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DESIGN OVERVIEW FOR DISTRICT ENERGY

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Description	**Overview of available energy technologies and district energy designs used in comparable developments around the world.**

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1. INTRODUCTION

The City of St. Paul is in a process of preparing for the redevelopment the former Ford production facility into a sustainable urban neighbourhood which aims to be a show case for an attractive and liveable community developed around a district energy system.

This memorandum responds to Activity 1.5 Energy technologies and district energy design with the objective to provide an overview of available energy technologies and district energy design based on the good practices from Europe and in particular Denmark.

District energy offers the opportunity to implement the most efficient, clean and future proof energy supply, but it is important to ensure that the solution chosen is optimised both in terms of its production, distribution and usage.

This report gives an introduction to the fundamentals of a district energy system, both district heating and district cooling including setup and components of the network and building systems. Some general guidelines are also outlined regarding design temperature and pressure conditions.

The city of St. Paul has already a well-functioning district energy system, District Energy St. Paul that provides highly efficient hot water service to almost 200 buildings in Downtown.

Although the Ford site is somewhat remote from the Downtown, it makes good sense that a potential new energy system in the town aims to be compatible and/or aims to be capable of connecting to the existing system if such an opportunity should arise in the future.

The existing system is designed for a supply temperature of 250°F (121°C) in the winter and 190°F (88°C) in the summer time.

A district energy system is a great foundation for low-carbon energy supply of buildings. By having both district heating and district cooling, certain synergies can be achieved, which can increase the energy efficiency and reduce the price of both heating and cooling for the end consumers.

The design recommendations in this memorandum are inspired by know-how and experience from European countries like Denmark where district heating is well established. In Denmark more than 63% of all building stock is connected to district heating. Likewise, district cooling is becoming widespread. Historically the Danish heat act has not supported district cooling systems, but this has changed in recent years, as it has been proven to be more efficient and thereby beneficial for an overall district energy system. District cooling systems are now being installed more frequently also in Denmark, but it is European countries like Sweden and France, which have the most district cooling capacity installed.

2. DISTRICT HEATING SYSTEM DESIGN

2.1 What is District Heating

The district heating (DH) system produces thermal energy in the form of hot water (or steam) at one or more central plants (heat sources) and then distributes this energy through underground pipes to buildings connected to the system. Buildings connected to district heating no longer need boilers or to maintain redundancy for heating needs. Customers use the hot water provided to meet their space heating, domestic water heating and heat processing needs. Once used, the water is returned to the central plant for reheating and then recirculated through the closed-loop piping system.

The heat is delivered to the buildings through a network of highly insulated pipes that are normally buried underground. DH networks are heat technology and fuel neutral. Any heat generating technology using a variety of fuels can in principal connect to DH networks such as conventional boilers, gas engines, energy from waste plants, power stations, biomass fuelled technologies, geothermal heat, solar heating, waste heat from industry and excessive power from wind and solar panels.

2.2 Overall design concept

In general a DH network can be divided into three main parts:

- The transmission network
- The distribution network
- The internal heating system at the consumer.

Generally the transmission network is used for larger systems and operates at high temperatures and pressures, carrying large amounts of heat from larger heat producing units such as central power plants, waste incineration plants etc., to strategically placed heat exchanger stations where the heat is transferred to a distribution network.

The distribution network generally operates at lower temperatures and pressures than the transmission network and supplies heat to each individual consumer. The consumers range from large companies/schools etc. with huge heating demands to blocks of flats and down to individual one-family houses.

Normally, the transmission and distribution network interact only through heat exchangers meaning that they are hydraulically separated. In many cases this also applies for the interface between the distribution network and the internal heating system at the consumers.

Back-up and peak-load plants are also strategically placed around the network to secure the supply of heat in case of service or maintenance but also at peak load demanding situations.

The figure below illustrates the overall district heating concept.

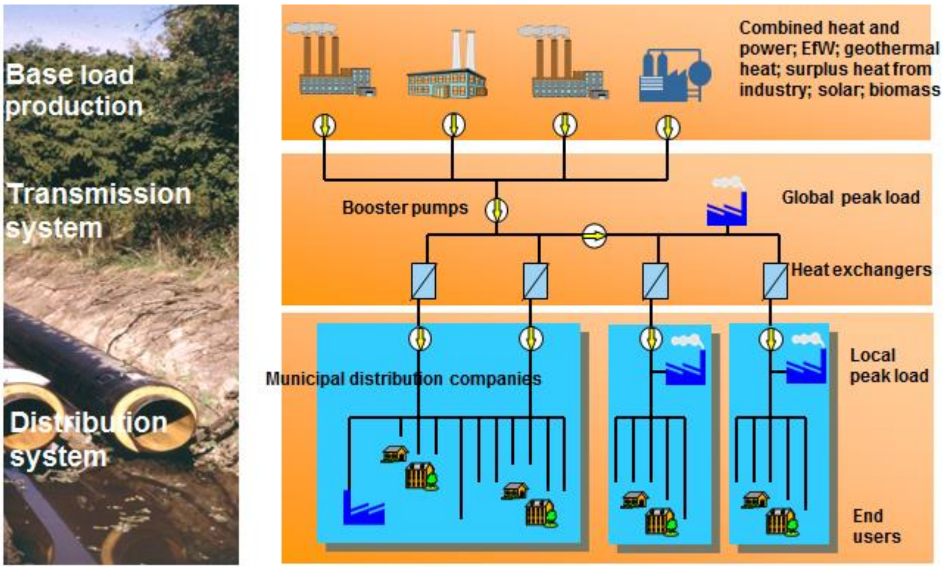

Figure 2-2 Example of an overall district heating supply concept (Photo curtesy of CTR)

A transmission network is not presently envisaged for the Ford Site project, but could be a future option to consider for the connection in some way with the Downtown system. E.g. it could be envisaged that waste heat is captured from the Xcel Power Station close to Downtown and transported to the Ford Site, to the district energy St. Paul Downtown system and/or any other cluster distribution networks that can be established.

The design of a heat network should always seek to employ the smallest diameter pipes to help reduce the capital costs of its implementation. For this to happen, the operating temperature difference between the temperatures in the supply and return pipes needs to be as large as possible. In addition low supply and return temperatures are preferred to reduce the heat losses and thereby ensure high energy efficiency.

However, the heat network must also deliver energy at a temperature suitable for use in any given type of building which it will connect. The difficulty, therefore, is to satisfy all criteria simultaneously.

When planning a DH system for the Ford site and once the overall vision is decided a detailed hydraulic modelling of the planned network must be carried out. This should be done in order to find the optimal dimensions of the pipe network, in relation to the proposed consumers.

For an efficient network and low network heat loss, high heat density also becomes an important parameter for a better overall economy.

When implementing a district energy system, the network generally carries the largest cost and it is therefore important that great consideration is given to its design parameters and optimisation both in respect to capital costs and ongoing operational expenses.

2.3 Consumer connection

The choice of consumer connection method is central to the design and operation of the DH network since it:

1) Dictates the constraints on the resulting temperatures and pressures adopted in the network.

2) Defines the opportunities and constraints around ownership models, operational risks and operating regimes during the operational phase of the project.

The recommendation around connection method therefore needs to reflect all of these factors as well as consider construction and operational costs and the need to retain as much flexibility as possible. For the Ford site this means leaving flexibility for a single site or for individual plot developers to develop according to their particular requirements (domestic, office, retail, industry, swimming pool, school, hotel etc.).

The main options available for connecting individual consumers to a district heating distribution network are as follows:

1) Direct heating and direct hot water connection
2) Indirect heating and indirect hot water connection
3) Direct heating and indirect hot water connection

The direct approach involves connecting the network system to the consumer's internal heating system directly, without any physical separation of the two systems (i.e. without a heat interface unit like a heat exchanger).

The indirect approach involves introducing physical separation between the network (primary side) and the consumer's internal heating system (secondary side) in the form of a heat exchanger (or hydraulic interface unit - HIU) so that the two systems are hydraulically separated. This type of connection allows, in principle, any DH system to connect to any building. The differing temperatures and pressures are accommodated by the heat exchanger within the limits of the overall operating temperatures and pressures. This type of connection helps eliminate issues of ownership and responsibility between DH system operator and building owner.

The interface can be located at each individual building or apartment or in the form of a communal interface located in the basement/ground floor of an apartment block.

The figure below shows a simple schematic of a network with either a direct connection or an indirect connection.

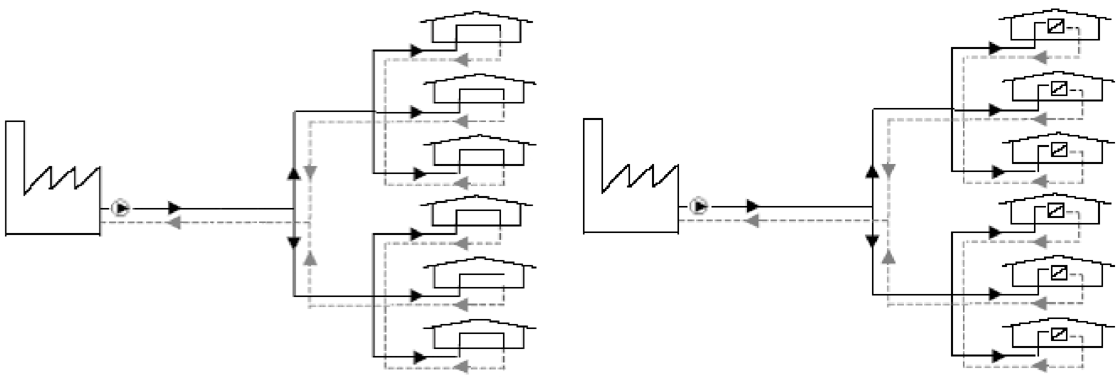

Figure 2-3: Simple schematic of a network with a direct connection (left) and a network with an indirect connection [Source: Euroheat & Power]

2.4 System Pressures

The system pressures are determined through the combination of the pressure required for pumping hot water around a network to meet the maximum heat demand and the pressure required to maintain the static head in a system and efficiently deliver the heat required to all consumers.

The design pressure of distribution networks typically ranges between 87-232 psi (6-16 bar), depending on the type of installation at the consumer, the altitude levels in the network and depending on the size of the distribution network.

If consumers are directly connected to the distribution network, then it is the internal heating system in the buildings that determines the maximum allowed pressure in the distribution network. The design pressure in district heating networks where the consumers are directly connected is typically 87 psi (6 bar).

If consumers are indirectly connected to the distribution network, then the design pressure is typically around 145 psi (10 bar). The higher design pressure allows pipe sizes to be reduced (through increased pumping head) and the indirect connection avoids then need to specify higher pressure ratings for the heating systems within the dwellings.

Design pressures above 145 psi (10 bar) are optimal for larger distribution networks or where there are large variations in terrain profiles altitudes or high-rise buildings. In such cases, it could be necessary with a design pressure of up to 232 psi (16 bar), but it should be analysed further in hydraulic models of the system in order to find the economically optimal solution for the system.

A 16 bar system could give higher costs of the energy plant/centre equipment, but in return lower pipe network costs because pipe dimensions can be smaller (compared to a 10 bar system).

Design pressure for transmission networks are generally 232 psi (16bar) or 362.6 psi (25 bar). Transmission networks operates at high temperatures and pressures so to carry large amounts of heat for longer distances with a minimum heat loss from larger heat producing units such as central power plants, waste incineration plants etc. to strategically placed heat exchanger stations where the heat is transferred to the distribution network.

2.5 System temperatures

The system temperatures will be determined partly by the requirements of the buildings connected to the heat network, partly by the choice of pipe technology and partly by the primary energy source.

In order to find the optimum supply temperature it is necessary to find a compromise between temperature difference (between supply and return) and low supply temperature.

An increase in temperature difference is an advantage as smaller pipe dimensions can be used and subsequently installation costs can be reduced. Furthermore, operation and maintenance costs are also likely to be reduced. An increase in the temperature difference between supply and return is achieved by optimising the end-user installations, but can also be achieved by increasing the supply temperature.

Low supply temperature has the advantage of reducing the heat loss from the network significantly and subsequently reducing the operation costs. However, reducing the supply temperature could also lead to a reduction in temperature difference (delta T) and thereby increased flow and pumping energy.

Furthermore, it is worth noting that every time there is a heat exchanger in the system there is a temperature loss, which generally means that the supply temperature in the distribution network needs to be higher than the supply temperature required internally in the buildings that are to be connected.

The ideal DH temperatures needs should be finally determined as part of the hydraulic optimisation of the network as a whole once the principal system and development concept has been determined.

2.5.1 Low temperature district heating

The optimum operating temperatures have been investigated in a research financed by the IEA District Heating and Cooling programme. The report "The Optimisation of District Heating Operating Temperatures and an Appraisal of the Benefits of Low Temperature District Heating" from 1999 describes the research. The research identified the optimum operating temperatures for district heating schemes by minimising the total costs, which is the sum of operation costs, network costs and building internals costs. The optimum design temperature for a distribution network was then here found to be 194ºF (90ºC) for the supply and 131ºF (55ºC) for the return when supplying heat to a residential building.

However, 4th generation district heating seen in Europe and in particular in Denmark, look to quite low sets of temperatures for buildings build to newer design standards and with lower heat demand. But this should also be seen in combination with the instruction of renewable fuel sources such as solar thermal for low or near zero carbon systems and the utilisation of heat pumps.

Below is seen an example of rather low DH temperatures, where the operating supply temperatures in the system (at the consumer) will range from 140ºF (60ºC) during summer time to 176 ºF (80°C) during the coldest winter time. The return temperatures in the network are 77-95 ºF (25-35°C) which represents a mix of return temperatures from the customers heating and domestic hot water system.

The example is based on an indirect system with heat exchangers for hydraulic separation of the primary side (distribution network) and the secondary side (consumer system). The heating system is floor heating, which has a very low temperature demand.

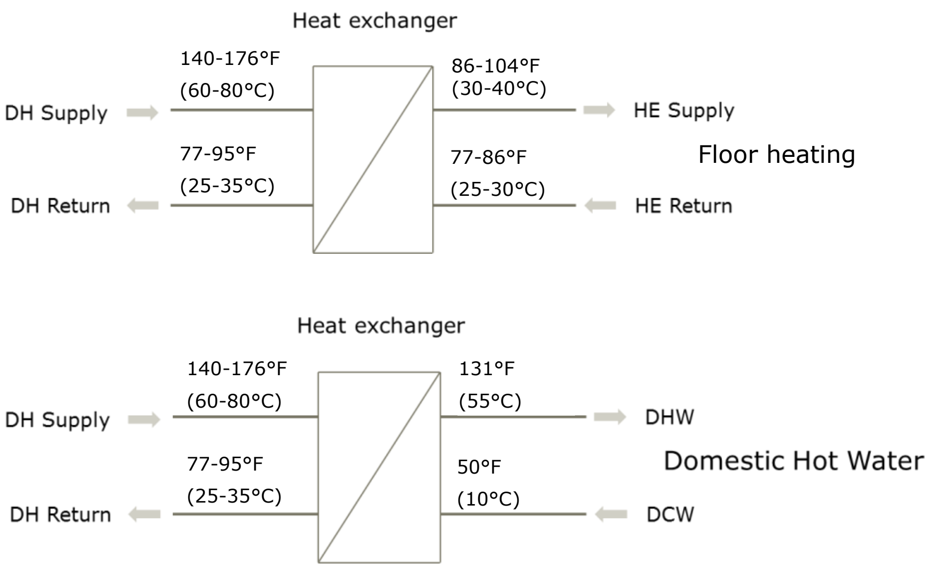

Figure 2-5-1 Example of (low) DH temperatures in a heating circuit and a domestic hot water circuit

2.5.2 Connection of new buildings

With respect to new buildings construction, new building standards generally lead to lower heat demand requirements and as such the design of the individual buildings heating systems can be for lower supply temperatures to accommodate condensing and near condensing boilers. Typically supply temperatures in the range of 130-160ºF (54-71ºC) supply is seen and return temperatures of 110-140ºF (43-60ºC) depending on the specified delta-T and the use of condensing boilers. In Denmark, The Danish District Heating Association recommend a supply temperature of 158ºF (70ºC) and a delta T of 95ºF (35ºC) for heating systems and a hot water return temperature of 86ºF (30ºC).

The supply temperature will depend on whether the heating systems are hydronic or air based and if hydronic, whether glycol has been used.

2.5.3 Connection of (older) existing buildings

If older existing buildings are to be connected to the district heating network, higher DH temperatures would normally be required, because the internal system of the buildings traditionally are designed for higher operation temperatures. It could be in the range of 180ºF (~ 82 ºC) in supply and 160ºF (~ 71ºC) in return. However, indications are that the supply temperature could range from 170-200ºF (~ 77-93ºC) depending how they have been designed.

The supply temperature will depend on whether the heating systems are hydronic or air based and if hydronic, whether glycol has been used.

In some cases the heating surface area (area of the radiators) may be very small, which leads to a low temperature difference. Therefore connecting existing buildings to the district heating network is likely to lead to the need for delivery of higher supply temperatures whilst also incurring higher return temperatures by virtue of the design of the building's internal systems.

For this reason if existing buildings of older design standards are to be connected, the design of the internal heating system in the buildings may need to be modified to ensure that they can operate based on the requirements of the distribution network set by the delivered supply temperature and the limit for the maximum return temperatures. For example, a building with an internal heating system designed for supply/return at 180ºF/160ºF (82ºC/71ºC), can be designed to operate with 176ºF/122ºF (80ºC/50ºC) if the heat losses from the building can be reduced by 25% since the reduction in heat output from the heating system will be compensated for by the reduction in thermal losses from the building.

2.6 Consumer substation

Consumer substations, also known as hydraulic interface units (HIU), are normally equipped completely with circulating pumps, heat meter, controls and other ancillary equipment required for a heating installation. An individual residence substation (for smaller thermal loads) are relatively simple to install and easy to start-up.

There are many producers of substations and they also come in many designs with many different suppliers of components. Typically the larger ones are built to order either on site or in a factory, whereas the smaller and medium sized are standardized in design and size and are produced to stock (pre-fabricated units). The large substations are floor mounted whereas the smaller substations are designed to be wall hung to fit within standard kitchen module spaces.

The choice of unit reflects the type of connection i.e. direct / indirect heating and cylinder / instantaneous domestic hot water connection. Temperatures and pressure levels, also for the mains cold water supply and for the domestic hot water, are among the important parameters when specifying the units.

One important issue is the capacity of the unit in relation to the building's heat demand and the demand for domestic hot water. This will lead to requirements in terms of flow over the installation, combined with the obtainable supply and return temperature.

The pre-fabricated units have to be designed for the special conditions in the US.
These conditions include water quality and pressure as well as the way in which the heating system is operated. Generally, there will not be significant differences in layout and size of these units between different manufactures but there can be a difference in the quality of the components used. A cheaper brand may be compromising on the quality of for instance the heat exchanger and/or the control valves.

A minimum design pressure difference at the consumer interfaces will be specified to accommodate losses through the heat exchanger station and associated equipment and to ensure adequate control valve authority. This will typically lie between 7.3-14.5 psi (0.5-1 bar (g)), depending on the type of connection.

A typical consumer substation for individual residences (for apartments, one-family houses and row of houses) could look like the examples below. One of the substations in Figure 2-6a is equipped with a heat exchanger for the heating system as well as a heat exchanger for the domestic hot water system, while the other substation only has a heat exchanger for domestic hot water (i.e. direct system on heating).

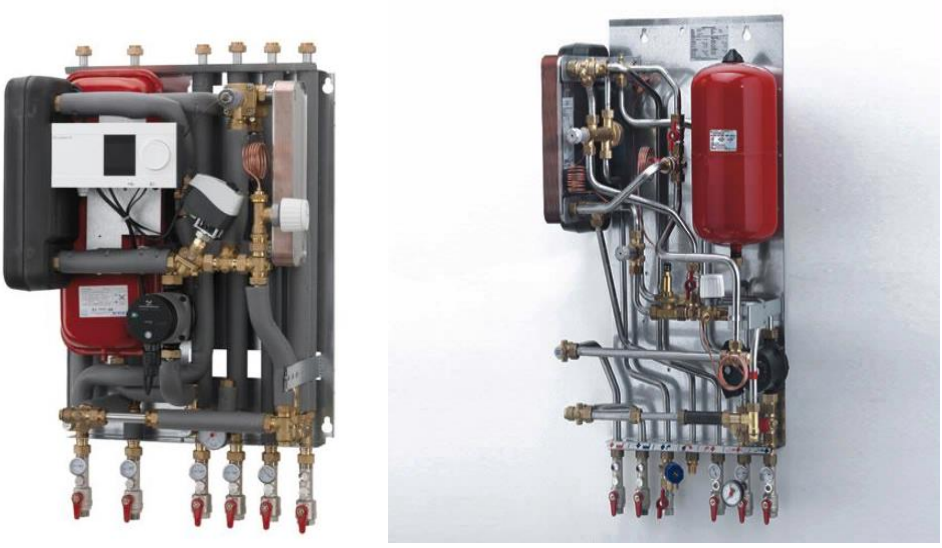

Figure 2-6a Examples of a consumer substation for an individual residence. The substations are illustrated without casing (Photo: Danfoss)

Also you can find district heating substations with integrated floor heating systems like the below examples from Danfoss and PEWO.

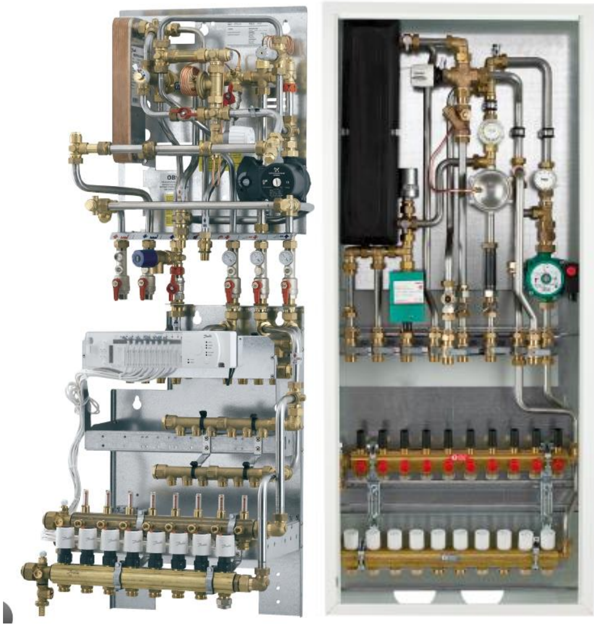

Figure 2-1b Examples of consumer substations for an individual residence with integrated heating manifolds (Photo: Danfoss and PEWO)

In the larger apartment buildings there can be a central substation with a heat exchanger at the ground floor supplying every flat with direct heating (no heat-exchanger) to radiators and/or through a mixing circuit (loop) for the floor heating system as well as for the domestic hot water via a small heat exchanger.

A typical example of a larger central floor mounted substation is seen below and will be supplying into larger and high rise buildings via a heat exchanger. Such a large substation solution could also be used commercial, retail and offices buildings.

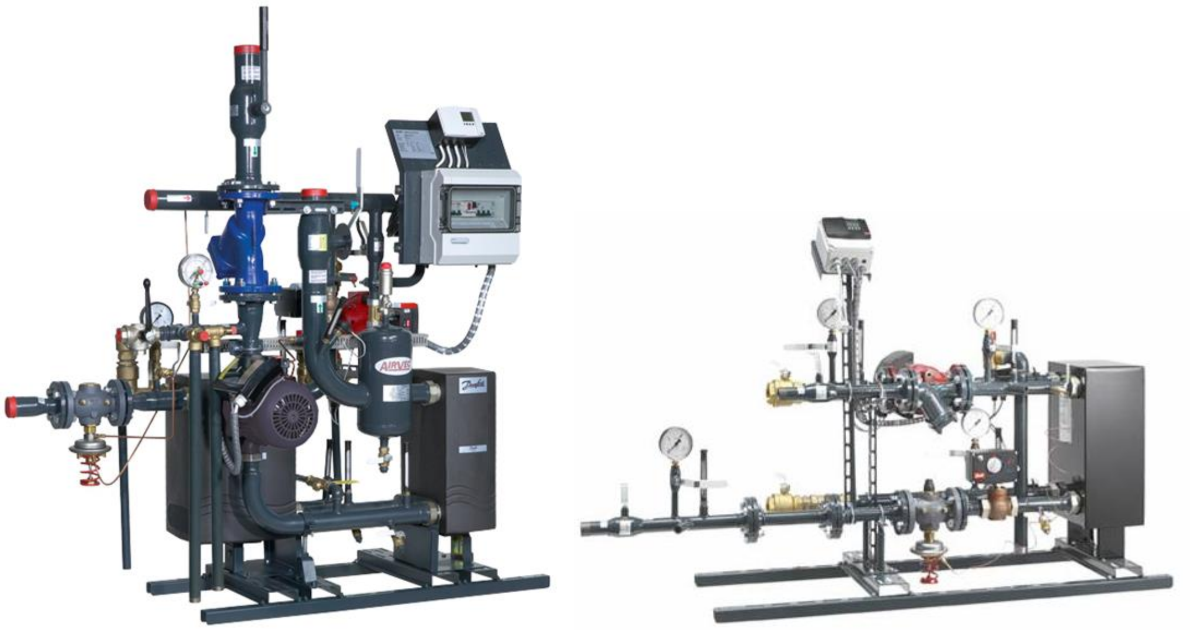

Figure 2-6c Examples of floor mounted substations with heat exchanger for blocks or large commercial, retail or office connections. The components are illustrated without insulation /casing (Photo: Danfoss)

Instead of having a large central substation in the basement of an apartment block / high rise building, which require a 5-pipe system for heating and water supply (incl. circulation) another concept, can be to have a system with "flat stations". This will be heating and domestic water supply with decentralised produced domestic hot water. Such a system will only require a 3 pipe distribution system in the building and installation of a small individual consumer substation in each flat.

The 3-pipe system can also be made without the large heat exchanger in the basement, so heating is supplied directly to the "flat stations" optionally also with a small heat exchanger for heating (the radiator / floor heating circuit) if an indirect system is required.

The concept is shown in the figures below.

Here it is applied with radiator panels, but it could also be with floor heating. The floor heating system will require a small mixing loop for each apartment to control the supply temperature into the apartment. The mixing loop is to be applied before the pipe manifold to the floor heating circuits. By applying a substation with an integrated floor heating system the mixing loop is already built in.

It is considered to be a more modern heat supply concept and should be considered for new buildings, including hotels and residential sector. Main advantages for the flat system compared to the central production of domestic hot water are:

- Possible to supply with a lower DH temperature (and the design can be suitable / prepared for low-temperature DH).
- Reduced distribution heat loss
- Individual metering of heating and domestic hot water energy consumption with only one meter
- Low volume of domestic hot water resulting in reduced risk of bacterial growth.

In case of high buildings the number of totally needed riser pipes is less for the flat station concept due to pressure zones. For each pressure zone typically two riser pipes are saved for every 2 flats per floor. Therefore especially for high buildings the flat station concept should be considered.

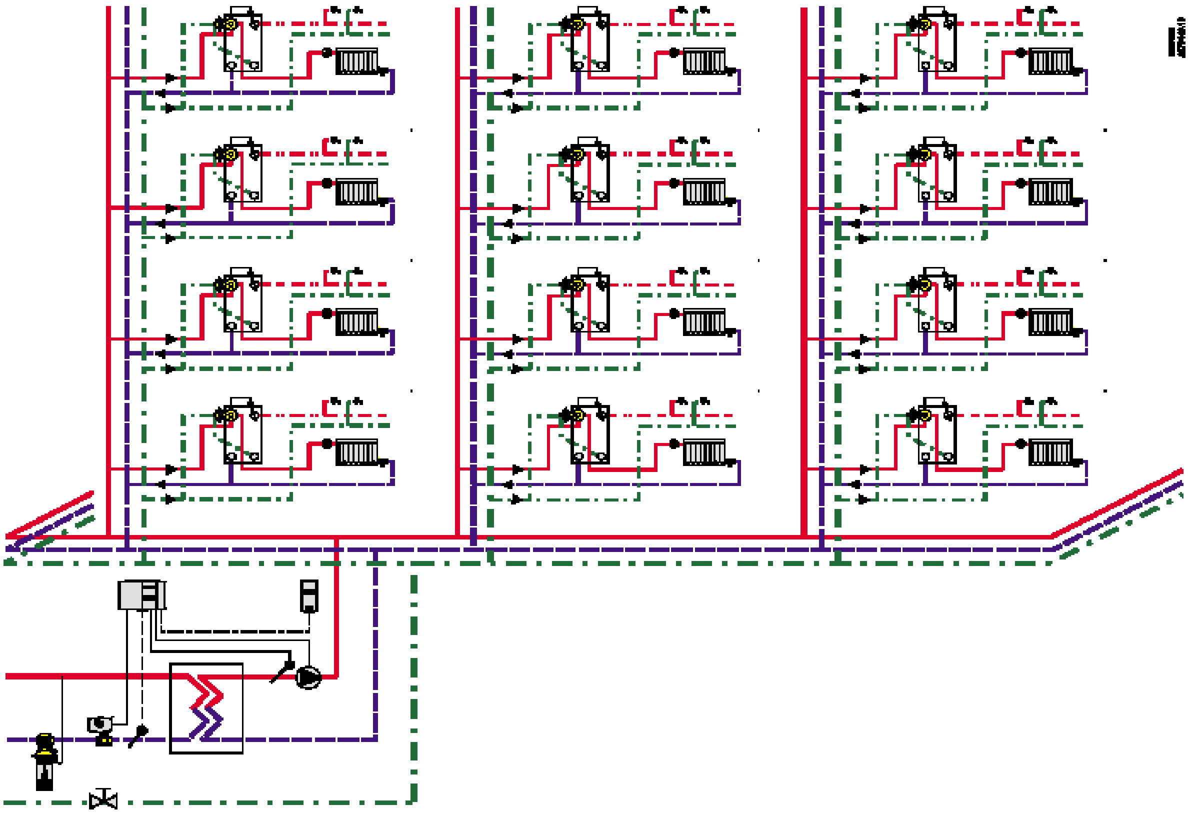

Figure 2-6d Example of district heating system connection in a high rise building (Illustration: Danfoss).

The next figure shows the same principle. It is seen that a buffer tank for the supply system in the building could be added. The necessity of such a buffer tank is to be verified by more specific system calculations for the larger apartment buildings.

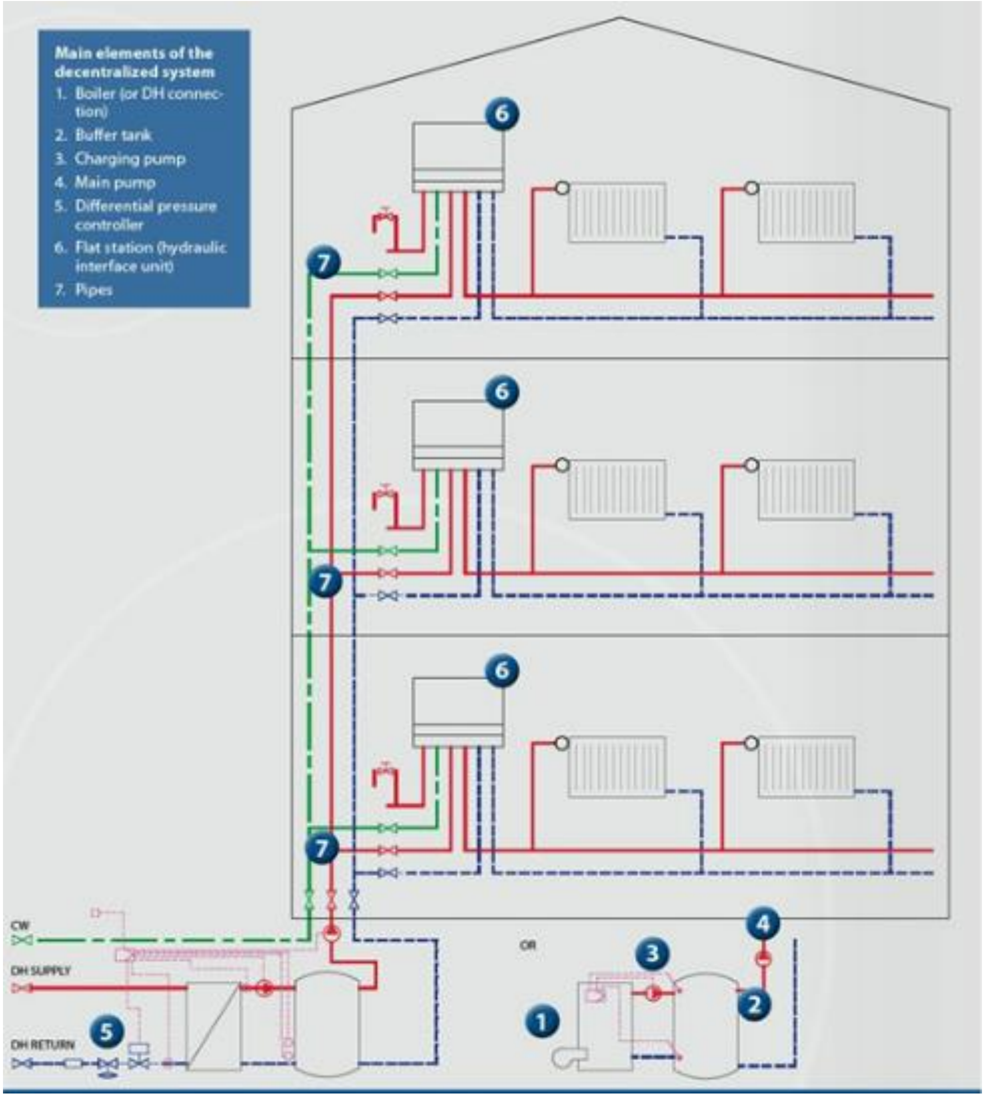

Figure 2-6f Example of district heating system connection in a high rise building (Illustration: Danfoss)

2.7 Metering equipment

Each individual costumer should have their own heat meter. Heat meters are normally installed in the return pipe and typically it is mounted in the substation at a pre-defined place.

Ultrasonic heat meters are the right solution for district heating and they are able to interface with the following communication devices/protocols;

- Optical ZVEI or similar
- M-Bus
- L-Bus
- Pulse output
- Analogue output
- RS232
- RS485

These can provide remote data collection for an operator, and a number of software products exist that can undertake automatic metering and billing functions. Remote monitored heat meters can also be used to help detect malfunctions in the building heating system.

Energy or utility metering, metering of electricity, domestic water and heat or gas has developed rapidly over the last 10 years. Individual heat metering specifically is especially used in the district heating business.

These days the energy meter is not only used for the settlement of the customer's energy consumption. The meter is also a natural tool for a constructive dialogue between the heat or cooling supplier and the consumer. The possibilities of the meter are such that it can help the consumer ensure that their heating or cooling needs are covered at the lowest possible costs.

Also energy meters are an important tool for the district energy supplier to detect possible operational errors in the district heating and cooling network. In larger buildings and heating or cooling plants it is also recommend with internal meters in order to get an overview of the operation conditions such as different internal specific energy consumptions, temperatures, pressure levels etc. The figure below shows an example of energy meters for district heating and cooling.

Figure 2-7a Example of energy meters for heating or cooling (Photo: Kamstrup).

Figure 2-7b Example of meters for heating or cooling (Photo: Kamstrup).

For the Ford Site, heat and cooling metering could for instance be provided at each building interface. Or in each flat if "flat stations" are installed, which will give the opportunity for direct settlement of the customer's energy and water consumption. The meters will record the heat or cooling delivered on the primary side of the heat interface units (i.e. upstream of the heat interface units). The meters could be connected to a SCADA system to enable automatic meter reading to take place at the energy plant/centre. Ultrasonic flow meters should be specified. These could be linked back to the energy plant/centre though a dedicated fibre optic network or via a broadband connection. Radio or mobile phone communication is also an option. Radio controlled remote reading meters are starting to be commonly used.

District heating utilities (in e.g. Denmark) are increasingly introducing intelligent district heating meters at the consumers. The meters provide, among other things the heating companies an exact overview of the actual heat consumption in the network and at the same time costs are saved due to no (yearly) physical reading at the consumers. The figure below shows an example of such a remote reading system.

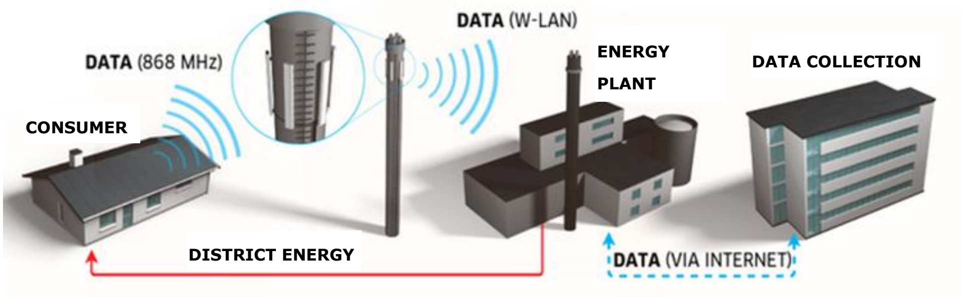

Figure 2-7c Example of an intelligent remote reading system with energy meters (Photo: www.ing.dk)

2.8 Communication

At the energy plant/centre a communication (SCADA) system can be installed to both gather information to help control the district heating network but also to receive data from each consumer or connection.

The energy plant/centre will also rely on one or more signals from specific locations in the network to control both pressure and temperature of the outgoing supply water.

2.9 Types of district heating pipes

Modern district heating (DH) systems generally use pre-insulated pipes directly buried in the ground. Several types of pipe are available and the selection of appropriate pipe depends mainly on operating conditions and cost.

The different type of pipe systems are ranging from rigid steel pipes to flexible plastic pipes produced as pre-insulated bonded pipe systems. A pre-insulated pipe consists of a medium pipe that can be of steel, copper, plastic (PEX - cross linked polyethylene) or Aluminium PEX. Common to each is a layer of polyurethane foam insulation and an outer protective casing. The outer casing is normally made of high density polyethylene.

A diffusion barrier is recommended (if possible for the type of DH pipe) between the insulation foam and the outer casing in order to guarantee a high quality of insulation properties during the whole service life of a pipe system.

The insulating foam thickness can vary to provide lower heat losses. DH pipes are typically available in different insulation classes (also called "series"), where series 1 has a standard insulation layer thickness, series 2 has a larger insulation layer thickness and series 3 has an even larger insulation layer thickness.

In most cases alarm wires, made of copper, are contained within the insulation for leakage monitoring (not possible in combination with PEX-plastic pipes).

Pipes can be either single or twin pipes, meaning that for single pipes you need two pipes for supplying district heating - one pipe for the supply and another pipe for the return. Twin pipes have two medium pipes (one supply and one return) within the same outer casing.

2.9.1 Pre-insulated steel pipes – single pipe system

Pre-insulated steel pipes in single pipe system are very commonly used in DH systems, particularly for the main distribution network.

The figure below shows an example of the structure in a pre-insulated steel single pipe.

Figure 2-9-1 Structure of a pre-insulated single pipe for DH (Photo: Logstor)

2.9.2 Pre-insulated steel pipes – twin pipe system

Pre-insulated steel pipes in twin pipe system are very commonly used in DH systems, particularly for the main distribution network, but also for service pipes.

Twin pipe systems can reduce the construction costs by some 10% (rough estimate) and reduce the system heat losses. It must be noted that twin pipes normally "only" are available in dimensions up to DN200 (ø219). In larger dimensions it is the single pipe system that has to be used.
In countries like Denmark twin pipes have become commonly used, especially when installing long length of pipes with no or few connections.

The figure below shows an example of the structure in a pre-insulated steel twin pipe.

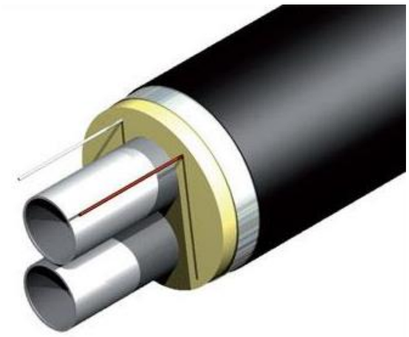

Figure 2-9-2 Structure of a pre-insulated twin pipe for district heating (Photo: Logstor)

2.9.3 Flexible pipes

Flexible pipes are typically most suitable for service pipes connecting the distribution network to the buildings. The following types are available:

- Flexible pre-insulated DH pipe with medium pipe of copper (cu-flex)
- Flexible pre-insulated DH pipe with medium pipe of PEX or AluPEX (diffusion tight) material
- Flexible pre-insulated DH pipe with medium pipe of steel (steelflex)

These DH pipe types are available in smaller pipe dimensions and can be delivered as twin pipes (recommended), but also in single pipe system.

Flexible pipes have operational limits in relation to maximum allowable pressure and temperatures. So if high DH operation temperatures are chosen for the Ford development area, flexible pipes are not recommended. For service pipes should instead be used steel pipes e.g. twin pipes.

2.9.4 Protection against water leakage

A leakage protection system can be built in to the heat network through an in-built surveillance system that continuously monitors the insulation for moisture through copper wires embedded into the insulation. If moisture is detected through a disturbance in the measured ohmic resistance, a fault will be generated at one or more monitoring stations. These monitoring stations will be linked to the SCADA system at the Energy plant across a communication network so that they provide immediate notice of an impending problem by raising an alarm.

It is recommended that leakage protection systems are also installed in the individual blocks to detect leakages within the risers and laterals within the blocks prior to entry to the individual apartments.

3. HISTORICAL DEVELOPMENT FOR DISTRICT HEATING TEMPERATURES

In a historical perspective, low temperature DH, can be categorized as the 4th generation of the technology development, following the steam-based systems (1st generation), the superheated water systems (2nd generation) and hot water systems (3rd generation). The district heating generations (supply temperatures):

- 1st generation, Steam: 572°F (300°C)
- 2nd generation, Superheated water: > 212°F (100°C)
- 3rd generation, Hot water: < 212°F (100°C)
- 4th generation, Low temperature water: 122-140°F (50-60°C)

The first generation of DH systems use steam as heat carrier and were introduced in particular the USA in the late 19th century; the majority of DH systems established until the Second World War used this technology. Steam-based DH represents an outdated technology, because of high heat loss, high operating and maintenance costs and it limits the application of community energy systems.

The technology is still used on many university campuses etc. across the US, in cities such as Seattle and Manhattan. In Europe most have been (e.g. Hamburg and Munich) or are being replaced e.g. in Copenhagen, where an ongoing replacement program is in place.
Where there is a (industrial) process need for steam. Often it can then be seen that a hospital or industry is supplied by hot water DH and then raise this to steam locally.

The second generation switched to pressurized hot water (e.g. 266°F ~ 130°C) as the heat carrier and they were applied until the 1970s. Remains of this technology can still be found in the older parts of the current water-based district heating systems.

The third generation of systems came after and gained a major success in the 1980s; they are the most used systems both in upgrading of existing network and in new projects as well including projects in USA and Canada and the UK. The energy carrier is still pressurised water, but supply temperatures are lower (e.g. 176°F ~ 80°C) and they are often combined with the use of the twin pipe system and plastic media pipes, when it is possible.

3.1 Low-temperature district heating

Low-temperature district heating (DH) is an interesting design concept, because it can meet the challenges of the future with high energy efficiency and a large or full share of renewable energy sources in the energy system. Renewable energy sources are normally exploitable and available in larger amounts at lower temperature than traditional DH temperatures. Low-temperature district heating could play a key role in the concept of (climate) smart cities, where the aim is to lower carbon emissions.

A low-temperature DH system is typically defined by having 122-140°F (50-60°C) in supply. To have a DH system with about 176-212°F (80-100°C) in supply can also in some countries / for some DH utilities be seen as "low-temperature" and could be the first step towards lower DH temperatures.

Design of a low-temperature DH system is not just all about lowering the DH temperature in the network. The consumer substations must be designed for the low temperature. Also the pipe network is preferred with twin pipes (in dimensions where this is possible) and must be in a high insulation class if the low heat loss and thereby high energy efficiency is to be achieved.

In Europe the low-temperature concept is especially suitable for new buildings, because the building design can be prepared in such a way, that the heat installation will fulfill all requirements for heating and hot water. However, the concept can also be implemented for existing buildings, but it will normally require that each building have undergone energy retrofit or just some heating installation upgrades.

It is possible to use low-temperature DH to buildings or areas placed next to existing areas with traditional DH temperatures. In that case decentralized mixing shunts could ensure the lower supply temperature. If the whole area then later is converted to low-temperature DH, the mixing shunt(s) could be removed again. An innovative solution would be to design the mixing shunt in such a way that return water from the traditional DH area can be used as supply in the low-temperature area if/when the flow is sufficient. This will increase the energy efficiency and the capacity of the network.

Several low-temperature networks have already been built in Denmark, but there are a few examples from other countries. In Denmark low-temperature DH has been implanted for both low energy houses and for existing buildings. The flow temperature in these district heating networks is as low as 122-140ºF (50-60ºC). Development is ongoing of consumer installations suitable for even lower DH supply temperature at 104-113ºF (40-45ºC) combined with an electric heating element). In these systems there is no storage tank for Domestic Hot Water (DHW). This heating is carried out with an instantaneous heat exchanger. The risk of bacterial growth in the DHW system is prevented by having no water storage and a water content in each DHW supply line, including the volume in the secondary side of the DHW heat exchanger kept to a minimum (below 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).

Examples of low-temperature DH networks in operation are described in Section 6.

4. HEAT PRODUCTION TECHNOLOGIES AND FUEL

Conventionally the heat demand in a DH system is met by waste heat from power stations (co-generation) and/or Energy from Waste (EfW) utilising a heat generation which would otherwise be wasted and subsequently it comes at a very low cost. In smaller schemes it is common to look at installing the heat production, which often unfortunately adds cost to the scheme.

Traditionally co-generation plants are fuelled on gas (or coal for large systems) but gas CHP will meet potential renewables target. The next obvious step would be to turn to biomass as a fuel. However, biomass fuelled technologies adds other complexities with fuel transportation and flue gas emissions and the surrounding air quality.

There is no doubt that local air quality will be affected by the installation of a biomass plant. However, for larger plants there are a number of possible gas cleaning technologies available that may be employed in order to meet regulatory requirements

Alternative technologies such as solar (both for generating electricity and heat), wind or heat pumps could come into play especially if low temperature systems are employed.

Once a DH network is in place it opens up for utilising a variation of heat producing sources. The potential phasing of the Ford development and its network may open up possibilities for changing technologies over time.

Go-generation should as a rule of thumb only be operated as a base load, as depending on the technology it may be difficult to operate according to daily variations in demand. This also accounts to some extent to biomass heat only boilers. Biomass boilers will for a given capacity BTUh (MW) have a given rate of modulation BTU (MWh).

A well-designed district heating network heat from go-generation will provide between 60% and 80% of the annual heat requirement with heat-only boiler plants providing the peak load and back-up.

For new developments where interim boilers have been used during build out these can later be utilised for peak load and back-up.

Where district heating is being installed to replace conventional heating systems there are opportunities to re-use existing boilers as heat-only boiler plant.

The use of thermal storage and the flexibility it gives should also be evaluated as it can add benefit to a scheme.

As mentioned earlier the advantage of a district heating system is the flexibility and the ability to utilise a variety of heat sources, including what can be called low-grade heat.

One example is the use of solar thermal energy. There are a number of examples in Europe where large-scale solar thermal arrays have been integrated with district heating networks as district heating schemes offer maximum energy utilisation from solar thermal as a heat sink for the low temperature water. The largest system in Denmark is connected to the district heating network in a small town, covering 30% of the annual heat demand of 1,200 single-family houses, a few public buildings, a school and a hotel.

4.1 Co-generation/Combined Heat and Power (CHP)

Co-generation or combined heat and power (CHP) is the simultaneous generation of electricity and heat.

Gas-engine CHP has been the CHP plant of choice in Denmark smaller communities for a number of years and also in the UK in hospitals, university campuses and housing estates. The Netherlands has also build up their DH around de-centralised gas CHP.

Biomass fuelled CHP plants have for many years been part of the Danish electricity and heat supply industry but for quite large scale power station units. The technology for medium range and small scale units are still seen to be technically and commercially viable, although it can vary depending on the proposed technology.

The most common used technology for producing heat and power with biomass is the steam circuit process. Initially the fuel is converted to thermal energy primarily in a heavy-duty steam boiler as high-pressure steam. The steam is expanded and subsequently cooled in the steam turbine driving a generator and producing electricity. The district heating water is afterwards used to cool the steam further, before it is returned to the boiler.

Newer technologies like gasification of biomass, Stirling engines etc. are being developed, though most of them are still not at a commercial level.

The specific heat demand and following the size of the CHP plant together with the electricity sales price are decisive determinants when choosing between a CHP and a heat only producing unit. CHP plants are considerable more expensive than boilers producing the same amount of heat. For small-scale biomass plants especially, the market price for electricity is not sufficient to cover the extra initial costs. Accordingly an investment grant for the plant or subsidies on the electricity tariff is essential.

In general, experience shows that plants with an installed capacity (use of fuels) less than 10 MW and a generating (power) capacity less than 2-3 MW would very seldom be economically feasible and other reasons will be the driving factor.

Small-scale demonstration plants in Denmark and Finland based on gasification technologies have shown promising results and are envisaged to be ready for commercial operation within a few years, albeit the sizing is fairly small >2MW heat.

4.2 Biomass heat only boilers

The use of solid bio fuels for heat production on heating boilers has increased significantly in many countries during the latest years. The new boilers are typically based on wood (pellets or chips) or straw substituting the more expensive and environmental hazardous fossil fuels.

In relation to solid bio fuels the matters concerning the transportation of the fuels (logistics) and the residuals from the incineration process should be considered beforehand.

4.3 Biomass issues

In Denmark we have several systems which incorporate biomass and which are placed close to the town. We do not in Denmark experience the same concerns over biomass emissions as seen in some other countries.

It may be down to a question of size of boilers and how the system is designed and installed. Larger boilers are more efficient but for larger boilers there are also more strenuous requirements to the allowed emissions resulting in better equipment and flue gas technologies. Some air emission technologies are not possible to implement for smaller boilers.

Generally there are three issues that should be given attention when considering biomass fuelled technology:

Emissions (dust, NOx, CO); the emissions allowed varies depending on the fuel and the size of plant. Generally there are less strenuous demand for emissions when considering smaller plants.

Comment: It is important that the demand in relation to emissions is met though combustion technique and/or flue gas cleaning.

Biomass storage; the store is likely to generate fungus spore and similar.

Comment: The store can be designed with vacuum (under pressure) avoiding the spores generating a problem to the local environment. Although the spores can be a problem to the local work environment and special precautions needs to be taken.

Transport of biomass and aches; the transport of biomass and ashes is generally the one which causes greatest concern and one which it is difficult to change. The plant need to be supplied with fuel and the ashes needs to be removed.

Comment: The plant should ideally be sensitively located to cause the least issues concerning the increase in local transport.

4.3.1 Wood Pellet / Wood chip comparison

District heating boilers or CHP plants designed for wood chips varies essentially from similar units based on wood pellets, as the fuels need to be handled in different ways. Both pellets and chips are made of wood, but they vary significantly concerning the size, density, water content etc.

Wood chips are typically made of fresh wood and have a relatively high content of water compared to wood pellets. Accordingly wood chips cause an increased corrosion and deterioration of the boiler.

Wood pellets are typically made of wood-waste e.g. from industrial processes. Typically the quality of the pellets varies a lot and can cause some troubles during incineration. For instance the content of problematic substances such as glue from a manufacturing process can cause some serious technical- and environmental impacts.

Accordingly the quality of the fuels is crucial and decisive for the maintenance level and durability of the heat producing unit. A guarantee for the quality should be applied by the supplier in all cases.

Grate combustion is the traditional technology used for burning both wood pellets and wood chips. Grates are still widely used for both boilers and steam production in small scale CHP plants. Grates are less tolerant for fuel quality than for instance fluidised bed boilers but they have been able to compete with modern combustion technologies due to a comprehensive technological development. Hence, improved grate firing technologies have made it possible to burn very wet fuels like certain wood-chips.

However, steam/heat producing boilers based on wood chips typically create higher demands for maintenance and reduce durability due to the higher water content of the chips. On the other hand wood chips are considerably cheaper than wood pellets taking into account the energy content of the solids.

Considering the lifetime economics of the plant and the existing technological level, a wood chip fired boiler with a grate is the most favourable option. There may be a higher rate of corrosion of the boiler, depending on the water content of the fuel but the quality of the fuel is generally more stable and the combustion is easier to control.

In a fuel market with an increasing interest in bio fuels it may also be advantageous to rely on a fuel that requires less processing and therefore should be available in larger quantities and at a more stable price.

For the purpose of this study wood chip has been assumed as the bio fuel. However, the final conclusion concerning the choice between wood pellets and chips should be based on a more thorough analysis.

4.4 Consideration of thermal storage

Thermal stores (heating or cooling storage tanks) make it possible to create a time delay between heat consumption and heat production. The purpose of such time delay is mainly of economical nature and is related to the fact that the cost of heat /cool production may vary with time. By introducing thermal stores into district heating / cooling systems it is possible to produce heat / cool at a time where the heat production price is low and then utilise this low cost heat / cool at a time, where the production cost for the heat / cool would be high. If the heat / cool is produced at a CHP plant, then the heat / cool production price is not only related to the fuel costs but also to the selling price of the electricity.

A thermal store can also be used to reduce the investment cost in the district heating / cooling system. Depending on the design, a storage tank can make it possible to reduce investments in peak load capacity although this is not something we generally recommend as it will affect the security of supply. If the thermal store is located further out in the network, it might be possible to reduce the network pipe size and the investment in the piping system. This same effect can be created by individual storage tanks (e.g. for domestic hot water) however.

With the right design, decentralised thermal stores may be able to act as a peak and/or reserve load capacity locally and therefore it is not necessary to design the network for peak load supply from the main heat / cool production installation i.e. the pipes can be smaller. However, the installation of decentralised thermal stores in order to reduce the mentioned investments may not be economically feasible and often the peak and/or back-up boiler / cooling unit is more economical to install locally. Therefore in a heating system, thermal stores are usually installed centrally at the heat production plant for the purposes of maximising the run hours of the CHP plant and for acting as a buffer between the varying demand in the heat network system and the biomass heating plant, which is generally not capable of rapidly modulating to meet these changes in demand. Likewise is there the same advantages in a cooling system, where thermal stores are usually installed centrally at the heat production plant for the purposes of maximising the run hours of the cooling units. The size of the thermal stores are generally determined through an optimisation process between the overall capital and operational costs which in turn will also be decided by the size of the network and the heat demand which is to be met.

4.5 Large heat pumps

A heat pump moves heat energy from one temperature level to another, which makes the heat sources crucial. If a district heating utility company is considering investing in a heat pump, is one of the first steps to identify which heat sources that are available in the immediate vicinity. After heat sources are identified, the potential of the heat sources must be assessed. This is done i.e. by looking at the availability, temperature, flow and variation during the year. Possible heat sources could be:

- Flue gas
- Waste heat (from industrial and cooling processes, including individual cooling or district cooling)
- Geothermal energy
- Wastewater
- Groundwater, including groundwater storage (ATES), and drain water (drainage wells) etc.
- River water
- Other heat sources (air, ground source, drinking water, solar heat and heat storage)

The heat pump could be a good option for the Ford Site but must be assessed in more detail, see also further in section 5.5 where synergies with district cooling are described.

A heat pump makes it possible to collect thermal energy from a heat source with low temperature and emit energy again at a higher temperature. It is necessary to supply energy, either in the form of power, i.e. electricity, or in the form of heat at a relatively high temperature, e.g. flue gas. The principle opens up a number of opportunities to exploit energy resources at low temperatures and therefore it entails a number of advantages for district heating:

1. Lower heat prices – the primary motivation to invest in a heat pump is an expectation of lower heat prices either now or in the long term.
2. Risk diversification – By introduction of a new "fuel" (electricity) in production, large heat pumps contribute to spread the financial risk in the heat production (diversification), making production more robust to variations in electricity and fuel prices.
3. Efficiency – possible to exploit residual and waste heat into the existing production facilities, or nearby industrial production. Furthermore, the possibility to optimize the utilization of solar thermal heating.
4. Introduction of new business areas – the ability to produce and sell cooling related to district heating production.
5. Strengthen environmental profile – by making use of RE based electricity generation and partly to take advantage of previously unexploited low-temperature heat sources in the surroundings such as wastewater, industrial waste heat, geothermal energy, groundwater, etc. and thereby delivers a renewable energy contribution to the heat production.
6. Strengthening new collaborations — by district heating's interacting with the electricity utility and with the possibility of cooling, and thus the role of district heating in integrated energy supply planning for the future.

It should be noted that an electrical driven heat pump only is truly renewable if the electricity comes from a renewable source.

4.5.1 Types of heat pumps

Heat pumps can generally be divided into two different types. A heat driven (also known as absorption heat pump) and a mechanical driven type, where the mechanical heat pump as a general rule, is driven by an electric motor. The ratio between the delivered heat and the "drive energy" is called the efficiency factor of the heat pump, COP (Coefficient of Performance). Electrically powered heat pumps typically have a COP of between 3 and 5. For each unit of electricity that drives the heat pump, between 3 and 5 units of heat will be delivered. The COP is very dependent of the temperature of the heat source and the temperature demand.

The COP will decrease if there is a demand of high district heating temperature. A demand of a district heating supply temperature of above 176-194°F (80-90°C) can be a barrier for implementing heat pumps in the district heating system due the drop in efficiency and limitations in available heat pump technology on the market.

The thermally driven heat pumps have a COP of approx. 1.7 and require so much more driving energy than the mechanical types. On the other hand, is the driving energy is heat, which often is cheaper than electricity, and therefore are the thermally driven heat pumps also interesting, both from an economic and an energy point of view. Mechanical heat pumps are usually compression heat pumps in accordance with the same principle as traditional cooling systems. Heat-driven heat pumps are typically absorption heat pumps with refrigerant and absorbent. In recent times, so-called hybrid heat pumps are also brought into use, which is a mechanically driven heat pump that combines compression and absorption technologies. Although the COP for absorption heat pumps is low compared with electrically driven, it is important to note that the technology does not have any energy consumption as such. It just exploits a high energy quality, which would otherwise have been lost. Therefore, should the COP for absorption heat pumps not be considered as energy consumption in relation to heat production, but just increased heat production.

Thermally driven heat pumps require that surplus heat at a high temperature is available. It could be minimum 80-140°C (176-284°F) depending on the type of absorption chiller.

4.5.2 Refrigerants

A wide range of synthetic (HFC) refrigerants have been developed over the years. Those have a various thermal and chemical properties that make them usable in a wide temperature range. All synthetic refrigerants are, however, associated with environmental issues, and today many of them banned in a number of countries. In Denmark are synthetic refrigerants not allowed in chillers, where refrigerant filling is greater than 10 kg. The European Union has decided to down phase the consumption of synthetic refrigerants.

For larger electrically powered heat pumps in Denmark are therefore used only natural refrigerants. This does not affect the efficiencies and performances, but means that some components developed for synthetic refrigerants, cannot be used directly for heat pumps in Denmark. Worldwide, however, the trend is primarily towards natural refrigerants, why the selection also gets larger and larger. In practice, the refrigerant legislation that excludes synthetic refrigerants, therefore not a problem for the prevalence / application of large heat pumps. The refrigerants which might be used for larger electrically powered heat pumps will be primarily carbon dioxide (CO_2), ammonia (NH_3), isobutane (C_4H_{10}) and propane (C_3H_8). In hybrid heat pumps are used ammonia as refrigerant and water as absorbent. Just as the hybrid heat pump, the heat-powered heat pumps take advantage of the absorption principle. Water is used as the refrigerant and a solution with lithium bromide as absorbent.

5. DISTRICT COOLING SYSTEM DESIGN

5.1 What is district cooling?

District cooling is distribution of chilled water to buildings, where there is a cooling demand. The water is cooled in a central plant and distributed through pipelines to customers, where a heat exchanger uses the chilled water to cool the water in the building systems. Subsequently the water is sent return to the central cooling plant, where it is cooled again. District cooling works in principle like district heating and has the advantage of achieving economies of scale because each individual building do not have to have its own cooling-producing plant, which can be more costly in investment and operation.

Advantages for consumers (building owners) with district cooling compared with individual solutions:

- Opportunity for lower costs for cooling
- Reduction of environmental impact.
- The consumer doesn’t have to take care of operation of cooling plants.
- Fewer places with noise nuisance and fewer costs for noise reduction arrangements
- Release of building area (inside and on roof etc.) for other purposes
- No visual pollution by cooling plants around the building and at the roof.

The benefits for the local society:

- It can be more attractive for a company to settle down in the city if district cooling if offered
- Better environment profile for the municipality / state.
- Cheaper cooling (and heating) for the citizens and local companies /business.

A district energy utility company having both district cooling and district heating supply can achieve a number of benefits:

- Surplus heat from the district cooling can be exploited for the local district heating system. This can make both the price of district cooling and district heating lower and thereby more attractive.
- Large energy savings and lower carbon foot print –> greener profile.
- Utilization of synergy between heat, cooling, cooling storage, heat storage and thereby ensure an efficient and future-proof production of cooling and heating.
- Large volume in the company organization = optimization of staff resources by having both district heating and cooling delivery.
- Closer relation to the large consumers in the area and thereby be able to give better guidance about energy savings at the consumers both regarding heating and cooling.

5.2 Overall design concept

This section describes the overall concept for a typical district cooling system.

Typical temperatures in the district cooling distribution network could be:

- Primary supply: 6°C
- Primary return: 16°C

Some buildings can have special cooling demands. Very low temperatures could be required. Buildings like supermarkets or other buildings with food storages etc. could need a lower supply temperature. For example if an air temperature of 2°C is needed, it could be necessary to have a supply temperature of -2°C in order to provide that. In such cases the base cooling load could be delivered by the district network with 6°C in supply and then by small-scale units locally at the consumer be cooling further down for the exact demand.

The figure below shows an overall principle for a district cooling system inclusive the cooling production plant and storage. The cooling is produced with chillers. Periods where the outdoor air temperature is optimal free cooling (with dry coolers) can be used directly.

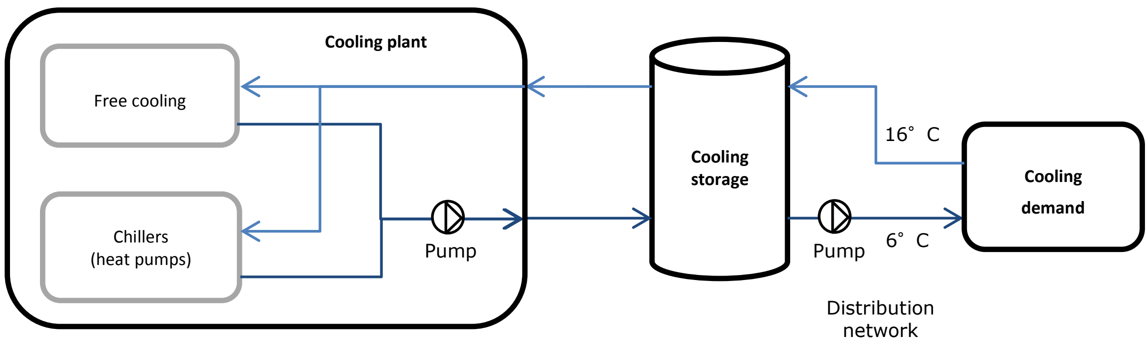

Figure 5-1 District cooling principle with cooling plant, storage and connection to the demand in the network.

From the cooling plant the produced cooling can be distributed to a cooling storage or directly to the cooling consumer in the network. The cooling storage will be necessary to reduce the size of the cooling plant (chillers etc.) and thereby the investment costs. It will level out daily peak loads and ensure more stable operation of the chillers. Also storage could reduce the pipe dimensions in the network if storage tanks are placed in high cooling density areas in the network. This will also increase the security of supply (redundancy).

Typical pressure level in the distribution network is between 6-16 bar (g).

5.3 Pipe network

A key component in the district cooling system is the pipe network for distribution of chilled water. It consists of supply and return flow to all the connected buildings (cooling consumers). In general the pipe network can be divided into two main parts:

1. The main distribution network incl. service pipes to the buildings.
2. The internal pipe system in each building (or group of buildings) connected via an energy transfer substation.

Different types of pipe for the distribution network can be used, but if the utility also offers district heating, it can be an advantage to use district heating pipes also for district cooling, because in that case the expertise and an attractive purchase agreements may already be established.

Pipe insulation thickness is of less importance compared to district heating, because the district cooling temperature are closer to the soil temperature. But it will be an advantage with pre-insulated pipes to protect the media pipe and in order to be able to have a leakage alarm system.

5.3.1 District heating pipes

District heating pipes are described earlier in section 2.9. In the following are alternatively pipe types for cooling briefly described.

5.3.2 Insulated PE-pipes

Another solution for the main distribution network could be a pre-insulated PE-pipe system typical in HDPE (10 bar) PE80/PE100. PE is polyethylene, which is type of plastic material. Except from the medium pipe, the pipe type is quite similar to the pre-insulated steel pipe system. It is available with the same type of insulation, with alarm wires, diffusion barriers and outer casing. The leakage alarm system can also include monitoring of pipe joints.
The advantage with this pipe type rather than steel is less weight, which can make the transport and installation easier. The reduced weight would also be an advantage for the mounting in a potential utility corridor.
Further, PE-pipes will have longer lifetime than steel pipes, because of lower risk of corrosion. PE-pipes are assumed to have lower cost especially for the large pipe dimensions mainly due to fewer requirements for control of the welding. Since it is electric welding, x-ray examination is not needed. This pipe type is also use for potable water etc.

5.3.3 Uninsulated PE-pipes

This type is like the PE-pipe described above, but without insulation, leakage alarm, casing etc. This type of pipe will have lower costs because of the less material required. The major disadvantages is the energy loss (depending on the yearly soil temperature conditions) - the chilled water (both supply and return) will be heated up in the soil or in the utility corridor – this also means that the supply temperature has to be delivered with an even lower temperature out of the cooling plant. Further, without insulation there can be a risk of condensation water outside the pipe and the pipe is generally less protected against the surroundings. And without the alarm wires it will be very difficult to locate a possible leakage.

5.3.4 Glass fibre pipes

This pipe type is corrosion resistant interior and exterior (suitable for chemistry and industry). It is light weight and easy to fabricate / install. The smooth interior can give higher flow rates, reducing energy consumption. But to be noticed is that experience previous from district cooling shows that this material is not suitable when there are heavy loads on pipes resulting in longitudinal cracks in the pipe. Like the uninsulated PE-pipe, glass fibre pipes are typical without insulation and have no alarm wires.

5.4 Consumer connections and substations

Consumer connections (and substations) are quite similar to what is used for district heating. In indirect systems the consumer connection includes a heat exchanger to separate the internal building chill water circuit from the distribution network. This will typical be necessary in district cooling systems which operates with pressures above 6 bar(g). If the pressure level is 6 bar(g) or lower in the distribution network, the consumer can be connected directly if preferred and no heat exchanger is needed. This has the advantage that the temperature demand from the cooling plant can be decreased – the cooling supply temperature can be higher, which can improve energy efficiency (COP) of the cooling plant and maybe reduce the investment cost for chillers. On the other hand, having higher pressure in the distribution network smaller pipe dimensions can be used, which will reduce the costs for the pipe network.

See further about consumer connections and substations in section 2.3.

5.5 District cooling and heating supply concepts

With both district cooling and district heating the supplier can achieve a number of benefits / synergies, in particularly that surplus heat from the cooling production can be exploited for the local district heating system. Thereby the heat removed by the cooling in the buildings is not wasted to the surroundings. This can lead to increased energy efficiency and a lower price of both district heating and cooling for the consumers.
However, such a solution depends on the actual temperature conditions in the district heating system etc. The technical solution will typical be with a heat pump (chiller) driven by electrical power. See the principle in the figure below. Heat can be exploited with up approx. 80°C, but lower temperatures e.g. 60°C will improve the energy efficiency of the heat pump and reduce investment costs as well.

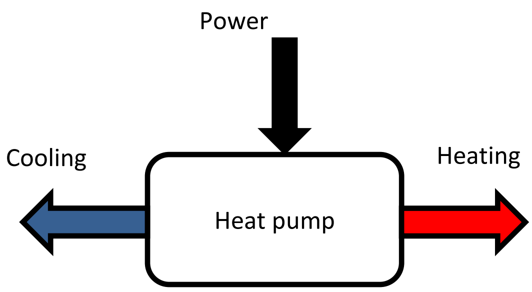

Figure 5.5a: Co-production of cooling and heating in a heat pump. The heat pump is placed in a thermal energy plant (cooling plant), which supplies both the district cooling network and the district heating network.

Such a solution with a heat pump with co-production of cool and heat will lead to energy savings. It will be a future proof solution and if a large share of the electrical power comes from renewable energy sources, it will be a very sustainable / low-carbon solution.

In case groundwater / ATES (Aquifer Thermal Energy Storage) is possible to use, it can improve the overall energy efficiency. Surplus heat from the summer period can be stored in the ground and utilized in the following winter period. Thereby an optimal energy balance can be achieved.

If large amounts of heat are accessible in the district heating network also during summer, a solution with a heat driven heat pump, a so called absorption chiller, could be an alternative. If the heating system is to be used to generate chilled water locally e.g. through absorption cooling it is important that the flow temperature is as high as possible.

The heat pump will be placed in a thermal energy / cooling plant, which supplies both the district cooling network and the district heating network. See principle of a district cooling system connected to district heating for delivery of surplus heat.

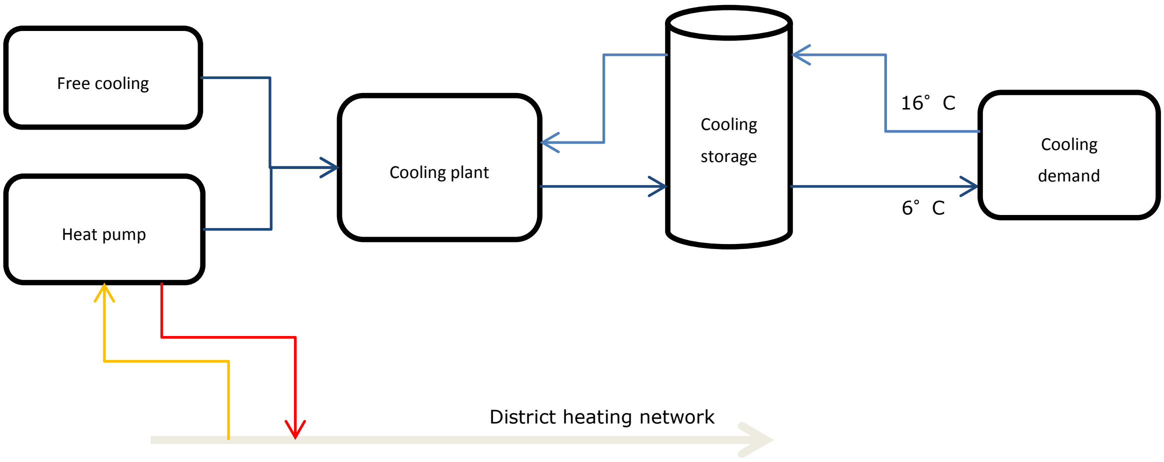

Figure 5.5b: District cooling principle with possible utilisation of surplus delivery heat to heating

The figure below shows an example of an overall design of a district energy system with both district cooling and district heating.

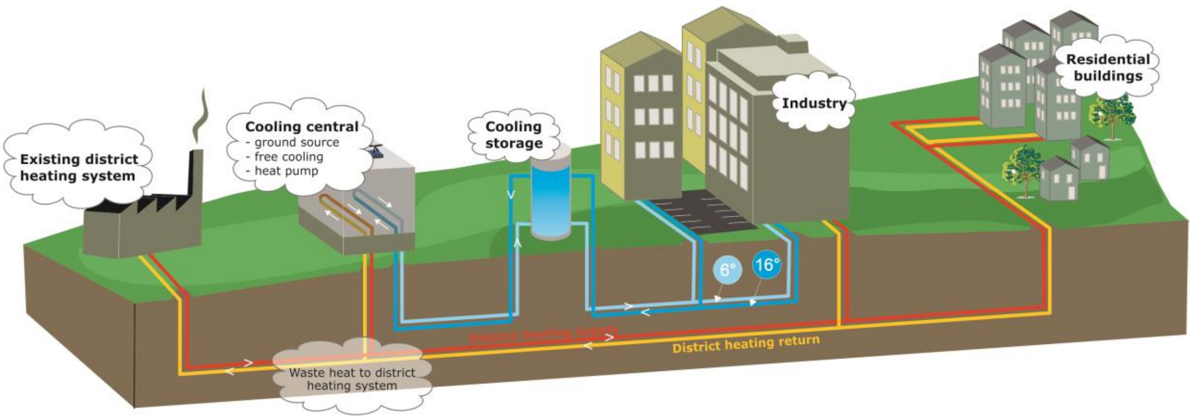

Figure 5.5c: Supply concept for district cooling and heating (Figure: Ramboll).

6. EXAMPLES OF LOW-TEMPERATURE DISTRICT HEATING

6.1 Brief case examples

6.1.1 Sønderby, Høje Taastrup, Greater Copenhagen, Denmark

A low-temperature heating network for 75 existing detached brick houses built in 1997/1998. Room heating is provided by floor heating in all houses. The district heating is delivered by the utility at a higher temperature and then lowered in a mixing shunt to about 127-131°F (53-55°C) before it is distributed in the low-temperature pipe network. The return temperature is about 95°F (35°C). The pipe network consists of twin pipes (supply and return pipe in one casing) in a high insulation class.

Although the existing local and privately owned district network for these 75 houses was only approximately 15 years old, the distribution pipelines – pair of single pipes with plastic media pipes – were in poor conditions. The annual network heat loss accounted for about 41% of the total heat delivery to the network. Due to the heat losses the heat costs where relatively high. It was decided to renew the existing district heating network and transfer the ownership of the network to the local district heating utility. Heat loss in the network was decreased to 13-14% corresponding to a reduction of 69%.

Total heated area: 11,230 sqm. Developer: Høje Taastrup Fjernvarme (district heating utility).

6.1.2 Lystrup near Aarhus, Denmark

A site which comprises of 40 low-energy terraced houses built in 2009/2010. Two types of consumer substations is installed; one type with primary side storage tank, which enables the reduction of design capacity to 3 kW and supply pipe dimensions accordingly, and one type with an heat exchanger designed for domestic hot water of 32 kW. Room heating is provided by mainly radiators, but also floor heating in the bathrooms. The district heating is delivered by the local district heating utility at a higher temperature and then lowered in a mixing shunt to about 126-131°F (52-55°C) before it is distributed in the low-temperature pipe network. The return temperature is about 86-95°F (30-35°C). The pipe network consist of twin pipes (supply and return pipe in one casing) in a medium-high insulation class.

Compared to a reference scenario with 176°F (80°C) in supply, 104°F (40°C) in return and single pipe pairs in standard insulation class, saved heat loss reduction has been measured to about 75%.

Total heated area: 4,115 sqm. Developer: Housing association BF Ringgården.

6.1.3 Østre Hageby, Stavanger, Norway

A low-temperature heating network for 66 new low-energy houses consisting of a mixture of terraced houses and blocks of flats. Heat is supplied with a temperature of about 131°F (55°C) from an energy central with heat pumps and drill holes in the mountain. A small local pipe network distributes the heat from the energy central. Each apartment has its own consumer substation with an instantaneous heat exchanger for heating up the domestic hot water. The low-temperature concept is ideal for the heat pumps, because with the lower temperature demand a higher energy efficiency (COP) can be achieved during the heat production. The low-temperature system will be put into operation in the end of 2014. Total heated area: 6,800 sqm. Developer: INEO Eiendom.

6.2 Examples of other district heating utilization possibilities

Briefly examples of other utilization possibilities for district heating (than room heating and normal domestic hot water heating) are described below.

6.2.1 Snow-melting and freeze protection

A practical solution – not an energy saving solution – is to utilize district heating to heat up exterior / outdoor construction surfaces in order to remove snow and ice.

Snowmelt technology can reduce or eliminate conventional snow removal, reduce wear and tear on walking and driving surfaces, and provide clean, safe, ice-free traffic areas. Walkways that are snow, ice, and salt-free will increase the comfort and confidence of users and building owners. Snowmelt systems can be designed into new or existing district systems. Buildings already connected to a district system can be readily connected to a supply or return line to heat and clear sidewalks, driveways, parking lots or ramps, and other major pedestrian or automotive traffic areas. These snowmelt applications reduce maintenance efforts for snow clearing and improve the safety of these areas.

Snowmelt systems utilize low water temperatures (for example at 95-120°F (35-50°C)) to circulate through the snowmelt tubing. Utilizing the lower temperature hot water allows for the incorporation of a wide variety of low-grade energy sources such as waste heat, condensate return, or district heating return lines. If the district heating is produced by a CHP plant, a lower return temperature to the plant will lead to higher energy efficiency of the plant.

Selection of piping for these installations is an important consideration for effective operations. Polyethylene (PEX) pipes are an attractive option because they are corrosion-free, manufactured in long sections with fewer joints, easy to handle, and require reduced installation time. Glycol selection is important in order to secure freeze protection, corrosion resistance, and low viscosity impacts for the circulating loop. Glycol selection should also consider design intent, pumping resistance, tubing spacing, r-value, freezing points, and load design.

6.2.2 Domestic appliances with hot water connection

Another idea to increase the potential for district heating is for households to install domestic appliances with hot water connection. Instead of usage of electrical power for heating up water, the appliances use hot water heated up by district heating. For households this will convert power consumption into an increased district heating consumption.

The economic benefit of this technology depends on the local prices of electricity and district heating, while the environmental benefit depends on the actual carbon emissions for electricity and district heating. District heating systems with a large share of surplus heat, solar heating etc. will particularly benefit from the technology, because it will increase the potential heat consumption during summer time.

Appliances on the market in Europe suitable for hot water supply:

Appliances with a heat exchanger – district heating can be connected directly HWC-machines (Heating Water Circuit):	Appliances with a direct domestic hot water intake / connection:
• Dishwasher • Washing machine (laundry) • Tumble dryer (laundry)	• Dishwasher • Washing machine (laundry)

Test studies of household appliances with built-in heat exchangers and/or washing machines with separate cold-and hot-water intake have been made in Denmark and Sweden. Results show that under ideal conditions, tumble dryers, washing machines and dishwashers with built-in heat exchangers can replace more than 80% of electricity consumption with district heating. For washing machines, that uses hot water over 70% of electricity demand can be replaced by district heating.

Washing machines with cold and hot water intake has been on the market in Europe for the professional segment e.g. for common laundries, institutions, etc. for a number of years. In the market for household appliances there have also been various attempts from the manufacturers. At the moment about 3 washing machines is being sold on the Danish market. In addition, many dishwashers on the market is designed in such a way that hot water can be connected directly – usually it is usually indicated in the user manual, if it is possible.

Studies from Denmark show that, the hot water usage increases in the range of 5-15 % with hot water connection of washer and dish washer machines, which in particular, will have a positive impact on district heating network's operation in the summer months. In addition, it is assessed that the introduction of hot water connected machines will not affect the design conditions of the layout design of the district heating network.

Increased district heating consumption during summer in particular will be an advantage for the pipe network heat loss, because it will be relatively smaller.