each flat has its own completely separated DHW system (with instantaneous DHW heat exchanger and water volume below 3 liter). By preparing the DHW in the flat station close to the point of tapping there is no need for the district heating utility to supply the high temperatures as would be required for centralized preparation with DHW circulation. In this way large domestic hot water circulation systems and requirements for high DHW temperatures are avoided. The other advantage of the flat station concept is individual metering of each flat heat consumption and complete control over space heating and DHW preparation.

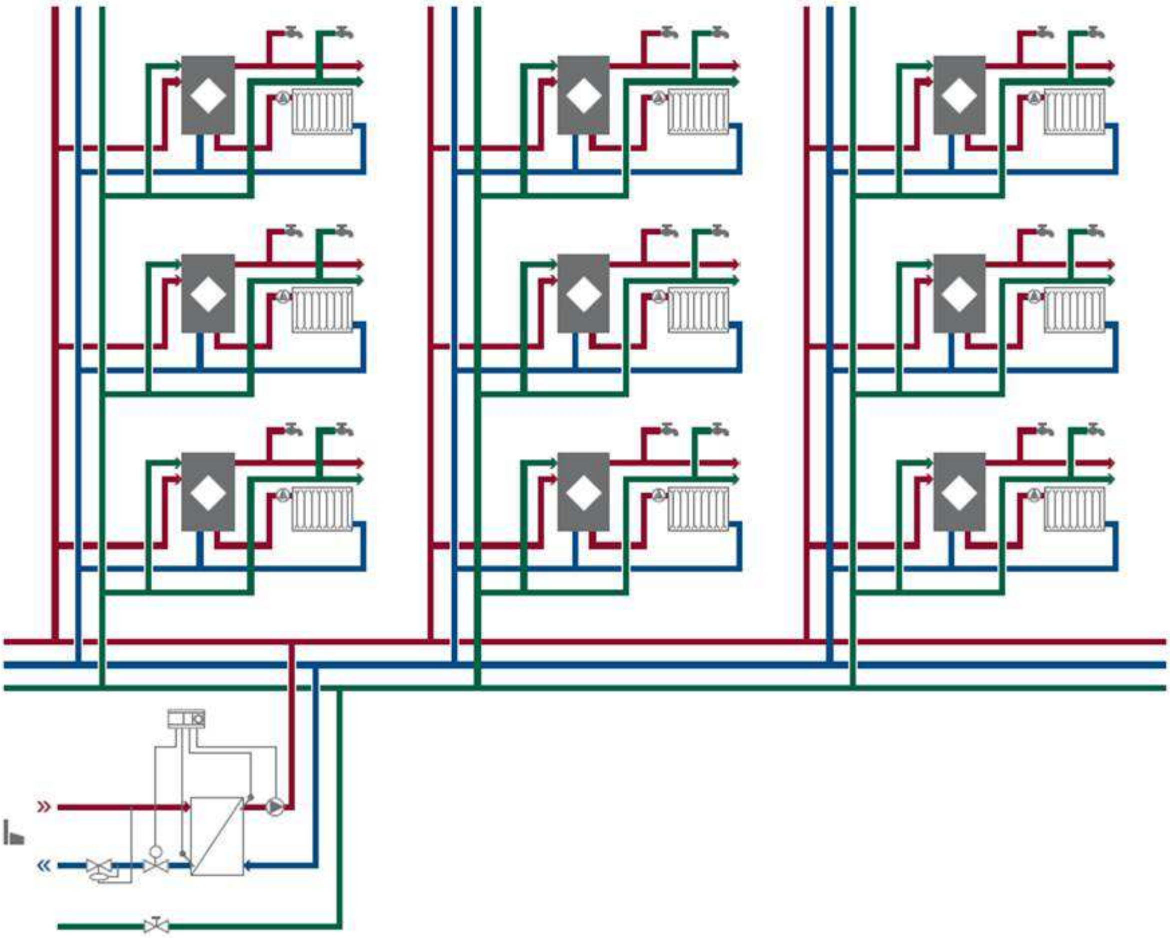

Figure 9 Flat stations installed in a multi-storey building. Domestic hot water is produced in each flat.

DH connection to consumer space heating systems

Type of space heating consumer connection should be chosen in accordance with the designed network pressures. If network pressures are below PN10 a direct consumer connection can be used. If the network is designed for higher network pressure indirect consumer connection should be used. Indirect consumer connection can be used in networks operating with up to PN25.

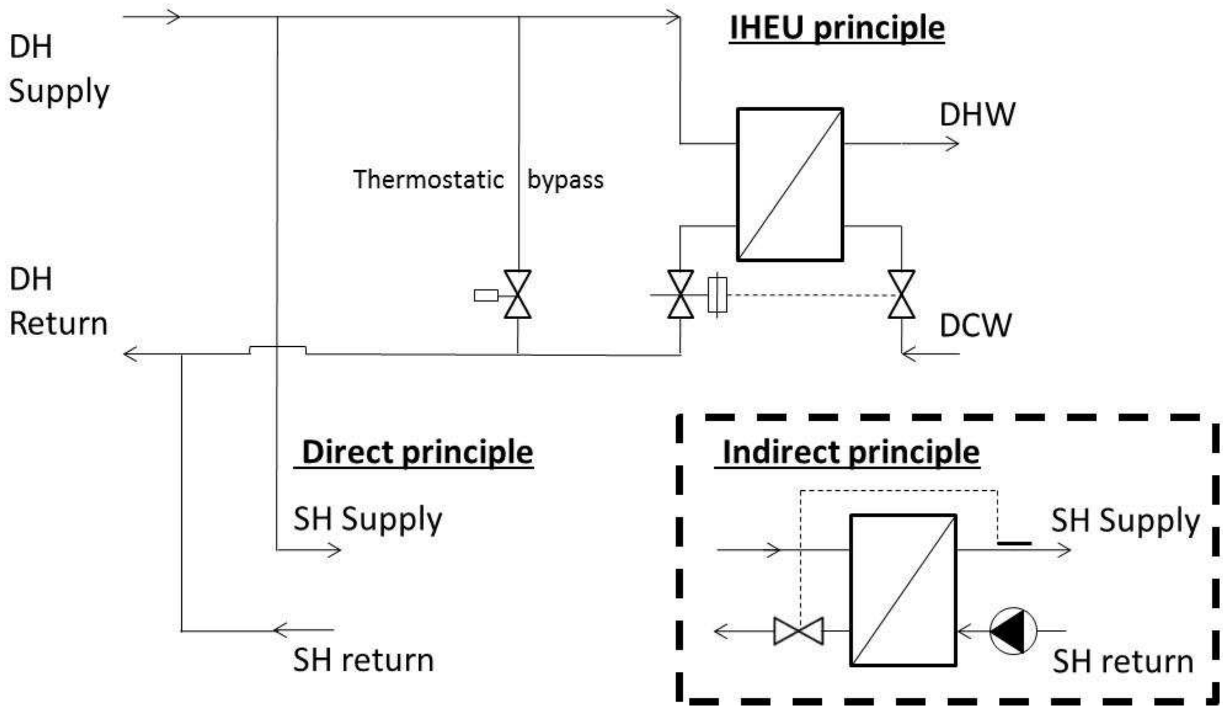

Figure 10 Principle of direct and indirect connection of the space heating (SH) system. Domestic hot water (DHW) system is coupled in parallel.

The *indirect* connection has a heat exchanger for the space heating system. Space heating system (under-floor heating or radiators) is coupled parallel to the DHW system, see figure 10. The heat exchanger hydraulically and pressure separates the distribution network from the buildings system, allowing for a higher network pressure. There are many benefits of implementing indirect systems, for example clear separation of the district heating network and the building installation, the district heating network can operate on pressure levels independent on the building installations, this can be especially important in hilly locations. Indirect systems also allow for higher network pressure which can be a benefit in larger district heating networks or where higher flow rates might be beneficial, for example to minimize temperature drop in pipes. On the other hand, for the same space heating system, the indirect system will require a higher DH supply temperature compared to a direct system due to the heat exchanger temperature efficiency. Further, for indirect systems it is recommended to focus on efficient heat exchanger to minimize the difference between DH supply and SH supply temperature and on control valves allowing for precise control of the SH supply temperature.

9 Design of low temperature district heating network

Design procedure

The design process for the LTDH network is the following:

- Heat demand is defined at consumer nodes with respect to *simultaneity factors*
- *Network pipes* are chosen in a hydraulic optimisation. The inputs to the optimisation are maximum system pressure, pipe and pump data.

Different consumer LTDH units (DHSU of IHEU) have different peak demands and thus requirements for design load, which allow different dimensions for pipes in the network and house-connection pipes. For example, DHSU station can have a design load of 4 kW and IHEU a design load of e.g. 32 kW. Thus, the DHSU in general requires smaller piping than the IHEU, however, it should be noted that piping dimensions depend highly on simultaneity factors. Demonstration of the LTDH in low energy buildings have shown that the dimensioning of DH systems in areas with low-energy buildings needs a better basis for *simultaneity factors* and a greater consideration must be given to the installations for DHW preparation and the SH systems for the calculation of the optimal size of the heat distribution system.

Due to lower DH temperature, the flow in the DH distribution net is increased. This could lead to the need for the larger pipe diameters. However, it has been estimated that it is reasonable to design the network according to the maximum hydraulic load that can be withstood by the distribution pipeline. The pipeline systems must by regulations withstand pressures 1.2-1.5 times the nominal value. Moreover, the duration of peak load situations, when the maximum pressures might occur, is marginal – typically between 50-300 h/yr. Therefore, when choosing network pipes it is recommended to utilise the maximum pressure that can be withstood by the DH pipes in order to reduce pipe diameters and consequently decrease potential heat losses in the network. This is particularly recommended for DH distribution networks with no plans for further expansion. Heat losses in the DH network are in this case reduced at the expense of additional, but less significant, demand for pumping energy.

Other parameters for designing an efficient LTDH network are recommended:

- External thermostatic by-pass valves set to 40°C, in the customer's substation at the end of each street line and set to 35°C, in all the other customers' substations when IHEU is used.
- Maximum water velocity: 2.0 m/s.
- Minimum supply/return pressure difference at the end-user's substation: 0.3 bar. To take into account pressure losses in additional building installation components like main valves, bends and piping connecting the consumer substation to the distribution network, the design pressure difference should be slightly higher e.g. 0.4 or 0.5 bar.
- Operating temperatures 55°C for the supply and 25°C for the return, i.e., design supply temperature from the mixing shunt: 55°C, design return temperature: 25°C. For the LTDH in low energy buildings such temperature range is considered to be sufficient all-year round. For existing buildings in the existing DH areas LTDH supply at 55°C might not be sufficient during peak load periods, but can in these situation be increased. .. It is recommended to implement such solution in the existing district heating areas supplying existing buildings, in order to prepare the areas for the all-year round LTDH operation, when energy performance of the existing buildings improves.

SUBNETS

A low temperature district heating system can be integrated into a larger DH network by applying a large heat exchanger or by a direct connection dependent on local conditions.

Utilizing DH return flow for LTDH supply

In case of the direct connection of a LTDH subnet, a *mixing shunt* or a *3-pipe connection shunt* can be applied. In the latter case, DH return water from a DH network with higher temperatures is utilised for LTDH supply.

Mixing shunt

A low-temperature DH scheme can be integrated to an existing network at higher operating temperature. The water flow at low supply temperature comes from a mixing shunt, where the water coming from the existing DH network is mixed with the return flow from the local LTDH network. The performance of the mixing loop is controlled by a temperature sensor in the main supply pipe to the local network. Such temperature sensor controls a valve in the return line of the same network. The valve opens/closes, thus regulating the amount of return water flow from the local network that is mixed with the supply flow, until the set temperature is reached. The system is shown in figure 11.

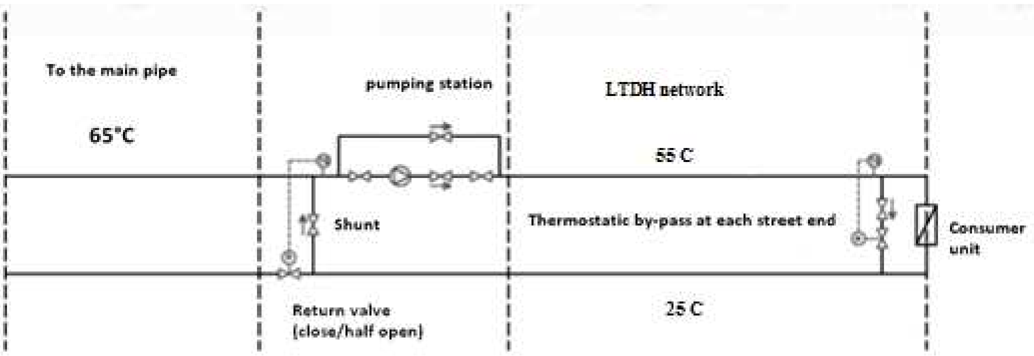

Figure 11 Sketch of the mixing shunt for integrating LTDH network into a conventional network. ***This system is applied in the demonstration case of Lystrup, see Appendix 1.***

3-pipe connection shunt

Regarding the mixing shunt at the central heating substation, a special design can be installed for the LTDH system - the so called *3-pipe connection shunt arrangement*. In the *3-pipe connection shunt arrangement* an extra connection to the return pipe in the main network is established. The arrangement makes it possible to utilise up to 100% of the return water from the main network. When the return water temperature is not sufficient for the LTDH network supply, it can be topped with hot water from the supply pipe. In this case the LTDH network is supplied by water mixed from both the supply pipe and the return pipe of the main district heating network. The system is seen in figure 12.

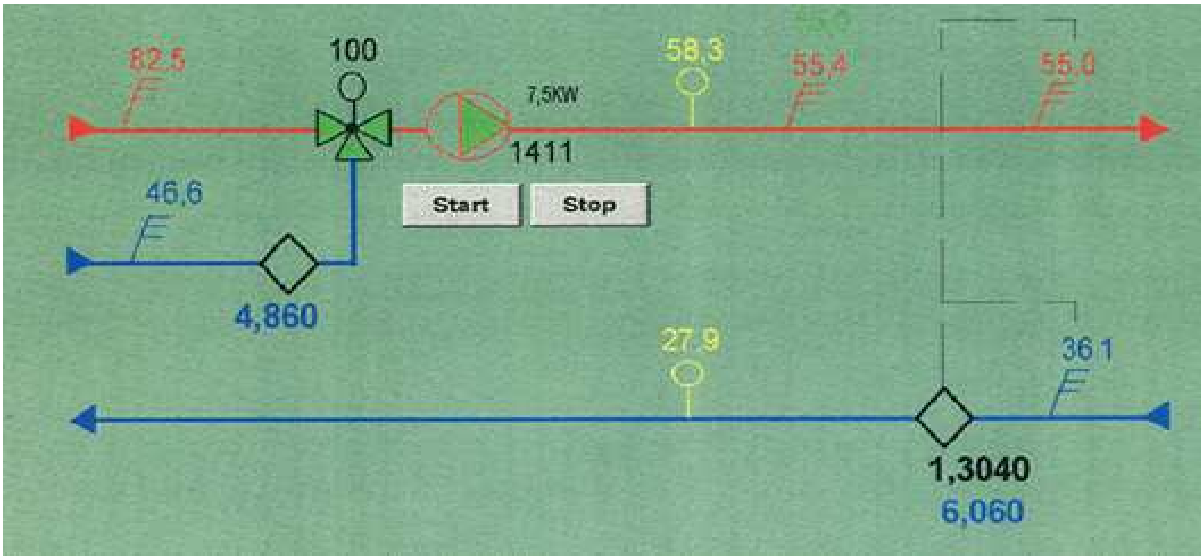

Figure 12 *Screendump of the SCADA system of the 3-pipe connection shunt arrangement. This system is applied in the demonstration case of Sønderby, see Appendix 2.*

The *3-pipe connection shunt arrangement* is a solution, which can be installed in an existing district heating network at a location having a sufficient flow in the return pipe. A 3-way valve is used for regulating the ratio between the return water and the supply water from the main network and booster pump.

The main advantage for a district heating company using the return water from other areas in the network as supply for a low-temperature network is that the district heating company can connect new customers/areas without need for increasing capacity in the existing network. In other words, the district heating network coverage can be increased, because more consumers can be connected without additional investment in pipes etc.

Pipes

In order to ensure the high district heat supply efficiency it is recommended focus on the following:

- Smaller pipe dimensions
- Larger insulation thickness
- PUR-foam heat conductivity
- Diffusion cell gas barrier at the outer casing pipe (keeps the properties of the PUR-foam)
- Twin pipes (double pipes)
- Reduced pipe lengths, if possible.

Two types of twin pipes can be used – flexible pipes and (bonded) steel pipes. Twin pipes have supply and return pipes in one casing pipe. The flexible pipes of diameter 14-32 mm. Steel twin pipes in straight length of 12-16 meters can be used for larger dimensions – up to diameter of 200 mm. Examples of twin pipe specifications can be seen in figure 13 for insulation class Series 2.

AluFlex twin pipe - Class 2		
Pressure class PN10		
Dimension (carrier pipe)	Casing pipe diameter	Heat loss
d_{supply}-d_{return}	D	Total
mm	mm	W/m
14-14	110	2.84
16-16	110	3.09
20-20	110	3.66
26-26	125	4.05
32-32	125	5.07

Steel twin pipe - Class 2		
Pressure class PN25		
Dimension (carrier pipe)	Casing pipe diameter	Heat loss
d_{supply}-d_{return}	D	Total
mm	mm	W/m
42-42 (DN 32)	182.7	4.96
48-48 (DN 40)	182.7	5.81
60-60 (DN 50)	227.9	5.62
76-76 (DN 65)	256.1	6.57
88-88 (DN 80)	283.8	7.34

Figure 13 Pipe data for the two DH twin pipe types. The heat losses are valid for T_{supply}/ T_{return}/T_{ground}=55/25/8 °C

Twin pipes Series 3 can also be used for house-connection pipes reducing heat losses even further.

10 Domestic hot water system and space heating system

The layout of the DHW distribution pipes should be carefully designed so that there is a separate pipe supplying each DHW fixture and the length and size of the pipes is minimised (Figure 14).

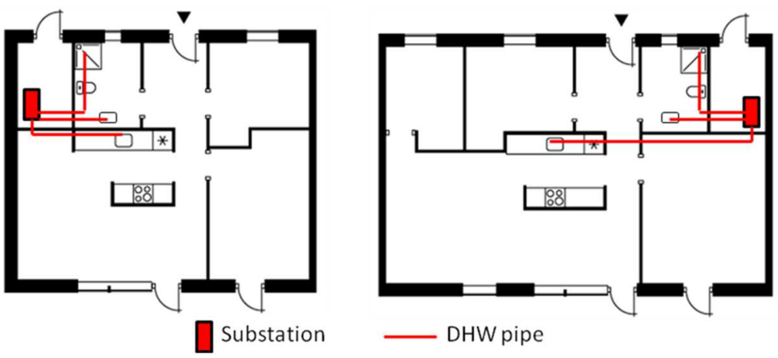

Figure 14 Sketch of the floor plans with the layout of the DHW distribution pipelines in the two dwellings without DHW circulation.

The water content in each DHW supply line, including the volume in the secondary side of the DHW heat exchanger should be kept to a minimum, and under 3 litres. This is the allowable water content for the instantaneous DHW preparation systems that is considered to assure safety in relation to the Legionella risk, even without any treatments, according to the German guidelines for DHW systems (DVGW, W551). It is important that DH substations do not require DHW storage, preferable solutions are DHSU and IHEU. Furthermore, the DHW system should be designed without DHW circulation, which requires high DHW temperatures.

In the multi-storey (multi-family) buildings DHW circulation can be eliminated by installing flat stations, so that each apartment has its own apartment substation", instead of a central equipment for DHW production and a DHW distribution pipes.

In new buildings, it is recommended that low temperature space heating systems are installed: under-floor heating or radiators - for radiators with design parameters of supply/return/indoor temperature – 55/25/20 ˚C. At these design parameters, it is very important that logarithmic mean temperature difference is used for calculation of radiator capacity to prevent under dimensioning. From an architectural point of view, it is interesting to know, that the size of radiators will not physically be much larger in new buildings compared to old buildings, because the reduced heat demand will compensate for the size according to reduced temperatures, see figure 15. A radiator designed for 75/65/20 ˚C in a building with design heat demand 70 W/m^2 will have almost the same length as a radiator designed for 55/25/20 ˚C in a low-energy building with design heat demand 15 W/m^2.

Dimensioning radiator temperatures			Dimensioning heat demand [W/m2]			
			70	40	25	15
Supply [°C]	Return [°C]	Indoor [°C]	Relative radiator length [m]			
75	65	20	**1,0**	0,6	0,3	0,2
70	40	20	1,7	**1,0**	0,6	0,4
60	30	20	2,9	1,7	**1,1**	0,6
55	25	20	4,6	2,6	1,6	**1,0**

Figure 15: The relative radiator length in the table refers to design space heating heat demand 70 W/m^2 and the radiator design temperatures 75/65/20 ˚C for a PKII radiator type 555 mm height. For different design radiator temperatures and design heat demands, the relative length can be found (based on logarithmic mean temperature difference).

In existing buildings, the reduction of supply temperature is much more challenging and large differences in design criteria and heat demand exists nationally. However, experience from Denmark shows that a combination of energy renovation of buildings and some over-dimensioning of radiator systems in the design phase, means that most radiator systems are able to operate at design conditions 70/40/20 ˚C even though they were originally designed for boiler operation at higher temperature levels back in time. Further, investigations show that the real heat demand due to internal gains and user behaviour might allow for further temperature reduction.

11 Operation and commissioning of the LTDH system

The reduction of the DH network operating temperatures requires proper operation of domestic hot water (DHW) and space heating (SH) systems in order to meet the low-temperature requirements and the limited available differential temperature in the buildings (difference between the supply and the return temperature also decreases). Therefore, in operation the focus should be on the proper cooling of the DH water and consequent low return temperature. Possible reasons for the high return temperature in the LTDH network:

- The by-pass flow in the consumer units is too high.
- Inappropriate control valves at the LTDH DHW substations
- The existing floor heating systems have poor control components

The presented concept envisages the possibility of increasing the supply temperature in peak load periods during the heating season to limit the dimensions of the distribution pipelines. The temperature level during these periods depends on the climate, availability of energy sources at higher temperature and total economy, and thus depends on the case considered.

A typical supply temperature for peak-load periods in the Northern European countries could be 65-75°C. The hypothesis is that the savings in capital investments and operational costs (in terms of heat losses and to some extent pumping power) exceed the higher operational costs derived from the use of higher operating temperatures in peak-load period, in which it would otherwise be necessary to increase the primary flow.

The demonstration cases, see appendices, have shown that the new low-temperature DH network has the expected low heat losses. Consumer installations and the mixing shunt installation should be checked and adjusted in the starting phase in order to ensure the lowest possible heat losses (especially lowest possible DH return temperature). Furthermore, demonstration of the LTDH systems has shown that even with utilised maximum allowable pressures in the pipes electricity demand for pumping is comparable to the well-established DH systems in Denmark.

12 Final remarks

The results of LTDH demonstration show that it is possible to guarantee an energy-efficient operation, but it is very important to obtain the proper functioning in each substation, otherwise unacceptable return temperatures can be expected, which leads to higher heat losses and insufficient utilisation of DH network capacity.

There is no superior substation concept, but the best system should be chosen taking into account the specific characteristics of the site and of the demand. The distribution heat loss in the DH area with DHSUs might be slightly lower than in the area with IHEUs. However, for one of the demonstration cases, the sum of the distribution heat loss and the heat loss from the substations was compared. The results showed a marginally larger total heat loss in the DHSU case than in case with IHEUs, because the additional heat loss due to the storage tanks more than counteracts the reduction of the distribution heat loss. On the other hand, in areas with hydraulic limitations, such as outer urban areas, DHSUs offer in turn some advantages, thanks to the lower peak pressure/load requirements.

The LTDH concept is specifying a range of supply temperatures from 50-55˚C up to 60-70˚C. The lower supply temperatures are pushing equipment and installation specifications to the limits, but can be new standard for supplying district heating to new buildings. As mentioned, higher supply temperatures might be more suitable for areas with existing buildings and should be adapted local or national conditions. Most important is that lowering supply temperatures generally is a long term effort and should be prepared well in advance. As house substations, domestic hot water and space heating installations has a technical lifetime of at least 20 years, a starting point could be setting more strict requirements on substations and installations already today in order to harvest the benefits of LTDH as soon as possible.

As general rule, lower operating temperatures can increase the investments costs of the end-users side equipment. The same is valid for the distribution network, unless the temperature difference between the design supply and return temperatures are kept similar. On the other hand, the savings can be achieved on the DH production side, which lead to lower DH production costs and higher share of renewable energy in the DH production mix.

13 Literature

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[3] Brandt, M., Thorsen, J. E., Svendsen S., Christiansen C. H., A heat exchanger unit used for domestic hot water supply in single-family house supplied by low energy district heating, The 12th International Symposium on District Heating and Cooling, Tallinn, 2010.

[4] Olsen, P.K, Lambertsen, H., Bøhm, B., Christiansen C. H., Svendsen, S., Larsen, C.T., Worm, J., A new Low-Temperature District Heating system for low-energy buildings, The 11th International Symposium on District Heating and Cooling, Reykjavik, 2008.

[5] Christiansen C. H., Dalla Rosa, A., Brandt, M., Olsen, P.K, Thorsen, J. E., Results and experiences from a 2-year study with measurements on a new Low-Temperature District Heating system for low-energy buildings, The 13th International Symposium on District Heating and Cooling, Copenhagen, 2012.

14 Appendices

Appendix 1, 2 and 3:

The appendices include description, results and conclusions of 3 demonstration sites in Denmark, which have been a part of the R&D projects financially supported by the Danish Energy Agency's Energy Research Programme.

The sites in Høje Taastrup and Tilst are low-temperature DH systems for existing houses, while the site in Lystrup is low-temperature DH system for low-energy houses. See the locations at the map of figure 16.

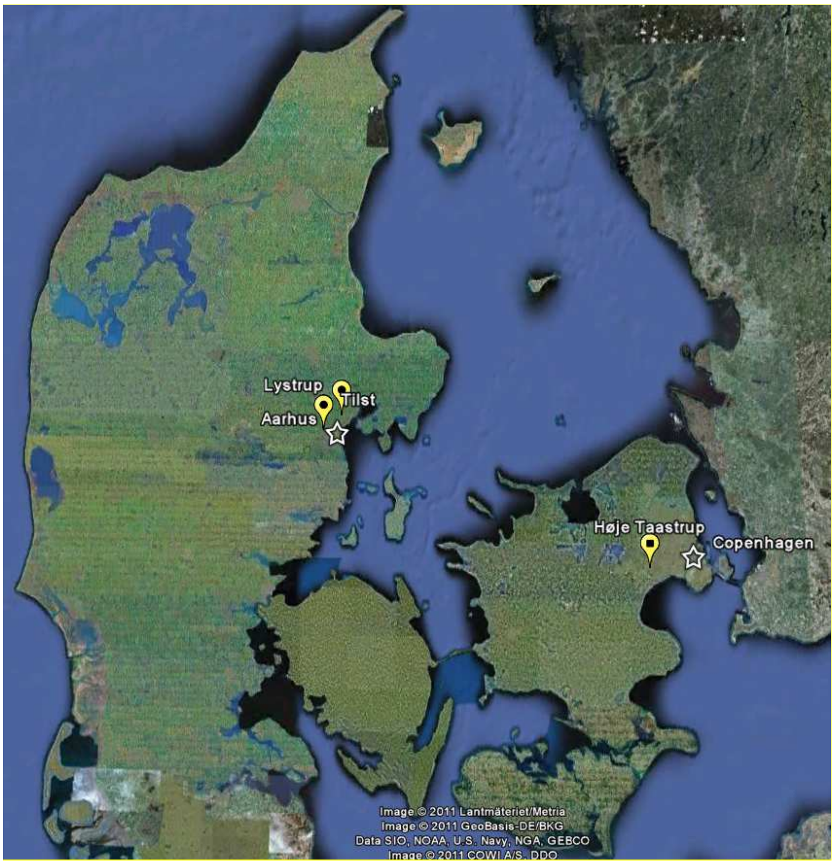


Figure 16 Map of demonstration sites for low-temperature DH systems in Denmark, which have been a part of R&D projects.

Appendix 4:

Additionally is found an appendix with a list of other low-temperature demonstration cases.

Appendix 1 - Demonstration of LTDH in 40 terraced low energy houses (Lystrup)

The demonstration site is situated in a new development area in Lystrup, a satellite town to the city of Aarhus, Denmark, with about 10,500 inhabitants. The demonstration site comprises 40 terraced low-energy houses and a communal building built in 2009-2010 by the housing association Boligforeningen Ringgården. The dwellings living area is 87-109 m^2 with a total heated area of 4115 m^2

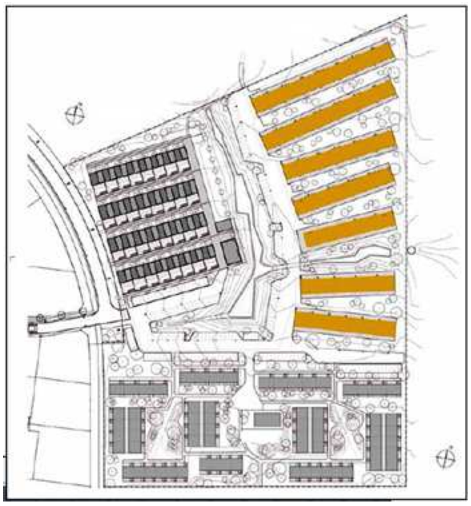


Figure A1.1: Site map and photo of the terraced low-energy houses in Lystrup

Planning of low-temperature district heating (LTDH)

In the original plans for the site, a traditional district heating distribution network with pair of single pipes and traditional supply temperatures as delivered by local utility Lystrup Fjernvarme was envisaged. However, with this design the distribution heat loss for the site would become rather high – according to pre-calculations about four times higher than if a new developed concept for LTDH was used. The project group behind this guideline was giving the job to redesign the system including network, substations and space heating systems in order to reduce distribution heat losses.

LTDH consumer connections and substations

Two types of consumer substations (Danfoss Redan) were developed and installed hereof 11 substations with 120 liter district heating storage tank (see section 8 of the guidelines) which allows for reduction of design capacity to 3 kW and supply pipe dimensions accordingly. The remainder substations were of the instantaneous water heater type designed for a capacity of 32.3 kW (according to Danish standards). For both types the design district heating supply temperature is 50°C for domestic hot water production allowing for a domestic hot water temperature of about 45°C. The space heating systems are supplied directly with district heating water.

Design of the LTDH network

District heating is delivered to a central spot at the demonstration site by utility Lystrup Fjernvarme. The design described is therefore for the site network only and with the main goal to lower distribution heat loss by reducing supply temperature, media pipes dimensions and lengths as well as improving pipe insulation specifications.

A mixing shunt was installed to reduce supply temperature and boost pressure. The booster pump (Grundfos CR-15-6-A-F-A-E) has a variable frequency drive and is controlled by pressure difference at the critical point of the network. In order to reduce media pipes dimensions, the design criteria allowed for a maximum pressure level up to 10 bar (g), minimum pressure difference at the substations of 0.3 bar and maximum velocities in the pipes of up to 2 m/s, which is somewhat higher than usual.

All pipes used (LOGSTOR) were twin-pipes with supply and return pipe placed within the same outer casing. The insulation class is series 2, the heat conductivity is λ = 0,023 W/(mK) and the pipes has cell gas diffusion barrier in the outer casing.

Ledningsdimensioner	[m tracé]
Alx 14/14-110 (16-16/110)	115
Alx 20/20-110	187
Alx 26/26-125	163
Alx 32/32-125	127
TWS-DN32 (42-42 /180)	89
TWS-DN40 (48-48/180)	34
TWS-DN50 (60-60/225)	8
I alt	723

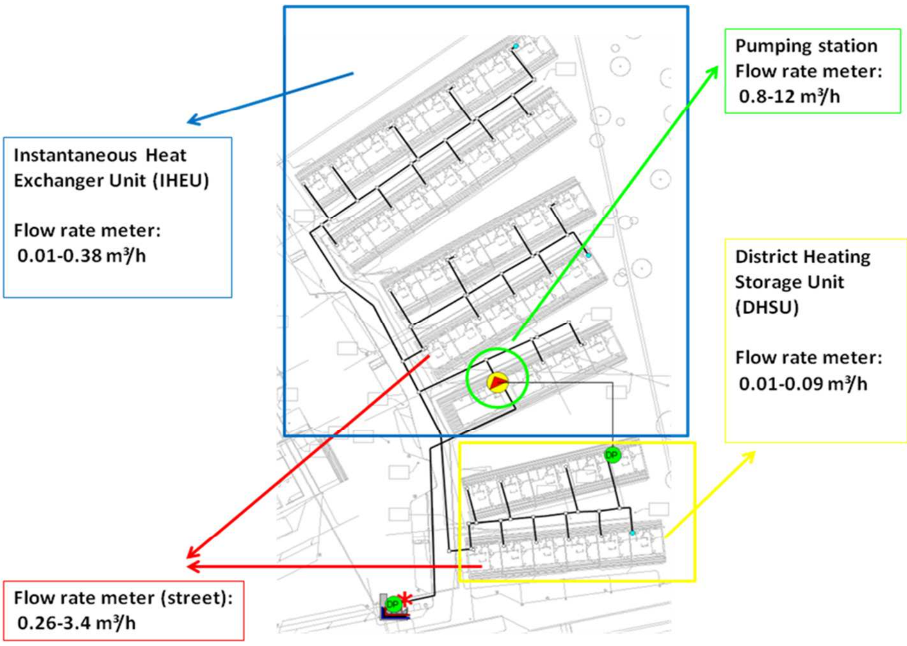


Figure A1.2: System Layout and pipe specifications: Alx: Aluflex twin pipes; Tws: Steel twin pipes, series 2, diffusion barrier at the outer casing

Domestic hot water system and space heating system

The layouts of the DHW distribution pipes and the floor plan of the dwellings were carefully designed, so that there is a separate pipe supplying each DHW fixture and the length of the pipe is minimized. Consequently, the water content in each DHW supply line, including the volume in the secondary side of the DHW heat exchanger, is kept to a minimum and it is below 3 liter: this is the allowable water content for instantaneous DHW systems to assure safety in relation to bacteria.

The space heating system consist of a combination of radiators (RIO) – based on design supply/return/room temperature of 55/25/20°C – and floor heating in the bathroom.

Operation and comissioning of the LTDH system

An extensive monitoring program and data acquisition system was established and data from 2011-2012 are available. Lystrup Fjernvarme that supplies heat to the new low-temperature area is a medium-temperature DH system. DH is supplied with up to 80°C during winter and down to 60°C during summer. In figure A3, the average weekly supply and return temperatures and heat load are seen for the 2 year monitoring period together with the shunted supply temperature. The maximum monitored (instantaneous) heat load is 161.3 kW compared to maximum weekly average of 87.4 kW. The figure shows how the shunt has been adjusted during the period in order to get the low mixed supply temperature of just slightly above 50°C. Further the result of troubleshooting in individual building installations has secured a low return temperature.

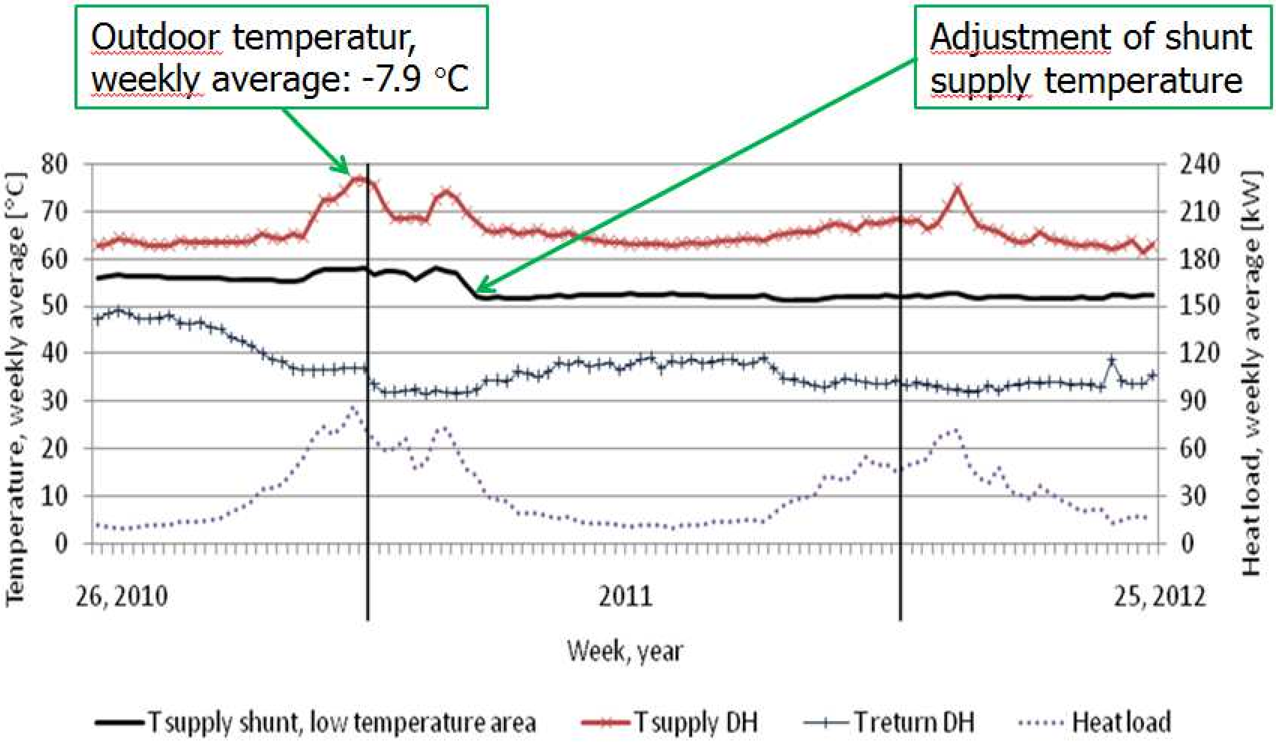


Figure A1.3: The average weekly supply and return temperatures and heat load are seen for the 2 year monitoring period together with the shunted supply temperature

For a Danish reference year DH demand, heat loss in the distribution network and the annual electricity use of the pump were calculated based on duration curves divided in 8 representative intervals combined with load vs. temperature curves derived for the first monitoring period of 2010. In addition, full year (2011 and 2012) measurements are available, see table A1.

Table A1.1: Key data of network operation

Year		**DK ref** (calc.)	**2011** (meas.)	**2012** (meas.)
Total heat delivered to LTDH network	MWh	287.2	273.9	282.6
Heat demand	MWh	238.1	219.4	232.0
Distribution heat loss	MWh	49.1	54.5	50.6
Distribution heat loss	%	17.1	19.9	17.9
Heat power, yearly avg.	kW	-	31.3	32.3
Supply temperature, DH	°C	-	67.4	66.2
Supply temperature, LTDH	°C	55	52.7	52.1
Return temperature DH	°C	30	34.1	33.7
Electricity use, pumping station	kWh	2600	2556	-

The demonstration project of a low-temperature DH network for low-energy buildings has shown that the concept works. The results show that it is possible to supply the customers with a supply temperature of approx. 50°C and satisfy both the SH requirements and the safe provision of DHW. This fact is confirmed by the fact that there were no complaints from residents about the lack of SH or DHW. The energy efficiency target was met, being the distribution heat loss equal to 17% of the total heat production for the Danish reference year.

The results demonstrate that it is possible to guarantee an energy-efficient operation, but it is very important to obtain proper functioning of each substation, otherwise unacceptable return temperatures result.

In the case considered, the distribution heat loss for the area with DHSU's are slightly lower than in the area with IHEU's. The sum of the distribution heat loss and the standby heat loss from the substation is on the other hand larger in the DHSU case than in the case with IHEUs, because the additional heat loss due to the storage tanks more than counteracts the reduction of the distribution heat loss. However, in areas with hydraulic limitations, such as outer urban areas, DHSUs offer in turn some advantages, thanks to the lower peak pressure/load requirements.

Appendix 2 - Demonstration of LTDH in 75 existing detached houses with under-floor heating (Sønderby)

The demonstration site is situated in an existing housing area called Sønderby (Soenderby) in Høje Taastrup (Hoeje Taastrup), a suburb to the Danish capital, Copenhagen. Høje Taastrup has about 48,500 inhabitants. The demonstration site compromises 75 detached brick houses built in 1997-98. The houses living area is 110-212 m^2 with a total heated area of 11,230 m^2. Typically 2-5 people live in each house.

Figure A2.1 Air photo of the demonstration site area (marked with red) and an example of one of the 75 existing single-family houses, which got the new LTDH system installed.

Planning of low-temperature district heating (LTDH)

All houses were connected directly to a private DH network, which was supplied by the local district heating utility Høje Taastrup Fjernvarme via a central heat exchanger. Although the existing local DH system was only approx. 15 years old, the distribution pipelines – pair of single pipe with plastic media pipes – were in poor conditions. The annual network heat loss did account for about 38-44% of the heat delivered from the central heat exchanger. The heat demand in the area is in the range 5-23 MWh/year per house. Some of the houses have wood-burning stoves, which were in common use, when the old pipe system was in operation, because the high distribution network heat losses made the district heating expensive. The houses were originally equipped with a consumer substation with DHW storage tank (either 110 L or 150 L), which some of the tenants considered insufficient when using the bathtub. In addition to that, there were also problems of calcification due to the high lime content in the water.

For these reasons it was decided to renew the existing DH system and the newly developed concept for LTDH was seen as the obvious solution. The project group behind the guidelines was given the job to redesign the system including network and substations in order to reduce distribution network heat losses.

It was decided, that the supplier Høje Taastrup Fjernvarme should be the owner of the new distribution network in Sønderby and that each house should be a direct heat consumer (agreement and accounting wise).

LTDH consumer connections and substations

A new consumer substation (Danfoss Redan Akvalux II VX) was installed in each of the 75 houses. The type of substation were an instantaneous water heater type designed for a capacity of 32.3 kW (according to Danish standards) and design district heating supply temperature is 50°C for domestic hot water production allowing for a domestic hot water temperature above 45°C. The space heating systems are supplied indirectly with district heating water via a heat exchanger in the consumer substation.

Design of the LTDH network

District heating is delivered by utility Høje Taastrup Fjernvarme to a central shunt and pumping station at the demonstration site. The design described is therefore for the site network only and with the main goal to lower distribution network heat loss by reducing supply temperature, media pipes dimensions and lengths as well as improving pipe insulation specifications.

Figure A2.2: Example of a new twin pipe with good insulation property, which replaces the old single pipes with poor insulation thickness (to the left). Examples of steel twin pipes for the main network in the streets (upper right) and examples of alupex twin house-connection pipes – one of the pictures shows also a sampling before it is insulated and sealed with a casing (lower right). The pipes have inbuilt copper wires for leakage alarm system.

A mixing shunt was installed to reduce supply temperature and boost pressure. The mixing shunt in this demonstration has a new technical design. It is a *3-pipe connection shunt arrangement* as described in the guidelines section. District heating return water from the neighbour area is used as the main supply for the LTDH-network. When the return water temperature is not sufficient for the LTDH-network, a portion of hot water from the hot supply (normal utility supply) is added in the mixing shunt.

The shunt is equipped with a special booster pump, which can provide a high pressure level at a given relatively low flow. To give security of supply an identical booster pump is installed as reserve. The booster pump (Grundfos CRE 20-7) has a variable frequency drive and is controlled by pressure difference at the critical point of the network. In order to reduce service pipe dimensions, the design criteria allowed for a maximum pressure level up to 10 bar (g), minimum pressure difference at the substations of 0.3 bar and maximum velocities in the pipes of up to 2 m/s, which is somewhat higher than usual.

All pipes used (LOGSTOR) were twin-pipes where supply and return pipe are placed within the same outer casing. For all main (street) pipes are used "conti-produced" twin steel pipes in insulation class / series 2 with heat conductivity λ = 0.023 W/(mK). For all house-connection pipes are used flexible twin alupex (aluflex) pipes in insulation class / series 3 with heat conductivity λ = 0.022 W/(mK). All pipes have a cell gas diffusion barrier in the outer casing. The DH pipes do have inbuilt copper wires for the use of a leakage alarm system.

Type	Main pipe (street) routing [m]	House-connection pipe routing [m]
Alx-20/20-125	18	1310
Tws-DN20	442	-
Tws-DN32	611	-
Tws-DN40	161	-
Tws-DN50	110	-
Tws-DN65	92	-
Total	**1433**	**1310**
	2743	

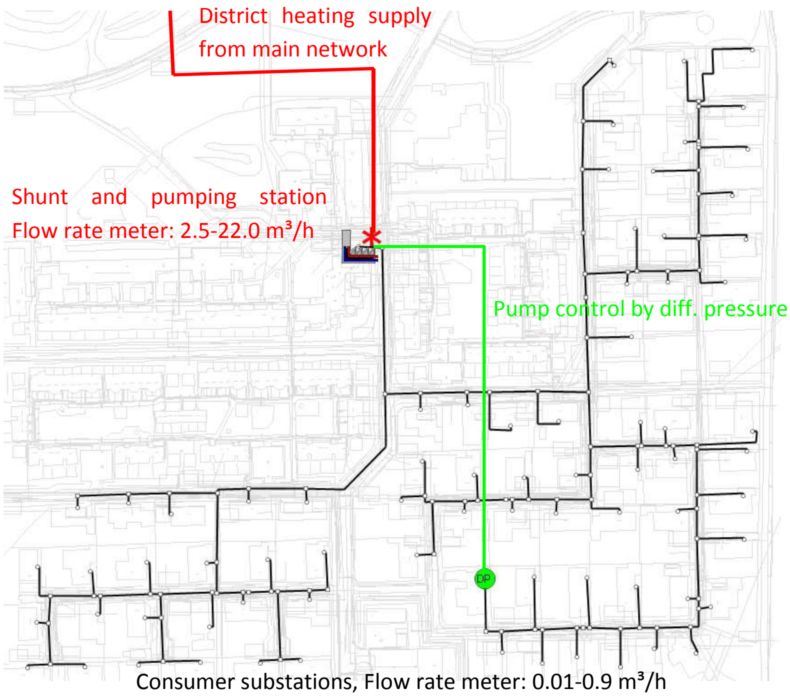


Figure A2. System Layout and pipe specifications. Main pipe (street) routing: "conti-produced" twin steel pipes, series 2. House-connection pipe routing: flexible twin alupex pipes, series 3. Both pipe types have diffusion barrier at the outer casing.

Domestic hot water system and space heating system

The new DH system with new consumer substations was connected to existing DHW and space heating installations in the houses. The consumer substation was typically installed in a closet in the scullery in the same place as where the former consumer substation was mounted. All DHW and space heating installations have their starting point from here. Some few houses have DHW circulation in order to operate bathrooms located in the other end of the house.

Consequently, the water content in each DHW supply line, including the volume in the secondary side of the DHW heat exchanger, is aimed to be below 3 litres: This is the allowable water content for instantaneous DHW systems to assure safety in relation to bacteria.

All houses do have floor heating as space heating system. This system is very suitable for the LTDH-concept due to the low temperature demand compared to traditional radiator systems. Each house has a control system for the floor heating. Some do have a system with central heat control and some a system with individual room control of the floor heating system.

Operation and commissioning of the LTDH system

An extensive monitoring program and data acquisition system was established and data from 2012-2013 are available. Høje Taastrup Fjernvarme supplies heat to the new LTDH area partly with the DH return water ("cold supply") from the neighbour area (buildings just area next to Sønderby) partly with DH water from main DH system ("hot supply"). The "cold supply" has been in the range of 30-67°C but in average 48°C - highest during summer. The main DH system is a medium-temperature DH system. The "hot supply" has been in the range of 65-107°C but in average 80°C - lowest during summer. The measurements show that the "cold supply" has covered 81% of the total supply to the LTDH system.

In figure A2.4, 5 minutes measurements for supply and return DH temperatures and heat load are seen for a 1.5 year monitoring period together with the shunted supply temperature ("Low-temperature supply). The maximum monitored (instantaneous) heat load is about 500 kW during winter and 90-200 kW during summer time.

The figure indicates the fact that the supply temperature to the LTDH network in average has been 55°C. The return temperature has in average been 40°C, which is higher than expected, but can be put down on some few consumer substations, where the bypass flow has been to high either due to faulty settings or defective components (valves etc.). Further troubleshooting in individual building installations is expected to lower the return temperature.

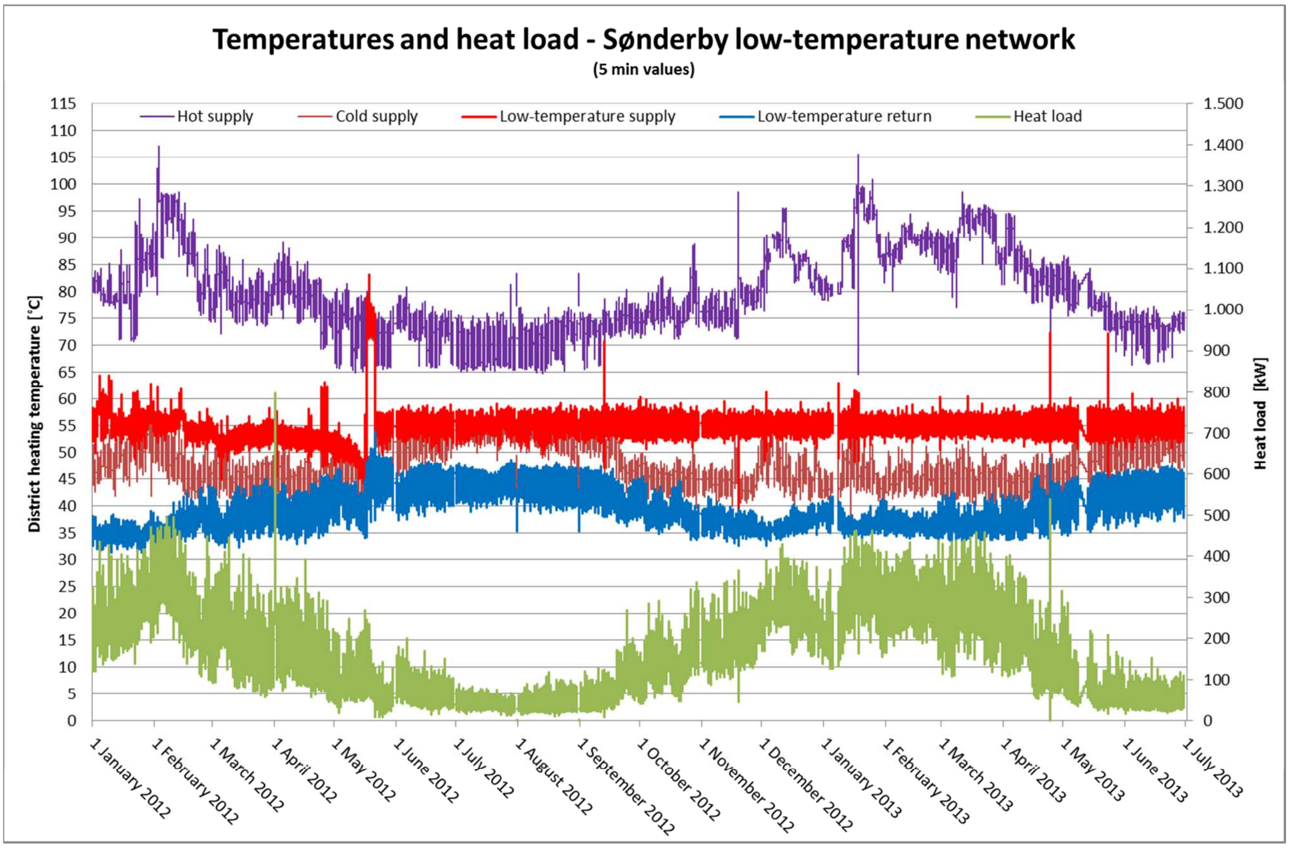


Figure A2.4: Monitoring results for Sønderby. 5 minutes values for DH temperature and heat load in the period 1 January 2012 – 30 June 2013.

Key figures for the monitoring period for the LTDH network in Sønderby are listed in the table below. Together with the monitoring data is seen some selected design figures.

Table A2.1: Key data of DH network operation in Sønderby.

Year		Design	2012 (meas.)	1 Jan 2012 – 30 Jun 2013 (meas.)
Total heat delivered to LTDH network	MWh	-	1227.7	1978.6
Heat demand	MWh	-	1051.8	1715.1
Distribution heat loss	MWh	-	175.9	263.5
Distribution heat loss	%	15.0	14.3	13.3
Heat power, yearly avg.	kW	-	139.6	151.2
Supply temperature, DH	°C	-	77.7	79.9
Supply temperature, LTDH network*	°C	55-52	55.0	55.1
Return temperature LTDH network*	°C	27-30	40.3	40.1
Supply temperature, consumer substation	°C	Approx. 50	53.0	53.2
Return temperature, consumer substation	°C	Approx. 25	37.9	37.9
Electricity use, pumping station	kWh	-	22,169	36,505

* At the central shunt and pumping station

Among other things, it is seen in the table that the DH temperature drops about 2°C in the distribution network. It is calculated as the difference between the supply temperature at the central shunt and pumping station and the supply temperature at the consumer substations (average). Contrary, the DH return temperature increases with about 2°C in the network. This is due to the heat loss from the supply media pipe in the twin pipe system.

The demonstration project has shown that the LTDH concept works for existing buildings with floor heating as space heating system. The results show that it is possible to supply the customers with a supply temperature of approx. 50°C and satisfy both the SH requirements and the safe provision of DHW.

The energy efficiency target was met. The distribution network heat loss has been measured 13-14% of the total heat supply to the LTDH network. This is below the target, which was put to 15%. With the LTDH concept and the new network and consumer substations the distribution network heat loss has been lowered from approx. 41% to 13%.

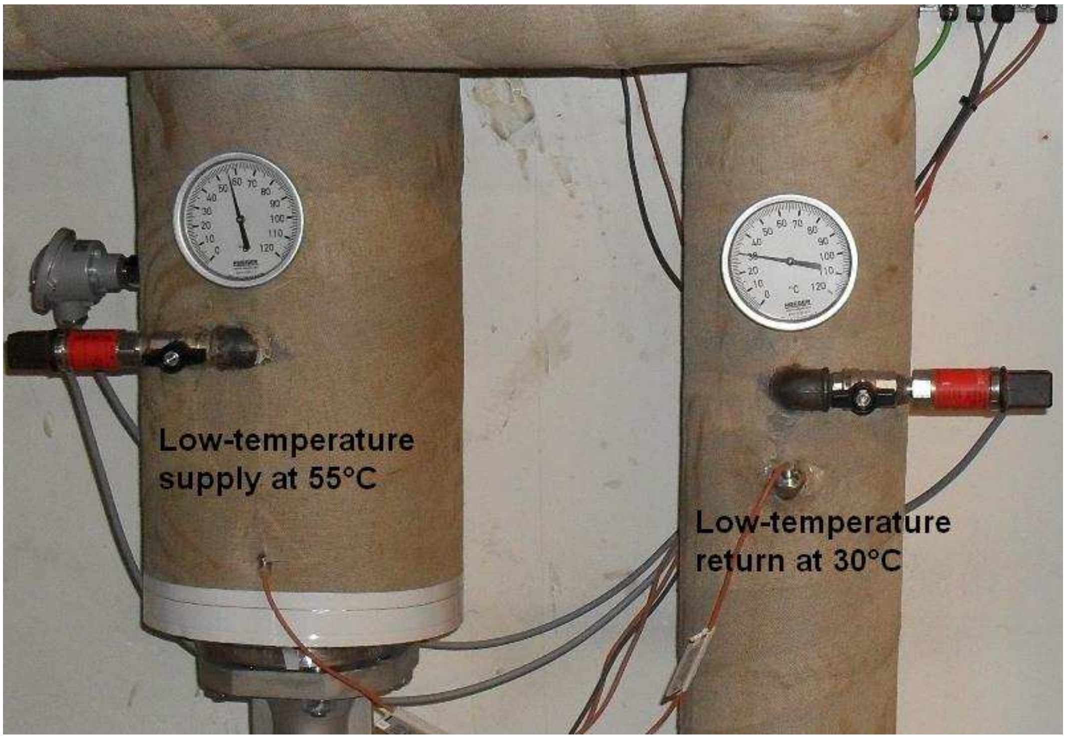


Figure A2.5: The supply and return pipe in the central shunt and pumping station. Example of the supply and return temperature measured during operation.

Appendix 3 - Demonstration of LTDH in 8 existing detached houses with radiators (Tilst)

The utility AffaldVarme is supplying the city of Aarhus with district heating. Totally, 95% of the heat market in the municipality with 315,000 inhabitants is covered. Altogether, the district heating system has some 77,000 customers, who may be owners of commercial buildings, multi-family buildings or one-family houses (the latter group comprises more than 30.000 customers). Skjoldhøjparken in the suburb of Tilst is with a total of 1013 detached houses the largest single area in Denmark with detached one-family houses. The houses were built in the beginning of the 1970s and the building design is representative for about 40% of the Danish building stock of detached houses. The demonstration site comprises a street in Skjoldhøjparken with 8 privately owned houses with radiator space heating systems. The dwellings living area is between 108 and 178 m^2 with a total heated area of 1049 m^2

Planning of low-temperature district heating (LTDH)

The municipality of Aarhus has the goal of being CO2-neutral in 2030 and district heating has a key role in achieving that. The measures include fuel-shift from mainly coal to renewable energy sources at the production sites but also energy savings in the distribution network as well as energy savings at the end-user. Danish district heating utilities are obliged to demonstrate annual savings in the final energy consumption in line with the Energy Efficiency Directive (2012/27/EU), article 7 about Energy efficiency obligation schemes.

The street with 8 houses serves as demonstration of a way to implement low temperature district heating in existing buildings by combined energy renovation of houses and distribution network.

As part of this the houses were investigated in relation to the building energy installations and to the building envelope. AffaldVarme was afterwards in close dialogue with the residents to verify whether it was possible to get them investing in energy renovation. The residents were offered advantageous funding opportunities and some measures were performed during the project period that ended December 2013.LTDH consumer connections and substations

Realising that reducing the supply temperature is a long term effort, AffaldVarme has by 2012 set up new obliged design specifications for substations, water heaters and space heating systems. These specifications are to be used both in new installations and by replacement of existing installations. For direct connection heating installations shall be designed according to district heating supply and return temperatures of 60/30 °C by outdoor temperature -12 °C. For indirect systems the heat exchanger for space heating shall be designed for 60/30 °C on the primary side and 55/25 °C on the secondary side. Domestic hot water heaters must be designed according to district heating temperatures 55/20 °C.

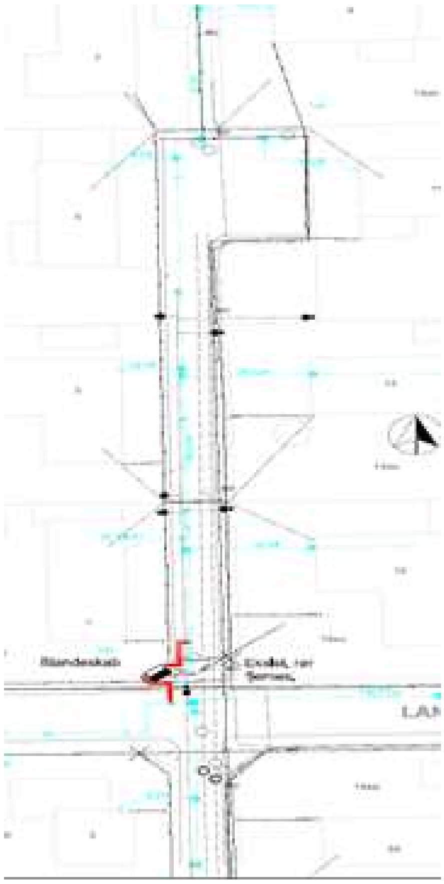
The low temperature district heating system has been designed according to these specifications.

Design of the LTDH network

The 8 houses were originally supplied with heat from individual oil-fired boilers, so district heating connection was not established until 1983. Two of the houses were connected later in 1991 and 2009. The network consist of pair of single pipes with insulation class series 1.

House nr.	Pipe type	Inside diameter [mm]	Length [m]	Year
A	20 Sapx+	16	8	2009
B	18 Dfl	16	7	1983
C	18 Dfl	16	8	1983
D	18 Dfl	16	39	1983
E	18 Dfl	16	8	1983
F	18 Dfl	16	15	1983
G	22 Lpx	18	29	1991
H	18 Dfl	16	25	1983
Main Pipe	48,3 Dg	43,1	98	1983
Total			237	
Sapx = Starpipe aluflex single pipes (series 2), Dfl = Dürotan steel flex pipes, Lpx = Logstor and Dg = Dürotan gliding pipes (series 1)				

The network has mainly been operated with supply temperatures between 65°C and 85°C. In order to be able to reduce supply temperature to the demonstration site a mixing shunt was established at the street entrance and was operated for a period before renovation of the network.



The old network was replaced in 2013 with a new network using twin-pipes insulation class series 2 for main pipes and series 3 for house connections. In insulation class series 3 the house connection twin-pipes has an outer diameter of 125 mm. All houses have crawl space foundation which facilitated the introduction of the connection pipes into the houses.

House nr.	Pipe type	Inside diameter [mm]	Length [m]
A	20-20 Lapx-dr++	15	8
B	20-20 Lapx-dr++	15	7
C	20-20 Lapx-dr++	15	8
D	20-20 Lapx-dr++	15	15
E	20-20 Lapx-dr++	15	9
F	20-20 Lapx-dr++	15	19
G	20-20 Lapx-dr++	15	29
H	20-20 Lapx-dr++	15	25
Main Pipe	48,3 Iso-dr+	41,9	76
Main Pipe	33,7 Iso-dr+	27,3	29
Main Pipe (bypass)	20-20 Lapx-dr++	15	5
Total			230

Lapx-dr++ : Logstor alupex twin-pipes series 3 and Iso-dr+: Isoplus twin pipe series 2

Domestic hot water system and space heating system

Despite great effort and funding opportunities from the district heating utility, it was not possible to convince all house owners to exchange their water heaters for more efficient units designed for a supply temperature of 55 °C as originally planned. Although not all consumers changed their water heaters the utility managed to reach a supply temperature of 61 °C during summer and increased the temperature incrementally to 66 °C during the heating season without complaints from the consumers. In relation to space heating, the supply temperature was reduced much more than expected in the planning phase.

Operation and commissioning of the LTDH system

The results of the demonstration indicate that the heat loss saving potential in networks for this type of houses are in the range of 15 to 20% when reducing the supply temperature from 80 to 65 °C. Combined with the replacement of the old network, the distribution heat losses were reduced by more than 63% which is in line with the results from Sønderby and Lystrup.

Appendix 4 - Other relevant cases

Low-temperature heating network, Østre Hageby, Stavanger, Norway; 2012-2014:

A low-temperature heating network for 66 passive house dwellings in a mix of terraced houses and apartment blocks. The local heat supply system is based on boreholes with heat pumps. A local piping network supplies the dwellings with the heat from the local heating central. Each dwelling has its own flat station (consumer substation).

Developer: INEO Eiendom
Project partner(s): COWI A/S, COWI Norway and AC ENKO

Low-temperature district heating network, Albertslund South, Denmark; 2011-2015:

Low-temperature district heating to 544 terraced houses in Albertslund in Copenhagen.

Developer: Albertslund Forsyning (District heating company)

Project partner(s): COWI A/S

Small-scale low-temperature district heating network, Venning, Kortrijk, Belgium; 2010-2014

At Venning there are built four multi-family houses (82 dwellings in total) and 64 single-family houses; 50 single-family houses will be refurbished. All buildings at the Venning area will be supplied by a new low temperature district heating network, which is supplied by a 1 MW wood chip boiler. A small 10 kW biofuel cogeneration unit produces the auxiliary electricity for the system (pumps, control and monitoring equipment). Its small amount of heat is additionally fed into the district heating network. The hot water buffer tanks are 15 m3.

Developer: Goedkope Woning

Project partner(s): -

Small-scale low temperature district heating network, Slough, UK:

A small-scale low temperature district heating network is serving 10 low-energy homes in Slough, about 20 miles outside London, UK. The district heating network is made with twin pipes and the supply temperature is kept between 50 and 55 °C. A small experimental energy centre with four renewable energy sources supply the network: 30 kW biomass boiler, 2x17 kW ground source heat pumps, 40 kW air source heat pump, 20 m^2 evacuated tube solar panels.

Developer: SSE

Project partner(s): -