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How to create compliance in the district heating system when lowering the district heating grid temperature

Experiences from Denmark, and other countries

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How to create compliance in the district heating system when lowering the district heating grid temperature Experiences from Denmark, and other countries

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1. Executive summary

The objective of this report is to explain to techincal personnel, and key decision makers in buildings and district heating systems, how to create compliance in the district heating system when lowering the grid temperature. This is done by presenting a roadmap to low temperature district heating based on Danish experiences.

District heating will play an increasingly large role in the implementation of the EU's energy policy, with the possibility of decarbonising the energy sector and providing cost-effective and clean energy, with high security of supply. This is because almost all waste heat and renewable forms of energy can only be used efficiently on a large scale, and because most renewable energy sources are highly fluctuating. Among renewable energy sources used for heat production is excess heat from electricity production, waste incineration and P_2X, biomass, deep geothermal heat, as well as low-temperature excess heat from cooling processes, just to mention a few.

Almost all these resources are, unlike fossil fuels, only available at low temperatures. Therefore, lowering the district heating temperatures is essential to utilize these resources. Buildings prepared for lower supply temperatures are also a prerequisite for low temperature district heating, as this would otherwise result in a greater capacity reduction in the district heating network and reduced thermal comfort for consumers.

The district heating and building sector in Denmark kick-started the transition to lower temperatures in the years after 1980 due to intensive heat supply planning, tax incentives on fossil fuels and use of low-temperature heat from electricity generation. Today the majority of Danish district heating companies operate at 70°C supply and 40°C return on average, which is considered low temperature district heating. This definition is based on optimal utilization of low-temperature energy sources, and on the prerequisite of a 60°C supply temperature at consumer level to ensure safe domestic hot water production, meaning without the risk of legionella in the domestic hot water tank[1]. Danish experience therefore shows that conversion to low-temperature district heating is possible, but time-consuming. This report describes measures that help to reduce temperatures in district heating systems, with a focus on legal, institutional as well as technical measures in buildings, where the key takeaways are:

- Introduce a building code for design of installations in buildings, to ensure that all new and old renovated buildings are prepared for low-temperature district heating
- Introduce incentive tariffs for lower return temperature from buildings
- Invest in electronic remote meters (smart meters) for improved energy management in buildings, implementation of incentive tariffs, and improved communication between the district heating company and building owners
- Move the point of delivery from primary to secondary side of the district heating substation, which relieves the customers of operation and maintenance responsibilities, and gives the company access to all the relevant data, so that errors can be identified and acted upon immediately
- Upgrade the facade of old buildings (outside insulation and new windows, if acceptable), to lower the heat demand, and thereby lowering the necessary temperatures
- Install local temperature boosting at critical high-temperature consumers to enable the reduction of the overall temperature in the district heating system

[1] Legionella is a bacterium that occurs naturally in all wet and humid environments, except in salt water. The bacteria reproduce best at temperatures between 30°C and 46°C, and they therefore often thrive in hot water systems where the temperature is between 30°C and 50°C

- Utilize the return temperature of high-temperature consumers by connecting low-temperature consumers with a 3-pipe connection on the return pipe
- Allow a higher flow temperature from low-temperature heat sources (by local temperature boosting) in the coldest winter hours, to avoid unnecessary investment costs in upsizing of the district heating network

The transition to low-temperature district heating in countries such as Germany is slightly behind compared to countries such as Denmark. This is due, among other things, to a different political focus historically, and other local conditions, such as their building stock and a greater need for process heat. However, several of the measures from Denmark can be implemented either directly, or with minor adaptations, to German district heating systems. The following three main initiatives have been identified:

- On long term:
  - Implement technical solutions for the further improvement of the district heating networks
- On short term:
  - Consumers should be included as key stakeholders in the process of transformation of heating networks towards net-zero emissions
  - Greater focus on the digitalization of the substations in the buildings to provide 1) the possibility for the consumers to monitor their energy demand as well as return temperatures, and 2) tariff incentives for lowering the return temperature

In many other countries low temperature central heating in buildings and new district heating system is a challenge but can be introduce by co-ordinating with city wide energy planning with deep renovation of the buildings following the experiences from Denmark.

2. Introduction

District heating plays a major role in implementing the energy policy in the green transition. The energy planning in Denmark demonstrates that district heating is the most cost-effective solution meeting the energy policy objectives in most urban areas.

District heating has among others the following benefits:

- It eliminates the local air pollution from heating buildings and reduces the global air pollution from heating to almost zero due to economy of scale and the large customer base that allows to invest in advanced and efficient flue gas cleaning technologies.

- It increases the resilience through the use of different energy sources, i.e., increases the ability to change the heat source at short notice, e.g., shift from oil to gas and surplus heat from power generation, and from gas to biomass and electricity.

- It increases the efficiency and cost effectiveness as the district heating is able to use numerous efficient heat sources, which can-not be utilized optimally in stand-alone buildings

- It can contribute to climate goals and sustainability targets by utilizing renewable energy sources and reducing greenhouse gas emissions.

- It opens for cost effective heat storage facilities due to economy of scale and interaction with the power system.

In the past, heat production for district heating in Denmark and other countries came from central heat production plants and boilers based on coal, gas and later on biomass. But due to the continued work on CO_2 reductions through the removal of fossil fuels, the share of renewable energy resources in district heating systems has increased rapidly in recent years.

Most available renewable energy sources, e.g., ambient heat from wastewater, air, and surplus heat from industry to name just a few, requires upgrading by electric heat pumps. A heat pump uses similar technology to that found in a refrigerator or an air conditioner. It extracts heat from a source, such as the ones mentioned above, and then it amplifies and transfers the heat to where it is needed[2]. A heat pump is most efficient when it must raise the temperature from the renewable energy source as little as possible. This means, in most cases, there are significant advantages in lowering the outlet temperature from the heat pump and the return temperature from the consumers. However, there are several conditions that must be met when lowering the temperatures in a district heating system, in order to achieve these efficiency improvements.

Thus, the main objective of this report is to explain techincal personel, and key decision makers in buildings and district heating systems, how to create compliance in the district heating system when lowering the grid temperature. The results are presented in the form of a roadmap, showing how to lower the temperatures in district heating systems, based on Danish experiences. Furthermore, the aim is to transfer the most relevant experiences from Denmark into concrete recommendations for Germany, and to some extent other European countries systems which works toward lowering temperatures of their district heating system.

[2] Read more about how a heat pump works here: How a heat pump works – The Future of Heat Pumps – Analysis - IEA

3. District heating in Denmark

3.1 General history

Since district heating was first established in Denmark in 1903, the benefit of combined heat and power (CHP) has been the main driver for increasing the market share in Danish cities. In the smaller towns, district heating was booming in after 1960 as it benefitted from economy of scale and better comfort for consumers, who installed central heating systems in almost all buildings. In 1990 around 20% of the older apartments in the central part of Copenhagen still had individual stoves. However due to a special state aid scheme from 1992-2001 which gave incentives to building owners to install central heating systems in buildings and connect to the district heating system, 99% of all heated floor area in Copenhagen and Frederiksberg Municipality is today supplied with district heating. This grant was one element of a tax financed package of grants to district heating renovation and completion as well as central heating in apartment buildings.

Most district heating systems in Denmark has historically been water-based systems with a supply temperature below 110°C. The exception was a steam network based in the central part of Copenhagen (Greater Copenhagen Utility (HOFOR) and Frederiksberg), however the expansion of the steam system stopped around 1980, and the last steam customer was converted to water-based district heating in 2020. Besides a few district heating systems have been designed for super-heated water (with a temperature of up to 165°C) to serve e.g., process industries and absorption chillers. These have all been converted to hot water, or even low temperature district heating.

The market share of district heating has increased significantly since the Heat Supply Act came in force in 1980. In the coming decade, the market share will increase even further, as all gas for heat supply has to be replaced by district heating or individual heat pumps at the building level.

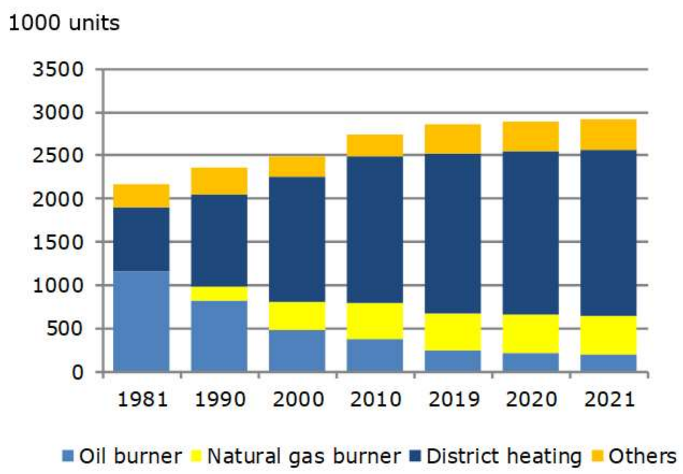

Figure 3-1 Market share of district heating, heated number of apartments (Energy Agency)

3.2 Heat production to district heating

In Demark, the heat production has traditionally been based central heating plants or large CHPs, based on coal, gas, waste incineration and followed by sustainable and thus CO_2 neutral biomass. In more recent years, the local Danish energy policies as well as the European energy policies have pushed for the penetration of even more renewable energy sources in district heating systems in Denmark as illustrated in Figure 3-2.

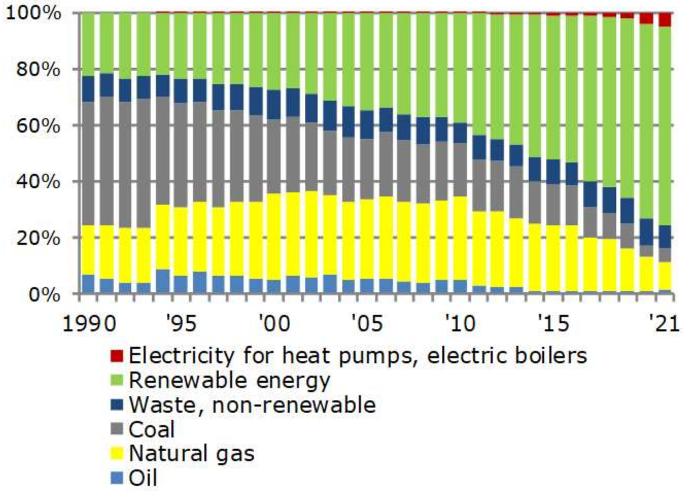

Figure 3-2 The share of heat production in Denmark from 1990 to 2021 (Danish Energy Agency)

In recent years, electricity has been introduced as a new (secondary) energy source for district heating to supply large electric boilers and large heat pumps and the market share is growing fast. In 2023 there are in total installed more than 1,000 MW electric boiler capacity and 800 MW electric heat pump capacity playing an important role integrating the fluctuating renewable energy from wind and solar PV.

3.3 Low temperature district heating

In a Danish context low-temperature district heating is typically considered for supply and return temperatures of about 70°C and 40°C respectively. As shown in Figure 3-3 and Figure 3-4, based on statistics from the Danish District Heating Association, the average supply and return temperature of more than 250 Danish district heating companies in the winter of 2016 was within the above-mentioned temperature interval.

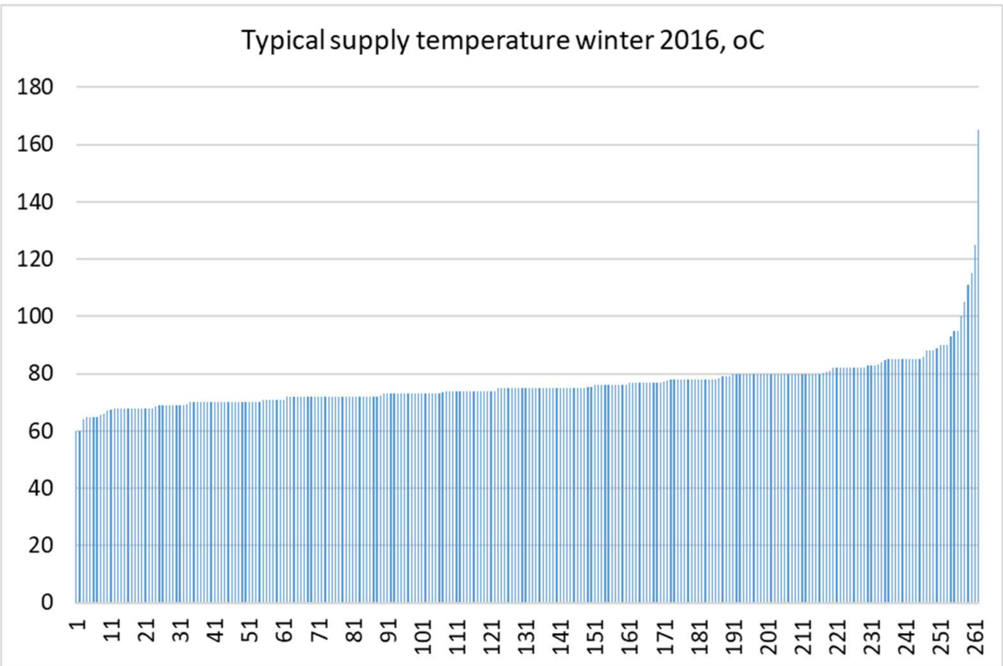

Figure 3-3 Average supply temperatures of Danish district heating companies in the winter of 2016

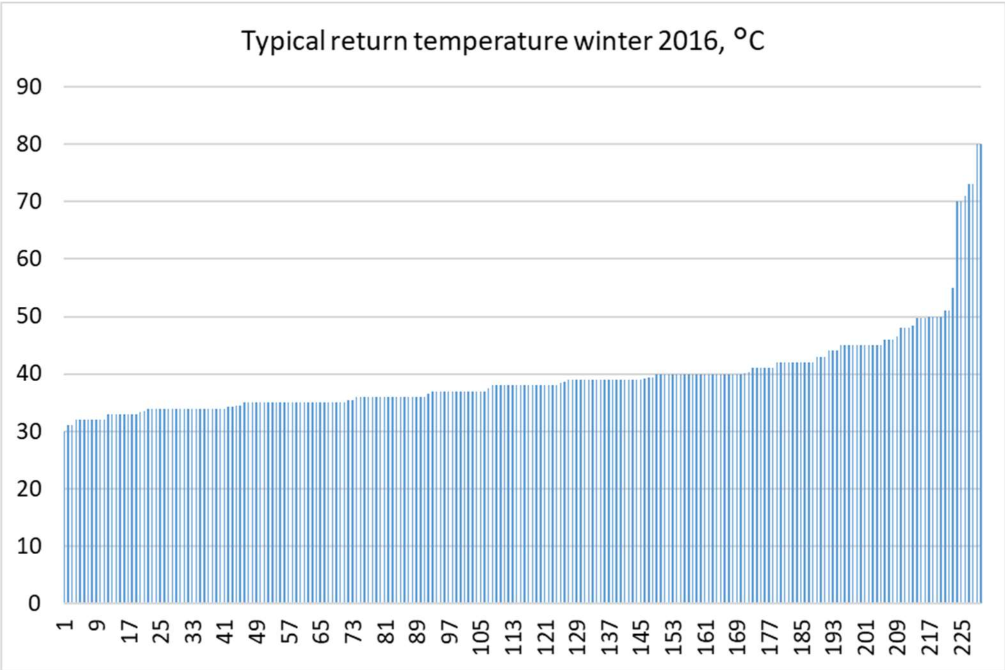

Figure 3-4 Average return temperatures of Danish district heating companies in the winter of 2016

However, when working with heat supply planning in Denmark, the temperature level is never an objective by itself, as the overall objective of all energy supply is always to meet the overall energy policy objectives, in the most cost-effective way including costs of the environmental impact.

This can be narrowed down to the requirement of the Danish Heat Supply Act, that all investments in the district heating sector shall be cost-effective for the society including costs of environment and for providing consumers with cost effective and sufficient quality of energy.

As the challenge of the district heating companies is at the same time to increase the market share by connecting more consumers to the existing network, to install more heat storage capacity and to install large heat pumps to use low temperature heat, the optimal supply temperature has to be balanced between cost of capacity in the network and cost of production.

Therefore, the optimal temperature levels in a district heating system in Denmark will depend on the actual local situation and the stage in a transition from high temperature energy to low temperature renewable energy. Thus, the optimal level of low temperature district heating should be determined based on the following criteria:

- The normal supply temperature to the district heating network should be adjusted throughout the year in order to utilize low temperature heat sources from ambient energy efficiently (e.g., wastewater-, air-, and surplus heat)
- As district heating in Denmark is always used to produce both space heating and domestic hot water, the supply temperature from district heating to the building should in general not be below 60°C in order to prevent risk of legionella[3] (unless local measures, e.g., temperature boosting, is installed) and offer sufficient quality of domestic hot water

[3] This applies in the case where there are hot water tanks, which is the case in most buildings in Copenhagen due to the high lime content in the water

- The maximal supply temperature to the network on cold days should not exceed 90-95°C in order to allow pressure less heat storage facilities.
- The return temperature from buildings should never exceed 40°C, as thermostatic valves and coils, radiators and floor heating systems in buildings can provide temperatures below this level at modest costs.

The above is detailed in the following sections.

3.3.1 Efficient and flexible heat production

As one regards multiple and efficient heat sources, the district heating can utilize among others the following for heat production:

- Efficient gas/oil boilers as back-up for electricity
- Efficient and clean biomass boilers with flue gas condensation
- Cost effective large scale solar water heating
- Surplus heat from power generation (CHP)
- Surplus heat from incineration of waste, from boilers with other primary purposes or CHP plants
- Surplus heat from industries at temperatures around 70°C
- Deep geothermal heat at temperatures around 70°C
- Large heat pumps, which can be interrupted in case of high electricity prices, utilizing low temperature heat sources, among others:

    - Additional flue gas condensation
    - Low temperature heat from industries, e.g., datacentres
    - Low temperature heat from combined heating and cooling
    - Low temperature deep geothermal heat
    - Low temperature heat from Carbon Capture Utilization (CCU) and electrolysis (in the pipeline)
    - Ambient heat from wastewater, ground water, sea water and air

The availability and efficiency of all these heat sources depends highly on the temperatures in the district heating supply and return pipes. The lower the temperature is, the more efficient and cost effective the system is. In many cases, the variable cost of extracting heat is even free. In case the necessary supply temperature is around 70°C, the variable cost of heat is zero for:

- Surplus heat above 70°C from industries.
- Surplus heat from CHP engines, which is in operation in the market meeting the demand in the grid
- Deep geothermal heat above 70°C, which is a natural resource in many countries.

3.3.2 Cost effective heat storage facilities

The cost of storing thermal heat to be used directly for heating depends on two factors:

- The economy of scale
- The temperature

The cost of the storage facility and the heat loss is significantly lower for large heat storage facilities in district heating compared to heat storage facilities at building level.

The costs per storage volume depends significantly on the maximal temperature:

- In case the maximal supply temperature is below around 80°C, a heat storage pit is an option, in case there is available space for it. The optimal size of a pit is typically below 100.000 m^3, but several pits can be combined.
- In case the maximal supply temperature is below 95°C, non-pressurised heat storage tanks are an option. Almost all Danish district heating systems have one or several non-pressurized heat storage tanks
- In case the maximal temperature is up to around 130°C a more expensive pressured tank is an option and can be up to around 20.000 m^3 per tank. Such tanks are installed at the two largest heat transmission systems in Denmark, located in Copenhagen and Aarhus
- In case the maximal temperature is up to around 160°C it is still possible to store the heat, but at a much higher cost, as the storage has to be constructed as a "battery of vertical tubes".

3.3.3 Efficient heat distribution for heating and domestic hot water

The cost effectiveness of the heat distribution greatly depends on the temperatures, namely the difference between supply and return temperature, also referred to as the cooling of the district heating water.

In the case where the supply temperature is reduced from 100°C to 80°C, to utilize a low temperature heat source efficiently it is important that all consumers can accept this temperature reduction and that the necessary temperature on the secondary side of the heat exchanger is below 75 °C or less. Otherwise their return temperature on the primary side will increase, as the heat transfer through the heat exchanger moved from the supply end to the return end of the heat exchanger. It might be necessary to increase the capacity of some heat exchangers for consumers who need supply temperatures close to 80 °C. In the best case scenario the return temperature from the consumers will remain around 60°C. Thus, the cooling is reduced from 40°C to 20°C, resulting in a 50% reduction in capacity of the network or a 100% increase of the design flow in case of a new network. If the design flow increases by 100% in a new district heating network in order to maintain the capacity, the investment cost will roughly be increased by 30%. This case illustrates that lowering the temperatures in a district heating system is complex, and that one cannot simply lower the supply temperature without taking into consideration the heat distribution and the heating installations at the consumer side.

As the indoor temperature of buildings is around 20°C, and as cold water at 10°C is heated to a temperature of about 60°C for production of domestic hot water there is a potential for a very low return temperature by improving the performance of the district heating substations and heating installations. Experience shows most building installations could cool the water to around 40°C, but simple faults, lack of hydronic balancing, and less optimal design increases the temperature to 60°C or more.

To be able to distribute heat cost-effectively from a heat source with a temperature of e.g., 80°C, the focus should be on lowering the return temperature in the design phase, and in energy renovations of buildings. In the above case a return temperature of 40°C would open for heat transfer of the maximal capacity at a supply temperature of 80°C.

The heating installations in many old buildings, which previously have been supplied by oil or gas boilers without flue gas condensation, have unfortunately been designed for higher temperatures, e.g., 90°C supply and 70°C return (90/70) with little heat transfer capacity in radiators and heat exchangers or even with a one-string heating system. The heating installations in newer buildings, which have been designed for district heating or heat pumps have typically been designed for lower temperatures, e.g., 60/40 (supply/return) or even 60/30 with efficient floor heating systems.

In order to deliver domestic hot water at a sufficient quality with little risk of legionella, the supply temperature to the building should not be lower than 60°C or eventual 55°C in special cases. Considering heat loss from the district heating pipes, which typically lies between 5-10%, depending on the age and general condition of the pipes, the heat supply from the production unit should be no lower than 65-70°C.

4. Road map to low temperature district heating

In the following sections is listed a wide range of incentives and measures to lower the temperature in the district heating system and in buildings to ensure compliance in the entire supply chain. The road map is inspired by the experiences from primarily Denmark, but also other countries. The roadmap is divided into legal-, institutional-, and technical incentives and measures respectively.

Some incentives will have a positive effect already in the short term, whereas others will be a long-term investment. Similarly, some investments will be very cost-effective whereas others may be too expensive considering the local conditions, and the local conditions may change in time.

4.1 Legal framework

4.1.1 Regulating district heating for low temperature

In general, regulation of the district heating for low temperature is not vital, as the district heating company has an interest in delivering heat in the most cost-effective way to provide profit to the owner.

- In case of private ownership, the owner will optimize the supply to maximize profit and give consumers incentives to be connected and buy heat
- In case of consumer or municipal ownership, the owner will optimize the supply to minimize the heat price, and thereby give the profit to the consumers which are the real owners.

4.1.2 Building regulations for low temperature

The legal requirements to buildings are vital to ensure that new buildings are designed and constructed in such a way that their heating system delivers good thermal comfort and energy efficiency, in a cost-effective way for the society long-term. Previously one might argue that low temperatures in building was not important in case the dominating heat source was oil or gas boilers. Today the dominating heat source will be either district heating primarily based on biomass, but also electricity, or individual heat pumps, which both can benefit from low temperatures.

To find the most cost-effective temperature level, the aim is in principle to deliver good thermal comfort and minimize total long-term costs of investments in the heating installations and minimize the total costs of the heat source.

The regulation could be divided into fixed design criteria and incentives, such as:

- Maximal heat transfer of building components (doors, windows, walls, roofs etc.) considering costs of additional insulation vs. variable heating cost.
- Maximal design temperatures of the heating system, e.g., 60/40 on the coldest day, considering quality of supply and costs of heating system vs. costs of heat supply.
- Design which enables optimal operation of the heating system providing the lowest return temperature at the given supply temperature. An example is that local supply temperature regulation of a one string system is important as lowering the supply temperature will lower the return temperature, whereas the opposite is the case for two string systems. In two string systems lower supply temperature will increase the return temperature (if no other technical interventions are made).

The Danish building code introduced design criteria for heating installations for the first time in 1990. Today the code refers to a standard for design of heating, ventilation, and domestic hot water systems, which specify:

For space heating:	60°C supply and not more than 40°C return on the primary side
For domestic hot water:	60°C supply and not more than 30°C return on the primary side

If the building regulations, as in Denmark, do not contain an obligation to connect to district heating, it is important that the building code includes incentives, which encourage the building owner to connected to these systems or at least ensure neutrality in comparison with building level production of heat and cooling. In some countries the building code is in contradiction with the EU directives and encourage or forces building owners not to connect to district heating.

4.2 Institutional set-up and soft measures

4.2.1 Ownership of the consumer heat substation

In Denmark, district heating is traditionally delivered to a heat substation (the point of sale) located in a boiler room or basement of a building as shown in Figure 4-1, where the energy is transferred from the district heating water to the internal building installations (space heating and domestic hot water). Another common solution is where district heating is delivered to a plug cabinet attached at the outside wall of a building, with two stop valves and a heat meter.

With this model the consumer has the full responsibility for the investment and operation of the substation, however the substation has to be installed in accordance with the design guide of the district heating company and they must approve the design.

A new idea is to offer the consumer to move the point of sale (or delivery) permanently from the primary side of the substation to the secondary side of the substation:

- The district heating company invests in the substation as agreed with the building owner.
- The district heating company takes care of operation and maintenance of the substation.
- The consumer accepts the supply temperature which can be available on the secondary side of the substation
- The consumer pays an annual fixed fee, which will cover the long-term costs of investment and maintenance of the substation.

This new institutional set-up has the following advantages for both parties:

- The costs of connection for the consumer will substantially lower, as the district heating company normally will finance the costs of the substation without increasing the connection fee, if any.
- The costs of equipment will be substantially lower as the district heating company get a large discount.
- The costs of installation will be lower as the district heating company can engage one contractor to install many substations, or the company has its own installation team.
- The district heating company will have access to all relevant data of the substation and be able to identify faults, not least faults, which increase the return temperature.
- The district heating company can act for maintenance whenever convenient.
- The district heating company can give the consumer better digital information on the performance of the heat demand and the return temperature and send a notice in case of large deviation. A sudden increase in the return temperature is e.g., a good indicator for a fault, which both increases the heat demand and the return temperature.

Moving the point of sale thus provides a strengthened institutional setup, including providing the basis for better information and cooperation between the district heating company and the heat consumer to lower the district heating temperature level.

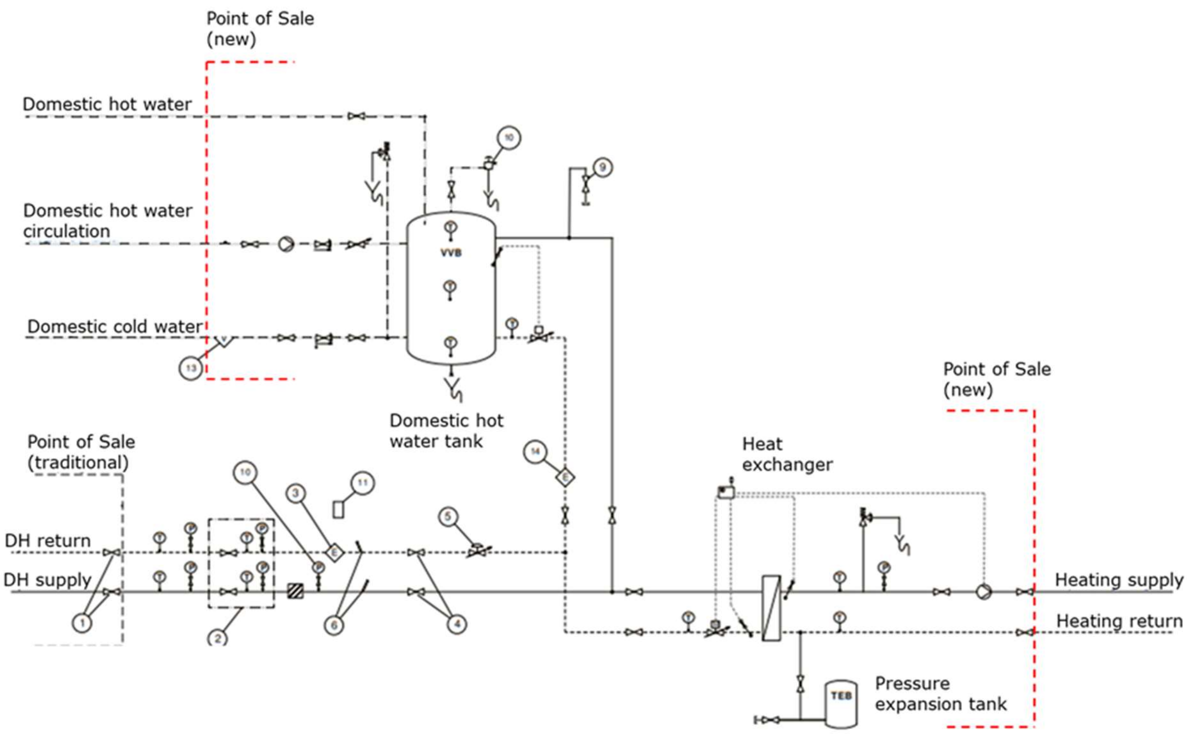

Figure 4-1 Illustration of a district heating substation where the traditional boundary between the district heating company and the consumers is indicated with a black dotted line, and the new model where the boundary is moved to the secondary side of the district heating substation is indicated in red dotted lines

Since 2020 the energy policy in Demark has changed, and now enforces replacement of individual gas boilers for heating with district heating or individual heat pumps, mainly in single-family houses. Many district heating companies have found that this gives district heating a competitive advantage if the point of delivery is moved to the secondary side of the substation. There might be a small or even no upfront payment for the connection, but the consumer pays a fixed annual fee for all services of investment and maintenance of the substation covering all long-term costs of the services. Experience shows that more than 80% of the new consumers prefer this solution and that this opportunity increases the connection rate. Some private companies offer the same type of contract for individual heat pumps including investment and maintenance, but not electricity.

The Danish district heating company Vestforbrænding started already in 2005 to offer district heating to consumers in business districts. It was very profitable for the society and the district heating company, but the consumers typically only accepted energy saving projects which had a short pay back-time. The district heating company decided to give the large consumers (more than 40 MWh/a) a special offer if they connected once the network was constructed. The offer included free connection and fee installation of the substation. Thus, the pay-back time was zero. The ownership was however transferred to the consumer with the obligation to operate and maintain it. Years later modern electronic remote meters was installed, and it appeared that the return temperature from many consumers was larger than expected due to poor operation and lack of maintenance. The district heating company now plans to offer the consumers to take back the ownership of the substation and thereby be responsible for operation and maintenance, free of charge. In other words, to move the point of delivery. The remote meters are important for this concept, as it gives the district heating operator access to important information on the operation and need for maintenance.

4.2.2 Tariff incentives and smart meters

Previously, many district heating companies in Denmark had simple flow meters installed and used the heated floor area for sharing all the fixed costs, and the circulated flow for sharing the variable costs between their customers. This flow tariff gave a strong incentive to save not only heat energy but also flow, and thereby to reduce the return temperatures well.

Tariff incentives for improved cooling

Around 1990 most district heating companies in Denmark had installed heat energy meters and based the variable tariff on the supplied thermal energy (MWh, GJ or GCal). The conditions for supply normally included a maximal return temperature, however without precise measurement and penalty. Accordingly, many consumers ignored the conditions for supply and returned the water to the district heating company without cooling the water to the requested return temperature.

Therefore, many district heating companies in Denmark introduced incentives for the consumers to reduce the flow and thereby also the return temperature.

- One method was to charge the distribution costs according to the circulated flow in m^3/year.
- Another method was to include an incentive to increase the annual average cooling.

The district heating company in Copenhagen Municipality, HOFOR, was in 1990 the first Danish district heating company to introduce an incentive to increase the annual cooling. It was based on measured average annual cooling (C°), and it could influence the annual payment of customers up to +/- 10%, however as HOFOR (as a municipality owned district heating company) was subject to the self-sustaining principle, they were not allowed to make a profit on their incentive tariff, which meant that the cooling tariff had to be budget neutral. The tariff was accompanied by a campaign which advised consumers on how to operate their building heating installations, to reduce the return temperature. The result was very positive as the average return temperature dropped from 60ºC to 50ºC during the first year. It was especially the many large social housing companies that contributed to this reduction, mainly through simple changes in the energy management.

Introduction of these methods improved the performance of the building installations, as they gave the energy manager of the building an incentive to operate the system differently and implement minor investments.

When introducing an incentive to increase the annual average cooling, consumers are paid an incentive for each degree their cooling is larger than the defined neutral cooling and they are charged a penalty for each degree their cooling is smaller than the neutral cooling. Before the tariff incentive is calculated, a neutral cooling must be set. The neutral cooling could be the average for all consumers and thereby be budget neutral balancing incentives and penalties, or it could be set a bit lower than the average to give all consumers an incentive. Most consumers prefer to receive a reward rather than to pay a penalty.

The value of the incentive should to some extend reflect the benefit of larger cooling and thereby also the benefit of a lower return temperature for lowering the costs of distribution and not least for lowering the cost of efficient production from low temperature heat sources.

When introducing an incentive tariff, such as the one described above, the following actions should be taken:

- Justify the tariff with reference to low temperature heat sources and costs of distribution.
- Announce the tariff at least one year in advance to all consumers.
- Test the impact of the tariff and focus on consumers who have to pay a lot more.
- Modify the tariff to ensure that the maximal price increase is e.g., 10%
- Give consumers who would have the largest price increase a notice and give advice on how to reduce the return temperature.
- Increase the heat price a few per cent if the incentives are higher than the penalties
- Increase the incentive step by step in order to reflect the value of larger cooling and lower return temperature.

Improved tariff incentives with smart meters

Both incentives described above depends a lot on the average supply temperature, which might not be the same in all parts of the network, and thus could be a disadvantage. For those district heating companies who have installed electronic heat meters, or so-called smart meters, it is possible to introduce a new more precise method, which focus directly on the return temperature.

Besides the instant parameters of flow (m^3), capacity (kW) and temperature (C°), the smart meters can also measure:

- accumulated enthalpy in the supply pipe

- accumulated enthalpy in the return pipe and
- accumulated circulated flow.

Previously these accumulated values were registered only once a year. However, in case remote reading of the smart meters are established for all consumers, it is convenient to measure the accumulated value by the end of every month and thereby calculate the monthly consumption of energy and average temperatures:

- The difference between the consumed enthalpy supply and return is the monthly heat consumption.
- The ration between consumed enthalpy return and circulated flow is the average return temperature.
- The ration between consumed enthalpy supply and circulated flow is the average return temperature.

In 2002 Viborg district heating company was among the first to introduce smart meters and an incentive tariff based on the return temperature, with a reference temperature considering the average supply temperature for each consumer. The return temperature was reduced by 10°C on average from 2002 to 2007. Moreover, the return temperature has been stable at this low level although the supply temperature has been reduced by 10°C.

Along with this reduction the company installed a large gas fueled CHP plant in 1995 and installs now large heat pumps including heat pumps connected to a large datacenter. This transformation is very impressive having in mind that the network was designed for super-heated (design temperature above 110°C) water and had severe problems with heat losses and leaking pipes around 1980. For further details see paper from Tom Diget in HOTCool 2/0222
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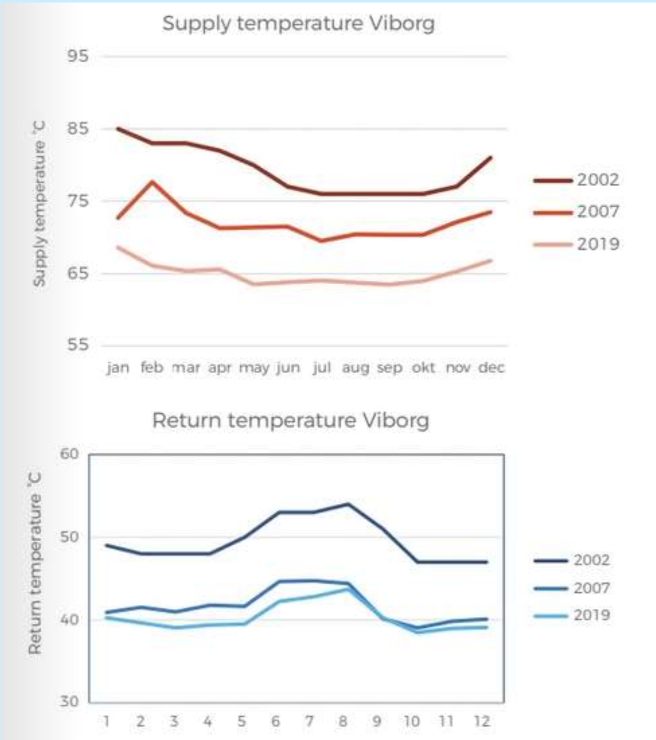
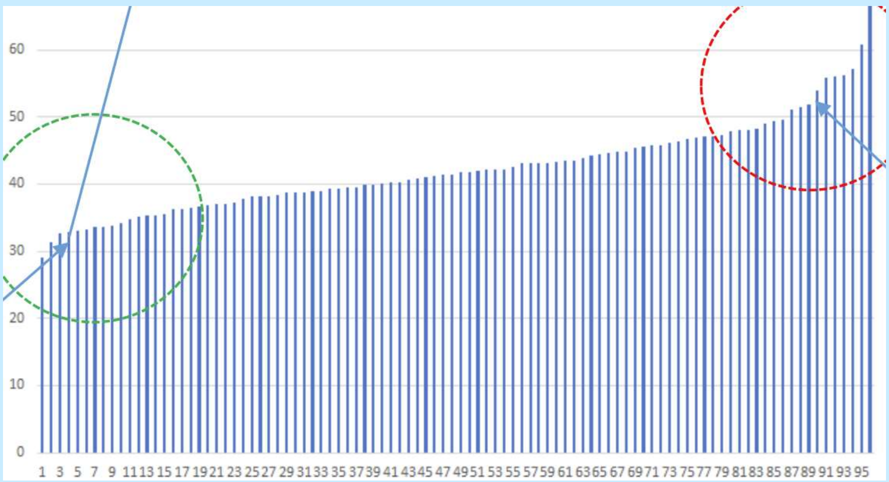


The electronic remote meters open for a lot more communication with the consumer. The consumer need not look at the meter but can log-in at the web of the district heating company and read the meter data as well as the historical data. Moreover, the data can be benchmarked against typical average values for the actual type of building. Finally, the software of the district heating company could include a routine to give an alert in case of unusual consumption, e.g., a sudden increase in the return temperature and the consumption.

4.2.3 Energy management in buildings

It is recommended that all consumers should have an energy manager or at person which is appointed with the responsibility for the operation of their heating installations. The district heating company has a lot to gain by strengthening the relationship with their consumers, and hereby the energy managers, as the key to a successful transition to low-temperature district heating largely lies within the buildings. Furthermore, the benefits of transitioning to low-temperature district heating should also benefit the consumers, which is why closer cooperation in this case should be in the interest of both parties. The district heating company should do so by offering more, and higher quality data to the consumers to encourage the consumers to be more active in terms of energy management. They could for instance benchmark the consumers to e.g., identify the poor performing consumers, which has the largest impact on the district heating system, meaning large consumers who have the highest specific heat consumption (kWh/m^2) and the highest return temperature.

Greater Copenhagen Utility (HOFOR) established a consumer information system based on the smart meters. The consumers can have access to their own data (Consumption (MWh), flow (m^3), supply- and return temperature (C°), and calculated cooling (°C)) through HOFORs online customer data management system). The system also allows for benchmarking the consumers. HOFOR has data for all their consumers and can compare measured data with the theoretical. Surprisingly it appears that many new buildings use more heat per m^2 and has higher return temperature than older buildings. This indicates that there is a huge potential for sharing information and introduce active energy management in co-operation with the building energy managers. To highlight the problem, HOFOR has analysed heat data from 100 new buildings and registered the average return temperature and the annual heat demand in kWh/m^2. The results in the graph below demonstrate clearly that measurements and follow up on operation is important. Most of the measured temperatures appeared to be significantly higher than the theoretical value, although they should be less than the design temperature (40 °C).



Besides informing the consumers about the problems and the potential savings, the company could allocate minor resources to an energy counsellor or a task force, which could offer active support to consumers. During a visit to a poor performing consumer, such a task force could:

- Present the data which indicates faults
- Point at severe faults and problems which should be solved
- Point at possible faults
- Propose cost effective solutions to reduce temperatures and heat demand
- Present a list of local contractors, which has passed a course in district heating and has experience working for district heating consumers in the region.

Further, the district heating companies should be encouraged to organise seminars and training courses for building energy managers.

4.3 Technical measures in the building

In order to introduce low temperature district heating it is important to ensure that the temperatures in the building installations can be reduced as well, first of all the return temperature to the district heating system, as low-temperature consumers are a precondition for a compliant low temperature district heating system.

4.3.1 Hydronic balancing of the heating installations

The aim of making hydronic balancing is to ensure that each radiator or heating element receives the right amount of hot water to achieve optimal performance and temperature control throughout the entire inhouse system. This balancing is crucial for maintaining a comfortable indoor climate, preventing energy waste, and allowing lower operation temperatures.

The heating installations in the building is normally designed in accordance with the calculated heat demand, however after the installations are mounted there can be several deviations from the design. Therefore, it is important that the system from time to time is balanced, which implies that the operating parameters of all components are adjusted according to the local conditions, and with a view to energy-efficient operation.

E.g., in an apartment building in which there are several vertical risers it is important that balancing valves are adjusted and compensated for deviating pressure difference. In case there are no thermostatic valves, this is vital for the performance of the heating system. In case all heat surfaces have thermostatic valves, a rough balancing is sufficient.

4.3.2 Control of the water flow

A low return temperature is essentially about controlling the flow of water in the building's heating system in relation to the calculated heat demand.

The water flow to the radiators must be set according to the calculated heat demand and the radiators heating surface. If the insulation of the building is upgraded and the space heating demand is reduced, the flow and/or the supply temperature can be reduced accordingly, and the return temperature should thus be reduced too.

If the flow, and the temperature is not adjusted, the water circulating at high flow leaves the individual radiators with a return temperature that is too high. This inevitably results in a high district heating return temperature. The solution to this issue is to limit the inhouse water flow, which can be done by either of the following:

- by replacing the existing radiator thermostats with radiator thermostats that has a built-in water flow limiter
- by fitting a return thermostat
- by fitting simple return valve on the radiator outlet

4.3.3 Temperature regulation of one and two stringed heating systems

In one-string systems, the supply and return water are on the same string, as the name implies, as opposed to two-string systems where the supply and return water run on two separate strings. See Figure 4-2 and Figure 4-3 respectively.

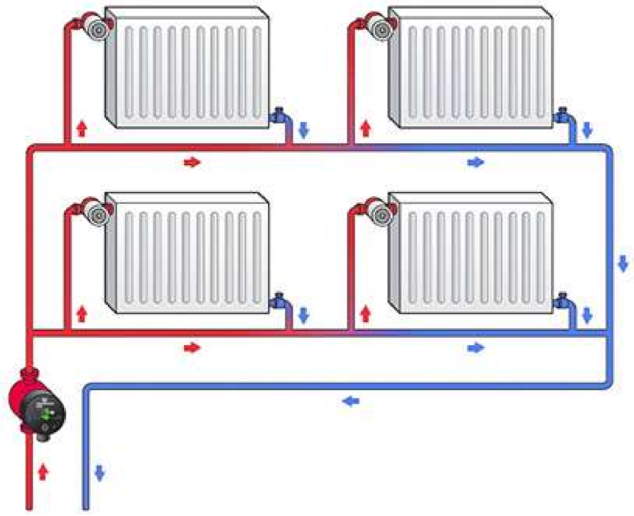


Figure 4-2 Illustration of one-stringed radiator system (two in a parallel loop) from https://www.frb-forsyning.dk/forside/varme/spareraad/daarlig-afkoeling

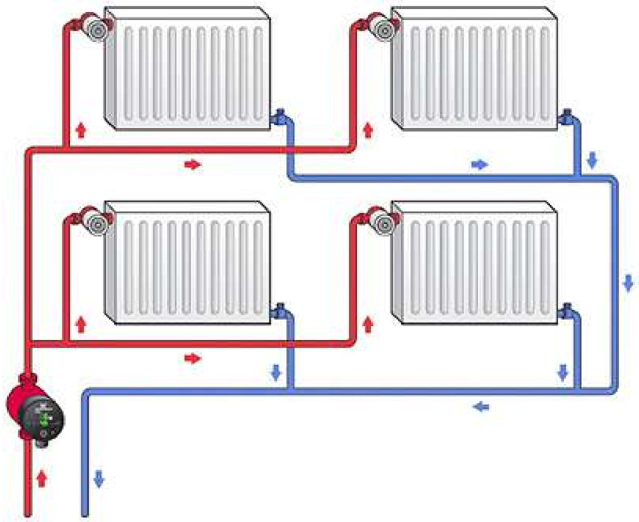


Figure 4-3 Illustration of two-string systems from https://www.frb-forsyning.dk/forside/varme/spareraad/daarlig-afkoeling

One-string systems are still in operation in some old buildings, and in these systems, it is important that that the water can circulate through a by-pass after the last radiator in the string, as illustrated for the one-string system in Figure 4-2. If this is not ensured, there will not be sufficient heat for the last radiators. Thus, lowering the supply temperature to the one-string system will lower the return temperature until the circulated flow reaches its maximum.

In order to meet the demand with the optimal supply temperature it is important that the supply temperature is adjusted to the out-door temperature following a standard curve for heat demand. Further, the radiators on the end of the string, should be made larger than the first ones, to account for the slightly lower supply temperature.

In the two-string heating systems, the opposite applies. In these systems, the supply temperature must, if possible be higher than the necessary supply temperature to ensure a lower flow and return temperature. Thus, lowering the supply temperature to the two-string system will increase the return temperature.

However, the cooling in a two-string building system can often be improved by a pressure difference regulator, which ensures a constant pressure difference across the radiator system. If some of the radiators are opened or closed, the amount of water is regulated automatically, while the pressure in front of each radiator will be kept constant.

4.3.4 Night setback issues

Night setbacks, meaning temporary reductions in heat supply, was previously recognized in Denmark as an important measure to obtain energy savings in buildings. It makes sense in the case where there is only one heat source, with a constant energy price, e.g., a gas boiler that covers all the heat demand, and if the end users can accept the reduced thermal comfort during the night. In a poorly insulated building with low thermal capacity, i.e., ability to store heat in the body of the building (e.g., plasterboard), the night setback can result in an indoor temperature drop of several degrees. The heat savings (the saved heat loss during the night hours) will in this case reflect the temperature drop. If, on the other hand, the building is well insulated and has a high thermal capacity (concrete or brick walls), the temperature reduction and the associated heat savings will be modest.

If the building is supplied with district heating, night setbacks will normally not be cost-effective, neither for the building owner nor for all the other consumers. The reason for this is that the extra heat load, which follows the night setback, risks overloading the district heating system (if a larger proportion of the building mass has night setbacks). When the system is overloaded, the need for a higher heat supply temperature increases and the return temperature increases due to this uneven use of the system. Thus, the required capacity in the pipes increases, and it may be necessary to the start expensive peak load heat production.

To reduce the extra capacity load in the morning, reverse night setback can be recommended as an alternative, if consumers can accept it and if there is cheap heat available during the night hours and not in the morning.

4.3.5 Upgrading of overloaded heating installations

Identify and upgrade the few overloaded heating installations in buildings which has too high return temperatures, e.g., radiators in bathrooms, and heating coils in ventilations systems, can be upgraded in several ways at fairly low cost e.g.,

- Replace the few overloaded radiators with larger radiators
- Use the return flow from existing radiator systems to feed into a new floor heating system, which will improve the thermal comfort in the building
- Replace the few overloaded heating coils in ventilation system with larger coils

Further, floor heating systems, or heating in the ceiling, could be installed upgrade the thermal comfort in the building and transfer more low temperature heat to the building. Thereby the existing and new heating system can be supplied with low temperature heat. By connecting low temperature installations, like a floor heating system to the return pipes (in a cascade connection) it is possible to reduce the temperature from the district heating substation.

4.3.6 Energy reductions by facade upgrades

Upgrading of the building envelope which reduces the heat demand has also a positive impact on the ability to use low temperature heating in case the existing heating system is unchanged.

In an old apartment building with a low level of insulation, and concrete facade there is a great potential for improving the energy performance significantly by adding external insulation and mounting new windows. This will typically halve the heating demand and enable the supply of low-temperature district heating to the building, as shown in Table 4-1.

Table 4-1 Examples of heating data in a building before and after renovation

	Before renovation	After renovation
Specific heat demand, kWh/m^2	180	90
Maximal temperature of heating system, C°	90/70	65/45
Average temperature of radiators at max load, C°	80	55
Average temperature difference between the radiator and room, C°	60	35

Most Danish buildings have been insulated with cavity insulation and roof insulation mainly due to relatively large energy prices, as well as tax on fossil fuels since 1980. This is one of the main reasons for the low return temperature in Danish district heating systems, which supply mainly old buildings.

There is however also Danish cases which demonstrates a lack of understanding lower return temperatures of the connection between lower return temperatures and energy efficiency. One example is a social housing company, which established a project for installation of outside insulation, new windows and a heat pump, resulting in a lower space heating demand. However, as they did not consider the advantage of lowering the return temperatures further, they removed a radiator. Because of this they missed the opportunity for lowering the return temperature further, and thus increasing the energy effieciency of the building.

4.4 Technical measures in the district heating substations

The interface between the consumer and the district heating system is important for optimizing the temperature levels in the district heating system and for the vital communication between the district heating company and the energy manager of the building.

4.4.1 Avoid heat exchangers in substations between legal entities

In general, the interface between the district heating system and the building heating installations is defined by the ownership and in most cases a heat exchanger between the district heating system and the building heating installations is installed. This will ensure a clear division of responsibility, but it will also increase the return temperature.

In larger district heating systems, in which there is also heat transmission system and distribution systems there will typically be a heat exchanger separating the transmission and the distribution system. The reason for this might be one, or more of the following.

- **Poor water quality**. If the water quality of local consumer network to be connected is not according to the standard it is a problem and there is a risk of corrosion in the district heating system if the systems are directly connected.

- **Water losses**. If the water losses in consumer network is relatively large, the water losses of the district heating system will increase and be difficult to control.

- **Monitoring and control** of the district heating flow and pressure. It is important that the district heating company can monitor all substations and control valves at the secondary network.

- **Different pressure level**. In case there are different pressure levels in the district heating network and the consumer network, a heat exchanger is the traditional solution, but to save investment costs and save the temperature drop, it should be considered to establish a pressure reduction.

- **Restricted area**. In case the consumer network is in a restricted area, (e.g., air site), some of the staff of the district heating company should be cleared to have access to the restricted area as well as other service staff.

Because of these technical and institutional issues there might be up to 3 or 4 heat exchangers between the central heat production plant and each end-user (building) heating installation in large district heating systems. As each heat exchanger typically has a temperature drop of 5°C, the temperature level at the central plant will be 15-20°C higher than the building level temperature, to meet the temperature requirement of the buildings heating installations. This will reduce the performance of most heat production facilities at the central plant, thus there is a great potential for reducing the number of heat exchangers in a district heating system.

How to avoid additional heat exchangers between legal entities

Case 1: A building in which there are individual gas boilers for each apartment. The district heating company asks the building owner (e.g., the homeowners association) to establish an internal heating system in the building and a building level substation. Most likely there will also be a heat exchanger between this internal heating system and the existing heat distribution in each apartment. **Alternative solution:** The district heating company prolongs the branch line to go directly to each apartment or to a connection point in the basement of the building and install a substation with a heat meter and heat exchangers for heating and hot tap water to each apartment.

Case 2: A building in which there is only one central boiler for heat production. The district heating asks the building owner (e.g., homeowners association) to replace the boiler with a building level substation with heat exchanger. **Alternative solution:** The district heating company installs a substation at the building.

Case 3: A large boiler plant which supplies several buildings with heat for heating and hot tap water via a local network. Each building is connected to the local network with heat exchangers for heating and hot tap water. The district heating asks the owner of the large boiler plant to establish a group substation with heat exchanger. **Alternative solution:** The district heating company connects to the secondary network without heat exchanger and supply heat directly to each building substation. In case the secondary network is old and need to be upgraded, a solution could be to install a temporary heat exchanger and plan how to shift all buildings from the old network to the district heating network.

Case 4: A large boiler plant which supplies several buildings with heat and central production of hot tap water via a 4-pipe system, 2 pipes for heating and 2 pipes for domestic water with recirculation. The internal heating and hot tap water system in the buildings are directly supplied from the 4-pipe system. The district heating asks the owner of the large boiler plant to establish a group substation with heat exchanger for heating and hot tap water. **Alternative solution:** The district heating company installs a temporary heat exchanger for heating and for hot tap water at the central plant. In case the 4-pipe system is large and inefficient, the district heating company offers to connect each building to the district heating network and establish a new substation at each building.

4.4.2 Efficient heat exchangers

If a direct connection between the district heating system and the building heating installations is not an option due to the pressure, and risk of leaks, an efficient tall plate heat exchanger is an option. The additional costs of increasing the capacity of the heat exchanger, and thereby reducing the temperature drop across the heat exchanger is relatively low.

It is however very important that the heat exchanger is cleaned sufficiently, and regularly, as there is always a risk that the heat exchanger will be filled up with deposits, which will lead to an increase in the temperature drop of the heat exchanger. In case the district heating company has access to the temperatures on the primary and secondary side, it is possible to monitor the performance and order a service company to clean it if the performance is poor.

4.4.3 Supply temperature regulation
Regulating the supply temperature from the district heating substation a bit up or down will give information about the performance of the building installation. If an upregulation of the supply temperature is followed by an increasing return temperature, it indicates faults, e.g., unregulated bypass valves or it indicates that part of the system is a one-string system.

In case the district heating company owns the substation, it is possible to take this end-user response into account in the strategy for lowering the supply temperature to the whole network.

4.4.4 Direct connection of heating in the substation
Direct connection to district heating (i.e., without a heat exchanger in the substation between the radiator circuit and the district heating network) is an obvious solution for reducing the operation temperatures. In addition, it requires less space and simplifies the heat substation design, which lead to lower installation and maintenance costs. But for safety reasons, the district heating company does not always allow/choose direct connection.

However, poor cooling can still occur with a direct connection due to the customer's installation not being designed for the larger and varying differential pressure with which the district heating operates compared to the original heating system with a local boiler, where the differential pressure was supplied by a small local circulation pump.

Thus, to achieve the benefits of direct connection, the correct automation must be installed, which can ensure that the district heating water flows at an appropriate (low) flowrate through the radiators, and that the buildings system can compensate for the varying differential pressure from outside. For this, suitable regulators should be installed, i.e., thermostatic regulators or supplementary flow regulation for temperature control as well as differential pressure regulators for differential pressure regulation.

4.4.5 Efficient heating of domestic hot water
Inefficient heating of domestic hot water is also a contributor to high return temperature, and for setting a demand for higher supply temperatures. Due to hardness of the potable water, there is a risk of calcium deposits if the flow heat exchanger, or the domestic hot water tank is supplied with temperatures above around 65°C. If the heat exchanger or the tank is not cleaned regularly and sufficiently, the heat transfer capacity is reduced, thus leading to even higher return temperatures.

4.4.6 Return temperature valve
One obvious measure to prevent maximal return temperature is to install a return temperature valve at the return pipe to the district heating and set it to close at the requested temperature. That is efficient but not to recommend, as it will reduce the quality of heat supply.

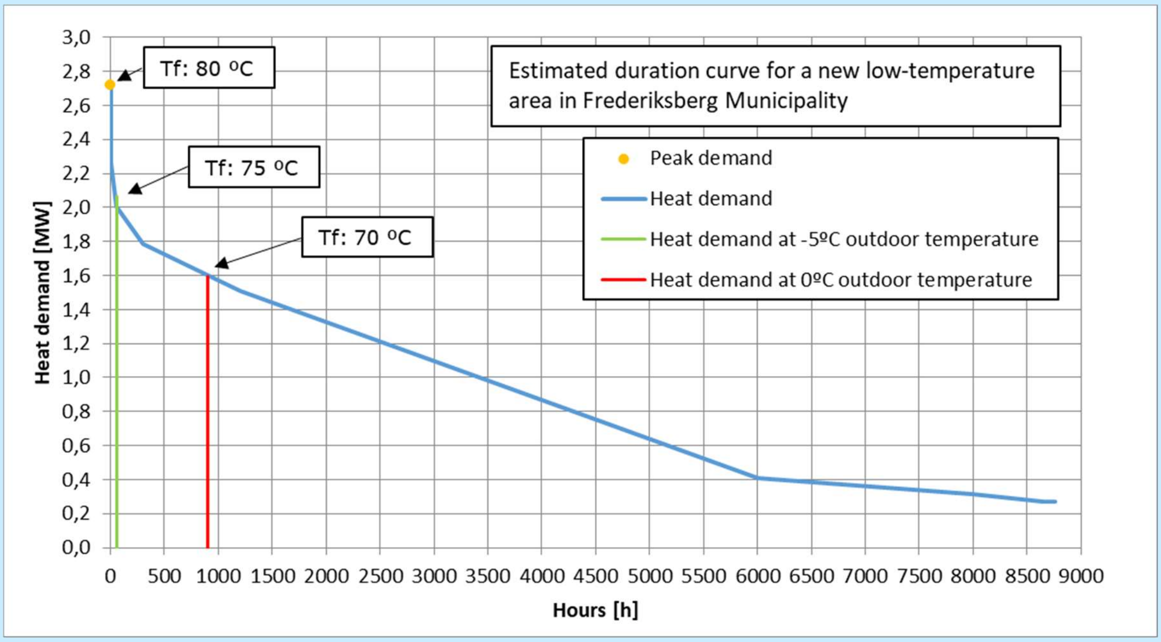
4.5 Technical measures in the district heating system
Based on realistic forecasts of total return temperature from all consumers, considering all efforts to reduce the temperature, as well as the needed flow temperature, it is possible to optimize the district heating system's configuration, production, and strategy for low-temperature supply. The aim will be to minimize the total costs for production and distribution (networks and substations). In a second phase, the costs of economic support to consumers could be weighed against the benefits of lower temperatures at the consumer.

4.5.1 Optimal supply temperature strategy

Based on Danish experiences, the optimal district heating supply temperature will in general be:

- As low as possible in the warmest 6-9 months in order to meet the temperature demand for heating and domestic hot water for all consumers, typically 70°C
- A higher temperature in the coldest 3-6 months in order to have sufficient capacity in the network and to meet the need for increased supply temperature, typically around 80-95°C

An example of where this supply temperature strategy was proposed implemented is from a preliminary design of a new low-temperature area in Frederiksberg Municipality. The area consists of mainly new buildings, and a few old, renovated buildings. The area has an estimated peak demand of 3.0 MW and will be supplied with district heating at a temperature of 70°C for most of the year as shown in the figure below. The heat demand exceeds 1.5 MW less than 10% of the year, and there is 1% of the year where the heat demand reaches close to the peak capacity of 3.0 MW. In these very few hours, the supply temperature will be increased to 75°C and 80°C respectively. In this case, this solution is economically advantageous over the alternative, which would be to upsize all pipes in the new low-temperature area in order to handle a higher water velocity as a result of the area being supplied with 70 degrees throughout the year.



It is important in the dialog with the consumers to have information on the temperature demand for all consumers and to match this with the measured and estimated supply temperature in the network considering the heat loss in the district heating network. In longer branch lines and pipes with high heat losses, and low flow, it is in general better to install a by-pass controlled by a thermostatic valve than it is to increase the supply temperature to all consumers.

4.5.2 Local temperature boost

In the case where there are only a few consumers that need a significantly higher supply temperature compared to the typical consumer (e.g., industrial consumers), a local heat booster at the consumer, e.g., a boiler, can be installed to upgrade the district heating supply temperature.

This solution is usually economically advantageous for the district heating company, as it allows for lower temperatures in the overall system, and thus full utilization of low-temperature renewable energy sources. However, this is depending on the heat demand of the high-temperature customer, and therefore, each high-temperature consumer must be assessed separately.

4.5.3 Central temperature boost

Another option is to boost the temperature at the low temperature heat production plant, for example, if the primary heat source is an electric heat pump, and the temperature is raised using an electric boiler for a period of three months (in the winter), then the total annual coefficient of performance (COP factor) for both plants will be reduced from e.g., 3.0 to 2.6 in the case of the electric boiler boosting the temperature to 85°C in three months.

The higher production costs for the district heating company due to the temperature boost, must be seen in relation to the savings in further investments in upsizing the district heating network (piping system), which in most cases are significantly higher. Therefore, local temperature boost at the production plant is generally a profitable solution, compared to supplying with low temperature all year round. Moreover, the need for temperature boosting will decrease if the high-temperature consumers gradually reduce their return temperature.

Table 4-2 Example of total costs (NPV) with and without temperature boost

		Constant low temperature	With temperature boost in winter
Operation of peak boiler		Low temperature	Boosting supply
Heat energy demand	MWh/a	100.000	100.000
Heat capacity demand	MW	35	35
Baseload capacity	MW	20	20
Number of large consumers	pc.	20	20
Maximal supply temperature coldest day	oC	70	90
Normal supply temperature 9 months	oC	70	70
Return temperature	oC	40	40
Cooling design	oC	30	50
Largest dimension of the network		DN400	DN300
Length of network	km	20	20
Length of branchlines	km	3	3
Heat losses	MWh/a	5.000	4.300
Investment in network (NPV)	mio.kr	260	200
Residual value of network (NPV 3% 60 year lifetime)	mio.kr	95	73
Base load energy, large heat pump	MWh/a	94.500	93.870
Peak load energy, electric boiler heat storage tank	MWh/a	10.500	10.430
COP baseload		3,0	3,0
COP peak load		1,0	1,0
Average COP factor		2,5	2,5
Annual energy cost of heat production	mio.kr./a	25	25
NPV of energy costs (NPV 3% 20 years)	mio.kr	375	373
Total costs (NPV 3% 20 years)	mio.kr	540	500

However, if, as in most cases, the heat pump is considered as the base load unit, and a gas boiler or woodpellet boiler provide the peak capacity, this peak capacity can be used to boost the supply temperature almost without additional cost. See example of calculated total costs with and with temperature boost in the winter in Table 4-2.

4.5.4 Decentral peak capacity

In the case where the supply temperature increases due to local capacity limitations in the district heating network, it may be more efficient to generate decentralized peak capacity at the most strategic locations in the network. The economic advantage of this solution is the same as for central temperature increase described above, i.e., saved investments in upsizing the district heating network.

In systems with variable flow operation and automatic load distribution, the peak load boiler will start operation and maintain the critical differential pressure at the end of the network.

4.5.5 Three-pipe connection of low-temperature consumers

If the district heating system consist of a mix of high- and low-temperature consumers, and the return temperature is too high, it is an opportunity to utilize some of the low temperature consumers to reduce the return temperature in the network. This can be done by connecting the low-temperature consumers to the return pipe as shown in Figure 4-4. The water flows from the high-temperature return pipe, e.g., at 60°C to the low-temperature consumer and back to the return pipe downstream towards the production plant. A third pipe from the supply pipe ensures that normal operation is possible.

With this solution the new low-temperature consumers can be connected to the network almost without loading the capacity of the network and the low-temperature consumers contributes to a lower return temperature at the production plant. This solution has low investments cost and is relatively easy to install. The investment cost depends on the dimension of the pipes, valves and pump.

> As an example, a preliminary design was made for a three-pipe connection which where to supply a low temperature area in Frederiksberg municipality, Denmark with a heat demand of approx. 3.0 MW. In this case two valves, and a pump was installed, as well as a third pipe (a DN150 of 225 meters) connected to the supply pipe of the existing network as illustrated in Figure 4 4. The investment cost for this solution was estimated at around 1.3 million DKK. This does not include the supply-and return pipes, which would be established regardless of the three-pipe connection.

The connection can be done for a single low-temperature consumer or a low-temperature district. It can be installed in the boiler house of a large high temperature consumer or at a return pipe which has large return temperature. E.g., if the return temperature of a high-temperature consumer is 60°C or higher, and a new consumer, e.g., a new building with low temperature heating (60/40) is in proximity of the high-temperature consumer (in the existing district heating network). In this case the low-temperature consumers could be supplied from the return pipe of the high-temperature consumer, with a shunt connection and thereby reduce the overall return temperature in the district heating system. To ensure at least 60°C to the new consumer, a normal connection to the supply pipe is necessary.

The Danish district heating company Vestforbrænding has used the three-pipe connection for connecting a new hospital to the main pipe, which has a return temperature of 50-55ºC. Thereby around 50% of the heat supply to the hospital can be supplied from the return pipe.

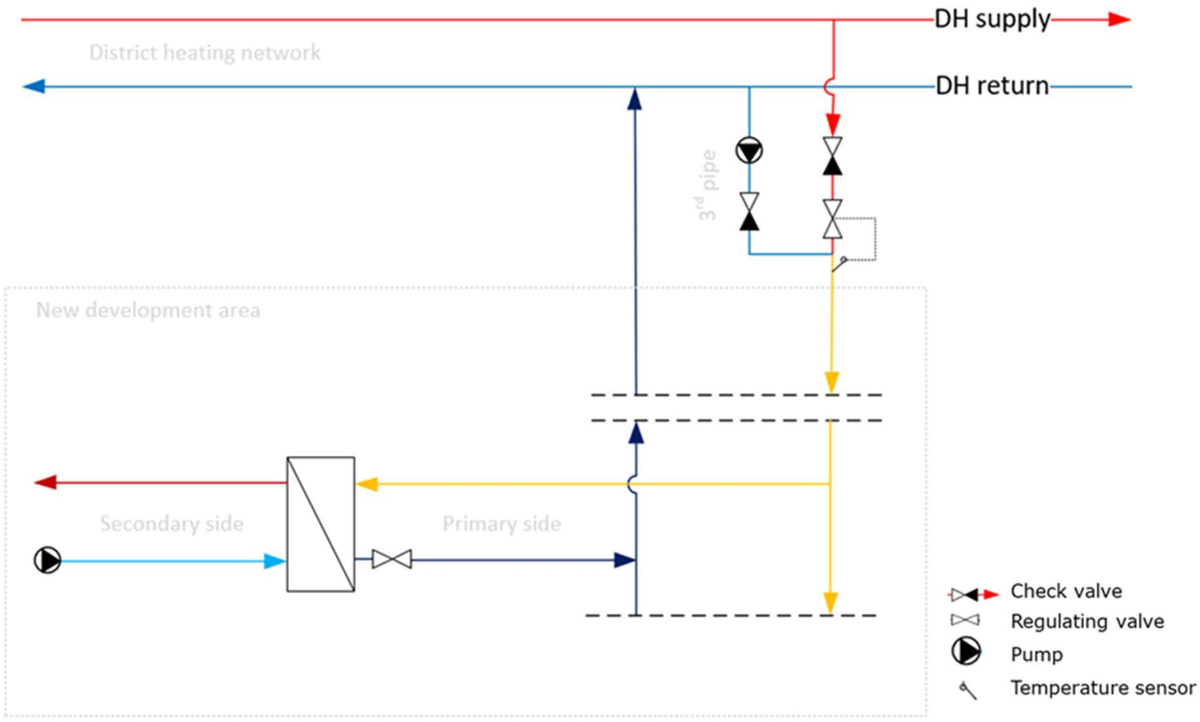


Figure 4-4 Three-pipe connection with a shunt (additional pipe) at the return pipe

The Danish district heating company Høje Taastrup District heating has used the 3-pipe connection for connecting a renovated low temperature area of the existing network to the branch line from a large apartment building. The heat demand of the apartment building is larger than the heat demand of the new area, with single-family houses. The return temperature from the apartment building is typically up to 60ºC and the maximal supply temperature of the low temperature section is 60ºC. Therefore almost 100% of the heat to the low temperature section can be supplied from the return pipe.

4.5.6 Combining high and low temperature districts

In the transition from high to low-temperature district heating it is typical that the central part of the system operates at a high temperature, e.g., 100ºC mainly due to many high-temperature consumers (typical industries) or capacity constraints and those other districts, can be operated at lower temperatures, e.g., typical one family house areas. Thereby all consumers in the low temperature districts are supplied with 100ºC, whereas they could be supplied with 70ºC. This opens for three opportunities:

- The district heating company installs a traditional shunt (from return to supply pipe) at the main line, as shown in Figure 4-5, to the low-temperature district which reduces the supply temperature to e.g., 75ºC (not too low, as this will increase the return temperature from the consumers). This will reduce the heat losses in the district by roughly 25% (e.g., from 16% to 12%).

- The district heating company identifies a large high-temperature industrial consumer close to the main line to the low-temperature district. The high-temperature consumers need a supply temperature of 100ºC, but can only reduce the return temperature a few degrees, e.g., to 70ºC. This is an opportunity for connecting the consumer with a three-pipe connection to the supply pipe. This solutions is similar to the one illustrated in Figure 4-4, however in this solution the shunt (extra pipe with a regulating valve and pump) is connected to the main supply pipe, and thus the water flows from the main supply pipe to the high-temperature industrial consumer, and back to the main supply pipe (at a slightly lower temperature) down streams towards the low-temperature district. The high-temperature consumer is still connected to the main return pipe to ensure that normal operation is possible.

- The district heating company identifies a source of low-temperature surplus heat at an industry close to the main line to the low-temperature district. It could even be the same industry as in the case above. This is an opportunity for connecting a supply- and return pipe from a heat pump facility, so that the low-temperature heat (which has a temperature of e.g., 60ºC) from the heat pumps can be fed into the supply pipe of the high-temperature network, and thus lowering the supply temperature to the low-temperature distribution area.

The two last opportunities will increase the overall efficiency and reduce the flow in the traditional shunt, as mentioned in the first opportunity.

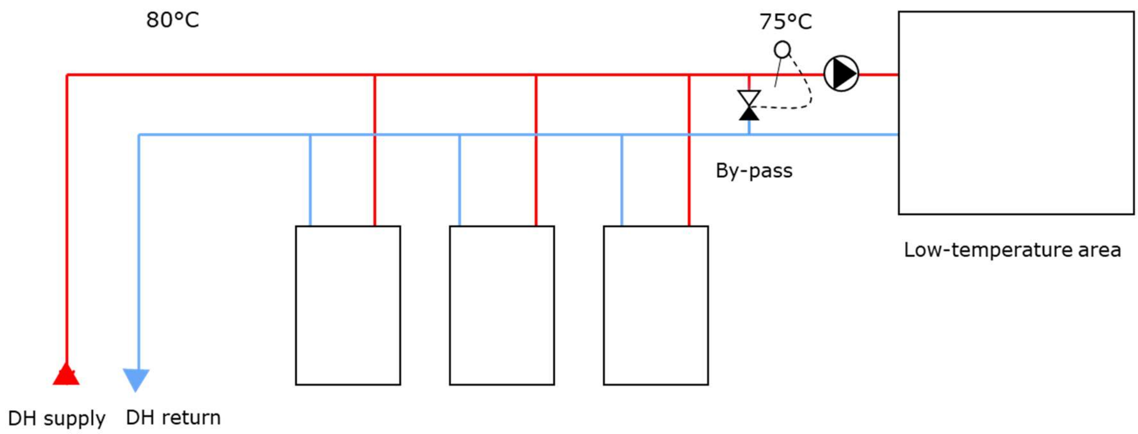


Figure 4-5 Illustration of a traditional shunt (from return to supply pipe) to a supply a low-temperature area

4.6 Gradual transition from natural gas to district heating

One of the main pillars in the green transition in Denmark, and in most other EU member states, is to replace individual gas boilers with individual electric heat pumps or district heating based on an optimal combination of existing infrastructure and large electric heat pumps which utilize low temperature heat sources and ambient heat.

In both cases it is vital for the efficiency of the system that the buildings are prepared for low supply and return temperatures. This gives district heating a competitive advantage over individual heat pumps, as it is possible to convert natural gas customers to district heating and maintain the high supply temperatures for a period, after which you can collaborate with the consumer on how to lower the temperatures.

However, it is a challenge for several district heating companies in Denmark, which have implemented many of the ideas in this report. Below are the most useful measures to convert natural gas customers to district heating, based on short-term considerations when expanding the network and negotiating with new potential consumers. The measures are listed in bullet form, with reference to the topical sections in the low temperature road map.

Many of the short-term solutions can be gradually modified in the longer term, when the authorities, consumers and the district heating company have implemented long-term measures, such as design criteria for new plants, incentive tariffs, and active energy management with a focus on e.g., the return temperature.

- **Shift point of delivery (point of sale) to the secondary side of the district heating substation** strengthen the institutional setup, by providing the basis for better information and cooperation between the district heating company and the heat consumer to lower the district heating temperature level (4.2.1 Ownership of the consumer heat substation)
- **Engage in dialog with new potential consumers individually** to find the optimal solution for how each customer can be converted to district heating (4.2.3 Energy management in buildings)
- **Install local temperature boost at high-temperature consumers** in order to lower the overall temperature in the district heating network (4.5.2 Local temperature boost)
- **Install a central boost of supply temperature** (e.g., an electric boiler paired with a heat storage tank) to avoid the often less cost-effective solution of upgrading the piping system (4.5.3 Central temperature boost)
- **Install local peak load capacity** where there are capacity limitations in the district heating network, in order to avoid the often less cost-effective solution of upgrading the piping system (4.5.4 Decentral peak capacity)
- **Install three-pipe connection** to utilize the high return temperature of high-temperature consumers to supply low-temperature consumers (4.5.5 Three-pipe connection of low-temperature consumers and 4.5.6 Combining high- and low-temperature districts)

5. German experiences

District heating in Germany have evolved greatly over the past decades, however in terms of low temperature district heating there is still a long way to go. In the following sections, the current state of district heating in Germany is described, as well as already existing incentives for further energy optimization and low temperature district heating. The purpose is to identify to what extent experiences with low temperature district heating in Denmark can be implemented in German District heating systems, either directly or with minor alterations.

5.1 Current state of heating networks in Germany

Of 41.9 million households in Germany, 15 % are heated with district heating. District heating is very common in the city states of Hamburg (32 %) and Berlin (38 %) related to households. DH also has a market share of around 30 % related to households in eastern Germany, particularly in Mecklenburg-Western Pomerania, Saxony, Saxony-Anhalt and Brandenburg. The share of district heating as a heat supply source has increased over the last years as seen in Figure 5-1. (BDEW Report "Wie heizt Deutschland", 2023)

The total length of district heating networks in Germany is over 31,000 km, of which more than 90 % are operated with water and around 2,500 km with steam. It should be outlined that there are a total of 3,792 individual district heating networks in Germany (2020).

North Rhine-Westphalia and Baden-Württemberg have the most district heating network kilometers with a total network length of 4,400 km (317 networks) and 4,200 km (828 networks), closely followed by Bavaria with 3,800 km (375 networks). Schleswig-Holstein has also a high number of 384 small district heating networks with a total length of 2,500 km.

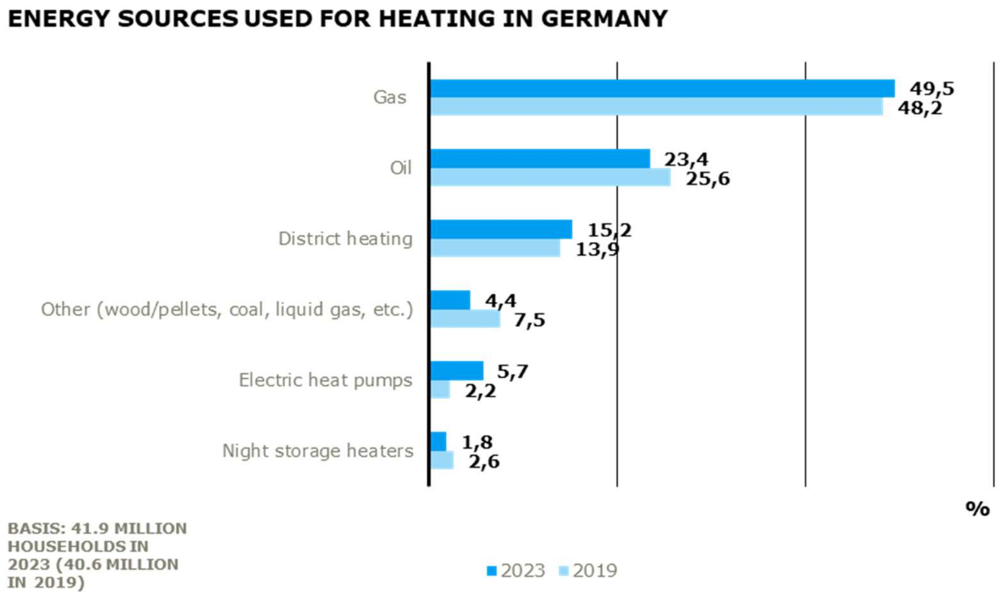


Figure 5-1: Comparison of energy sources used for heating in Germany in 2019 and 2023 (Source: BDEW)

<u>Production units</u>
A major part, namely 89 %, of the German district heating system is supplied by CHP plants (108 TWh). The fuels used here include mostly gas and coal, but also waste, geothermal energy and

biomass. 14 % of the heat (17 TWh) is generated by heating plants. These are predominantly gas-fired power plants, but also waste, other renewables such as heat pumps or solar thermal/geothermal energy or biomass.

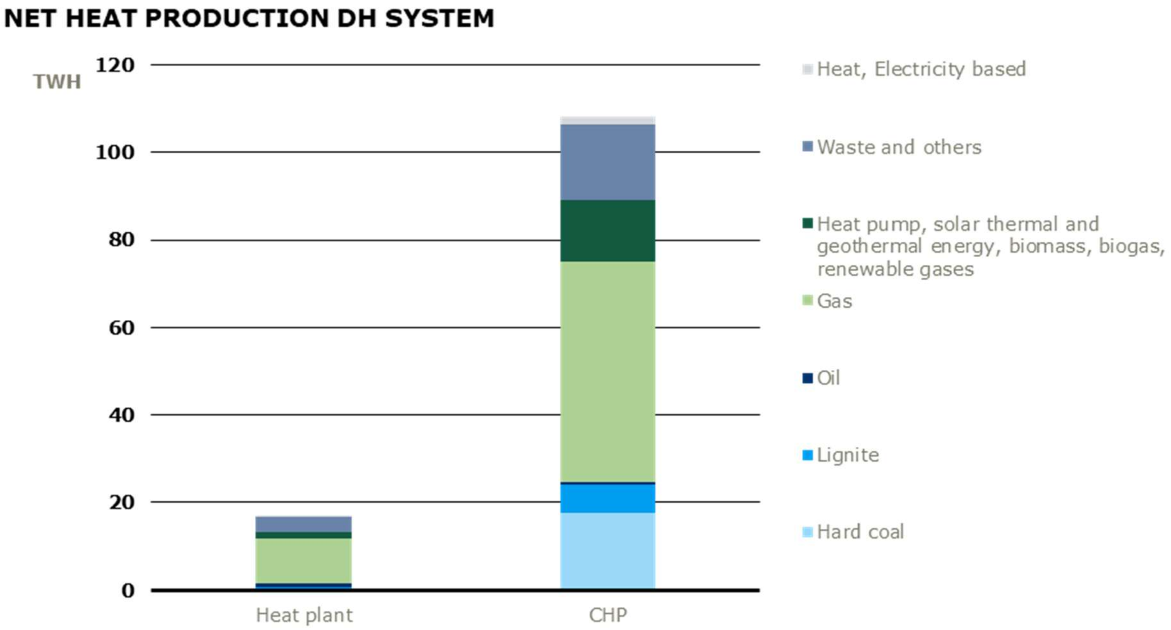


Figure 5-2: Net heat production for district heating in Germany (TWh)

Distribution losses are on average 13 % of the heat fed into the grid.

<u>Customers</u>

In 2022, 42 % of district heating was supplied to private households and 34 % to the industrial sector. A monthly analysis is shown in the following figure.

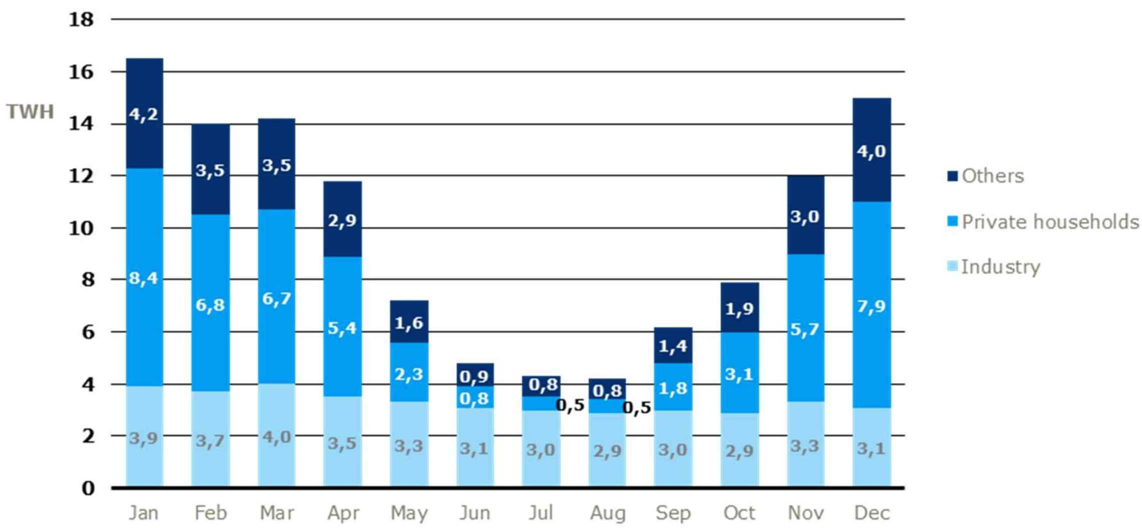


Figure 5-3: Monthly district heating consumption 2022, including district cooling; excluding operational het consumption, grid losses, storage differences.

There is a high demand for heat in the industrial sector in Germany. Part of this is also covered by district heating, as shown in the figure. A major part is process heat, which is needed in the industrial sector all year round. Industrial process heat supplied by district heating can cover a variety of processes. Some examples are (not exhaustive):

- Paper and pulp industry: drying of paper and pulp. The temperature level is medium to high, depending on the requirements.
- Chemical industry: chemical synthesis processes and distillation. The temperature level depends on the specific processes.
- Food industry: cooking, pasteurization, sterilization. The temperature level here tends to be low.
- Metal processing: melting processes. The temperature level is very high.
- Glass industry: glass production, melting processes. The temperature level is very high.

The temperature levels can vary significantly and depend heavily on the individual processes. It must also be noted that not all of the listed temperature levels can be achieved by district heating. However, the district heating is used for preheating or to supply auxiliary applications in these energy-intensive industries.

In Germany, efforts are being made to use industrial waste heat in district heating systems. It is also included in the funding system (see 5.3.4.2). The available potential is considered to be very high. The development and use of waste heat is currently still connected with various challenges and still varies greatly from region to region.

Temperature

The shares of temperature levels in district heating networks in Germany can be seen in the following figure. Less than a quarter related to the total length are operated below 90°C.

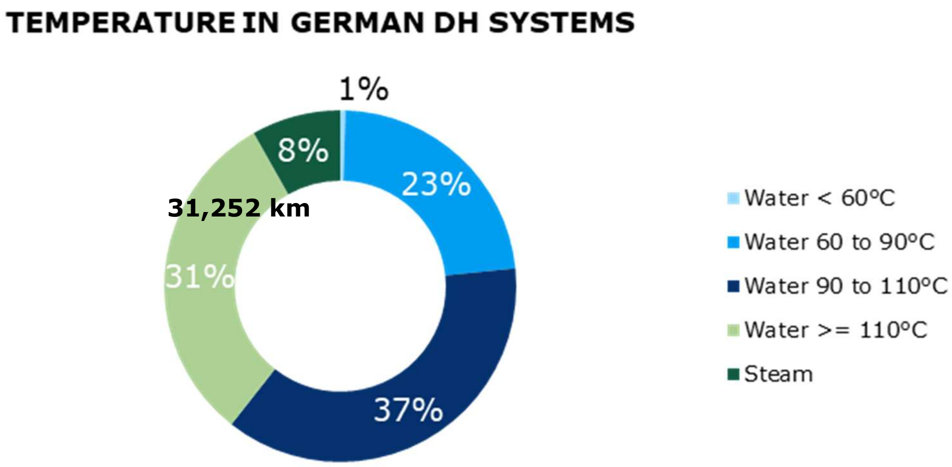


Figure 5-4: Temperature in German district heating systems related to the network kilometers (AGFW Data status official statistics, 2020)

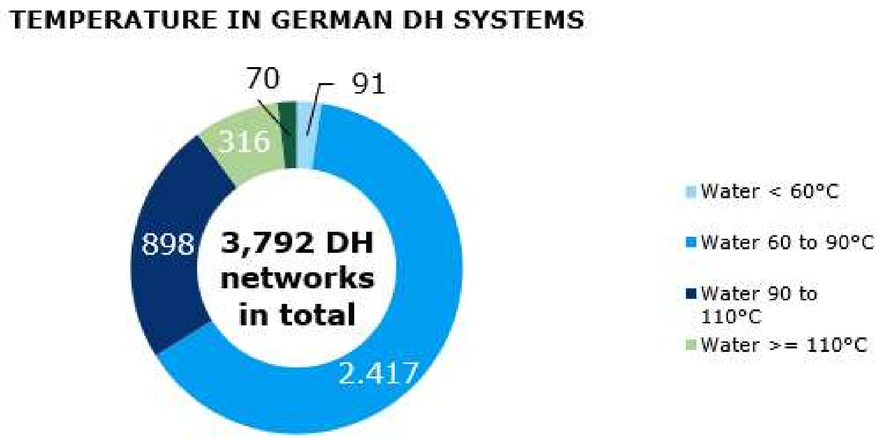


Figure 5-5: Temperature in German district heating systems related to the total number of DH systems (AGFW Data status official statistics, 2020)

As comparison, in a Danish context low-temperature district heating is typically considered for supply and return temperatures of about 70°C and 40°C, respectively.

An AGFW analysis of 165 district heating supply companies shows weighted average values for the supply and return temperatures of the main DH networks. (AGFW Main Report 2020)

Table 5-1: Weighted average of temperature of 165 DH supply companies

	Winter	**Summer**
Typical supply temperature	110°C	84°C
Typical return temperature	60°C	58°C

It is important to point out that an average district heating network supplies both residential buildings and industrial customers. As shown in Figure 5-3, industrial customers account for 21 % (Winter) to over 70 % (Summer) of district heating consumption, depending on the time of year.

5.2 Heat demand in buildings

As of 2019, there are around 3.2 million apartment buildings and around 15.75 million detached and semi-detached houses in Germany. In addition, there are 2.7 million non-residential buildings. Residential buildings are classified by efficiency categories, according to their end energy demand per usable area, which is mainly heat. The energy classes are illustrated in Table 5-2.

Table 5-2 Energy classes for residential buildings.

Energy efficiency class (since 2014)	End energy demand (kWh/m²/a)
A+	Below 30
A	30 – 50
B	50 – 75
C	75 – 100
D	130 – 160
E	200 – 250
F	Above 250

Since 2020, the theoretically calculated heat demand of new residential buildings has been in the range of 45 to 60 kwh/m², which corresponds to energy classes A to B. Figure 5-6 illustrates the specific energy demands of the residential buildings in Germany according to the years of construction. Old buildings built in the years 1900 to 1980 have demands of at least 120 kWh/m², whereas buildings after 1945 represent the highest overall values of approximately 170 to 260 kWh/m².

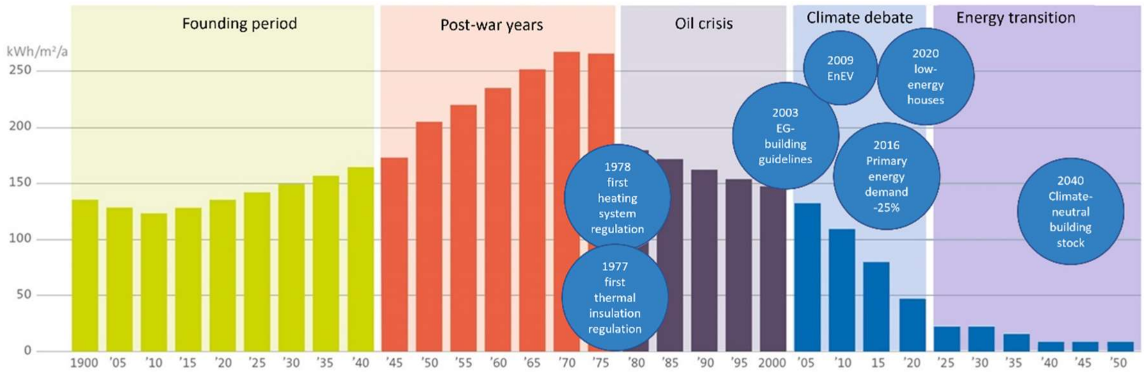


Figure 5-6: Specific energy demand for residential buildings as a function of year of construction (ASUE, https://asue.de/node/2691)

With high energy demand lowering the temperature of the supplied thermal energy is challenging. Therefore, it is important to know the current building standards.

As shown in Figure 5-7, most residential buildings were built before 1978 and thus have high heat demands. It is also noticeable that only 4 % of the buildings are younger than 13 years and thus require energy supplies below 100 kWh/m². Additionally, non-residential buildings share about 26.5% of total heated areas.

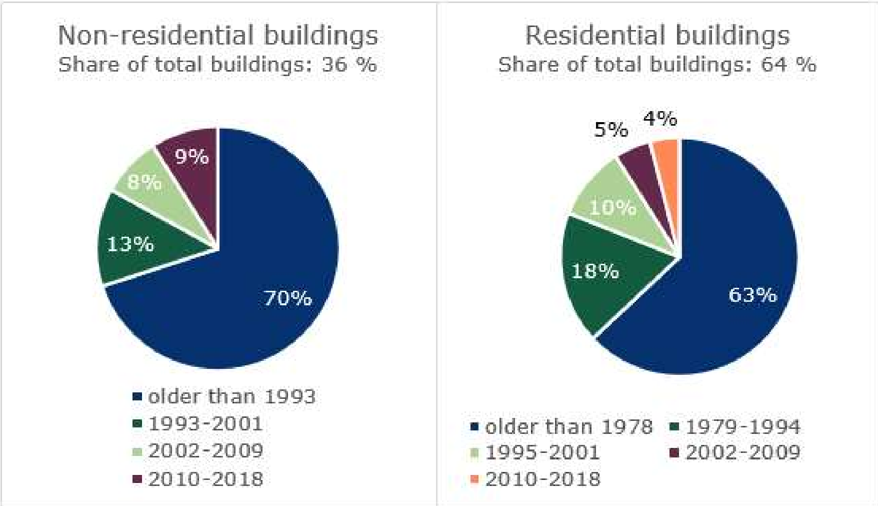


Figure 5-7: Year of construction for residential and non-residential buildings in Germany (DENA Factsheet Energieausweis 2020)

From the figures it can be concluded that there is a great potential for further energy savings in existing buildings by improving insulation. However, it must be identified for each specific building individually, if improving insulation or upgrading the heating installation (e.g., installing of a heat pump or connecting to a district heating network) should be prioritized.

In Germany, there are incentives to increase the energy efficiency of existing buildings by subsidies provided by the German bank KfW. In recent years, threshold of energy demand for which subsidies were granted have been decreased successively, nowadays reaching a primary energy demand of approximately 40 kWh/m², although this value also depends on many factors such as heating technology and insulation quality.

5.3 Current measures, tools, and incentives for energy regulation and optimization

5.3.1 Technical Guidelines

Each district heating supply company defines its own technical connection conditions (German: "Technische Anschlussbedingungen", Short: "TAB"). The AGFW published a template, the AGFW FW 515 standard. This standard form can be adapted to the respective company-specific parameters, enables the district heating supply companies to formulate their own TABs.

The TAB also specify information on the supply temperature and the maximum return temperature. The return temperature must be ensured by the design and operation of the building heating system. But even if these technical connection conditions exist, which specify the return temperatures on the customer side, they cannot be checked while in operation without appropriate measuring equipment.

An example from the district heating supplier Vattenfall Wärme Berlin, which operates a large part of the district heating system in Berlin, specifies a maximum return temperature of 56°C in its TAB. In general, they differentiate two supply areas: East and West. The Area West has a supply temperature of minimum 110°C and return temperature of 55°C (=Temperature spread of 55 K) and Area East with a supply temperature of in general minimum 135°C and return temperature of

45°C (=temperature spread of 90 K). The supply temperature is specifically defined for each sub-network and not standardized, as shown in the following table.

			Parameter zur Ermittlung der Nenndruckstufe der Bauteile von Wärmenetz, Übergabestation, Wärmeübertrager				Parameter zur Planung und Auslegung der Hausstation			
Netz-num-mer	Teilwärmenetz	Anzahl Versor-gungs-leitun-gen	max. zuläs-sige Betriebs-temp.	max. zulässi-ger Betriebs-druck	Bezugs-niveau	minimale Nenn-druckstufe	**max. Heizwasser-vorlauftemperatur der Fahrkurve** ($t_{V,max}$)	**min. Heizwasser-vorlauftemperatur der Fahrkurve** ($t_{V,min}$)	TAB-Fahr-kurve, Punkt 8.2	Mindest-auskühlung des HWD (Δtmin)
1000	FV Nord TN Reuter, Siemensstadt	3	120 °C	16 bar (Ü)	30 m ü. NN	PN25	**HZG = 110 °C KLB = 105 °C**	**HZG = 80 °C[4] KLB = 80 °C[1]**	A	55 K
1900	HN Bayernring (Tempelhof)	2	140 °C	16 bar (Ü)	15 m ü. NN	PN25	**100 °C**	**80 °C**	F	55 K
2000	HN Friedrichsfelde	2	140 °C	16 bar (Ü)	43 m ü. NN	PN25	**135 °C**	**80 °C**	B	90 K
2002	HN Friedrichsfelde TN Oberschöneweide	2	140 °C	16 bar (Ü)	43 m ü. NN	PN25	**135 °C**	**80 °C**	B	90 K
2081	Salzmannstraße (Sek. DM 16 L43WR1601)	2	140 °C	6 bar (Ü)	35 m ü. NN	PN16	**135 °C**	**80 °C**	B	90 K
2082	Dolgenseestraße (Sek. DM 18 L43WR1801)	2	140 °C	6 bar (Ü)	35 m ü. NN	PN16	**135 °C**	**80 °C**	B	90 K
2084	Michiganseestraße (Sek. DM 24 L43WR2401)	2	140 °C	6 bar (Ü)	35 m ü. NN	PN16	**135 °C**	**80 °C**	B	90 K
2085	Baikalstraße (Sek. DM 29 L43WR2901)	2	140 °C	6 bar (Ü)	35 m ü. NN	PN16	**135 °C**	**80 °C**	B	90 K
2086	Rummelsburger Straße (Sek. DM 35 L43WR3501)	2	140 °C	6 bar (Ü)	35 m ü. NN	PN16	**135 °C**	**80 °C**	B	90 K
2100	FV Klingenberg/Lichtenberg	2	140 °C	16 bar (Ü)	43 m ü. NN	PN25	**135 °C**	**80 °C**	B	90 K
2162	U-Gürtelstraße (Sek. P02WU0300)	2	120 °C	6 bar (Ü)	47 m ü. NN	PN16	**100 °C**	**70 °C**	G	55 K
2163	U-Buggenhagenstraße	2	120 °C	6 bar (Ü)	52 m ü.	PN16	**100 °C**	**70 °C**	G	55 K

Figure 5-8: Extract from the TAB of Vattenfall Wärme Berlin

5.3.2 Remote meters

In general, the EU's revised Energy Efficiency Directive (EED) requires that heating cost meters and cost distributors must be remotely readable via radio measurement technology. The aim is to provide owners and tenants with more frequent and better information about their energy consumption.

Thus, the regulation "Verordnung zur Fernauslesung von Wärmemengenzählern (FFVAV)" was taken into action on October 10th, 2021. Accordingly, the existing measuring devices must be replaced by 2026 in order to ensure remote transmission of the heating values to the company that supplies the energy to the consumer in the form of gas or district heating. The regulation includes the following requirements:

"A supply company shall provide the customer with bills and billing information, including consumption information, free of charge. At the customer's request, it shall also provide this information electronically free of charge." Typically, this information would include the consumed heat, peak heat demand, and supply and return temperatures with at least hourly resolution on a monthly basis.

This means that consumers have the option of receiving information about their heat consumption, but in most cases, if the heat supply company does not offer an application that regularly collects and displays the data, this is still done by post or electronic mail on individual request.

5.3.3 Tariff incentives

In Germany, tariff incentives are generally based on the amount of energy required. For district heating, gas and electricity supply, the specific energy price is reduced if a certain amount of energy is purchased per year. An example can be found in Table 5-3. The specific costs are reduced by 3.9% if more than 20,000 kWh are required per year. In terms of incentives to reduce energy demand, this can be seen as problematic as it could lead to higher energy consumption.

Table 5-3 Example of district heating prices dependent on the amount of energy required per year (EVO Energie EVO_AZ_PAP_Nah-Fernwaerme_2023_web.pdf (evo-energie.de))

Price component	Unit	Price	Price incl. taxes
Energy price below 20.000 kWh/a	Cent/kWh	14.88	15.92
Energy price from 20.001 kWh/a	Cent/kWh	14.30	15.30
CO_2 costs	Cent/kWh	0.98	1.05
Gas levy	Cent/kWh	0.05	0.05

When operating district heating networks, the network owner is often only aware of the consumption of major customers. As part of the transformation planning according to BEW, network-internal measurement technology will play an important role in future, so that the district heating operators can obtain a detailed overview of the network parameters to prevent supply bottlenecks, for example. The operating parameters of the house connection stations will thus be recorded, and the data evaluated. However, there are no plans in terms of regulations or policies in general to involve district heating customers in the future.

However, some district heating companies already use tariff incentives for their customers. In Table 5-4, some examples are shown. As can be seen from the data, most incentives are based on the required volume flow of the consumer. A more effective incentive is the approach of the Leipziger Stadtwerke GmbH, which relates to the return temperature. However, in each case the price reductions are always related to annual base prices which only cover a small part of the total costs, since the specific energy costs are not covered.

Table 5-4: Examples of tariff incentives in Germany.

District heating company	Type of incentive	Measured value, unit	Measure interval
Hamburger Energiewerke GmbH	Base annual price depending on connected load	Volume flow, l/h	unknown
Leipziger Stadtwerke GmbH	Base annual price depending on return temperature	below 50°C – 80% of base price 50°C to 55°C – 100% of base price 55°C to 80 °C – 140% of base price Above 80°C – 160% of base price	unknown
eins energie in sachsen GmbH & Co. KG	Base annual price depending on connected load	Volume flow, m^3/h	Each year

Uniper Castrop Rauxel	Billing price per measuring device depending on the volume flow	Volume flow, m³/h	monthly

5.3.4 Regulatory Framework

Germany's overall climate targets were specified by the Climate Protection Act in 2019. It demands carbon neutrality for all energy sectors until 2045 with an emission reduction by 65% in 2030 compared to 1990. In this context, the German government's plans foresee a doubling of the share of district heating in the heating energy mix by 2045.

To achieve these goals, the government currently increased its efforts by enactment of several laws and subsidies. The most important acts are namely the Building Energy Act, the Heat Planning Act and the Federal Funding for Efficient Heating Networks, which are described in the following sections.

In addition, the new Energy Efficiency Act (German: "Energieeffizienzgesetz") from September 2023 sets objectives for reducing energy consumption by 2030. The Energy Efficiency Act obliges authorities, companies and data centres to take energy-saving measures in line with EU requirements. Companies with a high annual energy consumption (more than 15 GWh) will be obliged to introduce energy or environmental management systems and to document and publish their energy efficiency measures in specific plans. In addition, companies must avoid generating waste heat during production processes. If this is not possible, they must use the waste heat appropriately. There are to be energy efficiency standards for data centres.

5.3.4.1 Heat planning for municipalities and cities (Kommunale Wärmeplanung, KWP) (2024)

On January 1, 2024, the Building Energy Act and the Heat Planning Act will be implemented. The Heat Planning Act sets out the framework for the step-by-step decarbonization and expansion of district heating. The aim is to have heat planning in all of Germany's 11,000 municipalities.
By then, 30% of the heating networks must be supplied with heat from renewable energies or unavoidable waste heat, and 80% by 2040. All heating networks must be climate-neutral by 2045. At least 65% of the energy supply for new heating networks is required to come from renewable energies.

5.3.4.2 Federal Funding for Efficient Heating Networks (2022)

The Federal Funding for Efficient Heating Networks (BEW) is a funding program of the Federal Ministry for Economic Affairs and Climate Protection that supports the construction and transformation of heating networks with a high proportion of renewable energy and waste heat. The BEW came into force on September 15, 2022, and replaces the previous funding programs Heating Network Systems 4.0 and Heating with Renewable Energies.

The BEW creates incentives for district heating network operators to invest in the construction of new heating networks with a high share of renewable energies and to decarbonize existing networks. Funding is provided for transformation plans and feasibility studies, new construction and transformation of existing grids, individual measures such as generators and storage facilities as well as operating costs.

The BEW consists of four modules that build on each other:

- Module 1: Concept development for heating networks
- Module 2: Investments in heating networks
- Module 3: Operating cost subsidies for renewable heat
- Module 4: Digitalization of heating networks

The funding is aimed at various stakeholders, such as municipalities, companies, cooperatives, associations or private individuals who plan, construct, operate or use heating networks. The amount of funding and the funding conditions depend on the type and scope of the project. Applications are submitted electronically via the online portal of the Federal Office of Economics and Export Control (BAFA).

Further information on BEW can be found here (in German): BAFA – Bundesförderung für effiziente Wärmenetze (BEW)

5.3.4.3 Building Energy Act (2020, update 2023)

The Building Energy Act is a German federal law that regulates the requirements for saving energy and using renewable energies for heating and cooling in buildings. It is a central component of the German heat transition. The application of the Building Energy Act started November 1st, 2020 and it will be updated in 2023. The law has the following objectives and contents:

- It combines the Energy Saving Act, the Energy Saving Ordinance and the Renewable Energies Heat Act.
- It prescribes that all new buildings must be energy efficient to a specified energy standard
- It prescribes that a certain proportion of the heat and cold energy demand must be covered by renewable energies.
- It contains regulations on the calculation of the annual primary energy demand and the thermal insulation of buildings.
- It applies to all buildings that are heated or cooled, as well as to systems of heating, cooling, ventilation and lighting technology.

5.4 Current approaches in Germany for lowering temperature in district heating systems

The district heating network operators have defined temperature limits in their technical guidelines. If they want to lower the temperature in the network, they must adjust their technical guidelines. Especially large customers in the industrial sector are dependent on certain temperatures, which have also been contractually agreed. These cannot be lowered without further action. An example from a grid operator in a large city shows that individual heating solutions (e.g., via heat pumps) would be necessary for a third of its industrial customers if the temperature in the grid is lowered. For the rest, a low temperature, e.g., by adapting the processes is possible. Network hydraulic requirements must also be taken into account. In winter, higher flow rates may be required at a lower temperature, which would significantly increase the specific pressure losses.

In a demonstration project with digital consumer substations, overdimensioning was identified in 40% of cases. This means that the capacity of the substation is above the contractually agreed capacity. In this case, it would be possible to reduce the flow and return temperature without changing the contractual output.

Typically, optimizations of required supply temperature and resulting return temperature from a given consumer installation go hand in hand and require careful consideration of the whole consumer installation. Therefore, it appears to be preferred to optimize larger consumers first, especially if they are among the few remaining consumers that require a higher supply temperature than the rest. An optimization of their whole heating system can be used as an opportunity to decrease their overall heating demand, giving an economical incentive rather than "simply lowering temperatures for the supplier".

Smaller installations, e.g., single houses, usually don't have a large impact on the resulting overall return temperature in the network. Required supply temperatures and corresponding return temperatures can be lowered by installing floor heating or suitable systems for domestic hot water heating (direct flow or electric). However, these have disadvantages as well:

- Floor heating is difficult and costly to install
- Direct flow water heating usually requires larger service pipes
- Electric water heating decreases heat demand, which is noticeable especially in summer. This effect might collide with the desire to operate "must-run" supply plants.

5.5 Translation of Danish experiences to German context

In the following section, some of the measures from the Danish experience are analysed regarding their possible realization in Germany.

5.5.1 Technical measures in the district heating system

Many networks are already being operated with optimized supply temperatures, taking into account the season, time of day and requirements of special consumers. Systems where this is not being done already lack the required incentive to do so. Existing systems are often designed around very few supply plants, with long travel times and temperature losses between production and far-out consumers. Those systems can benefit from a more spread-out production landscape or local measures to increase supply temperature for certain consumers, like bypasses.

Low-temperature base load plants appear to be rare still, but more and more heat sources with low supply temperature are being considered (industrial waste heat, heat pumps, geothermal sources and others). Pre-studies regularly combine these sources with additional means to increase their supply temperature and integrate them into the surrounding systems. Depending on the overall situation, the proposed solutions can be quite unique and creative. Economic challenges arise when base load heat sources provide more energy than needed in times of low heat demand in warm months.

5.5.2 Energy manager in buildings

A closer contact between energy supply companies and the consumers should be developed, e.g., by establishing a digital interface for tracking the individual energy demand for each household. The supplier can make use of the data measured at different locations in the network or at the transfer stations to the buildings to identify potentials for optimizing operation. Low return temperatures are highly relevant for a high efficiency of heat network operation.

Firstly, the consumers should be aware of their heat consumption and operation parameters of the district heating network they are connected to. With the installation of smart meters and by using an app suppliers could make every individual heat system transparent. This can, at least in some cases, increase interest by the consumers to reduce their heat consumption.

Secondly, incidents and potential for optimization can also be identified by the consumers themselves. The app or another way of communication channel could function as interface to the supplier to be contacted and to describe or show (e.g., by video) the issue.

5.5.3 Tariff incentives

For establishing tariff incentives as in Denmark, initially the existence of smart meters is mandatory. This measure can therefore be introduced at the earliest when smart meters are available in district heating systems.

The initial focus should therefore be on collecting data, especially from private households and not just from major customers and making it available to customers. As data becomes available, consumer installations that need optimization can be identified. However, only measuring the return temperature does not suffice for identifying potentials for reducing it. An actual optimization can only be carried out with professional assistance. This will require financial aid in many cases; either by means of tariff incentives or subsidies. Large consumers can be actively approached on a case-by-case base, by the district heating companies and energy consultancies.

Currently, smart meters are often installed primarily not to facilitate the introduction of tariff incentives, but to identify consumers who breach their existing contracts with excessively high return temperatures.

It must be noted that the way tariff incentives are introduced and adjusted in Denmark might face an additional challenge with existing contracts in Germany. This is due the possibility that clients can choose freely between supply companies to get the contract that best matches their requirements. This lowers the pressure to follow the requirements that come with the incentives of a given supply company.

5.5.4 Conclusion

In order to lower the overall return temperature in German district heating networks, three key measures have been identified. First, there are technical solutions for the further improvement of the district heating networks themselves. Second, consumers should be included as key stakeholders in the process of transformation of heating networks towards net-zero emissions, which has not been done so far on a large scale. And third, the digitalization of the substations in the buildings has to be focused to provide the possibility for the consumers to monitor their energy demand as well as return temperatures and thus that supply companies can effectively offer tariff incentives for lowering the return temperature. While the technical measures are more likely long-term measures, the other two should be implemented in short term.

6. Experiences from other countries

In the following section the current state of district heating in terms of lowering the system temperatures, is described briefly for a few selected countries. Further, the most relevant challenges in transitioning to low temperature is identified.

6.1 The United Kingdom

The market share of district heating in the UK is almost zero. The dominating heating form is individual gas boilers, mainly based on domestic gas resources. Therefore, the potential efficient heat sources from power generation, waste incineration and industries are almost not utilized. Several new waste incinerators and a biomass fuelled power plant are established far from the large urban areas, and the surplus heat is wasted.

The cheap domestic gas has influenced the heating systems in buildings. Many apartment buildings do not have centralized heating systems, but gas boilers or electric heating in each apartment, and the heating systems are in general not designed for low temperatures.

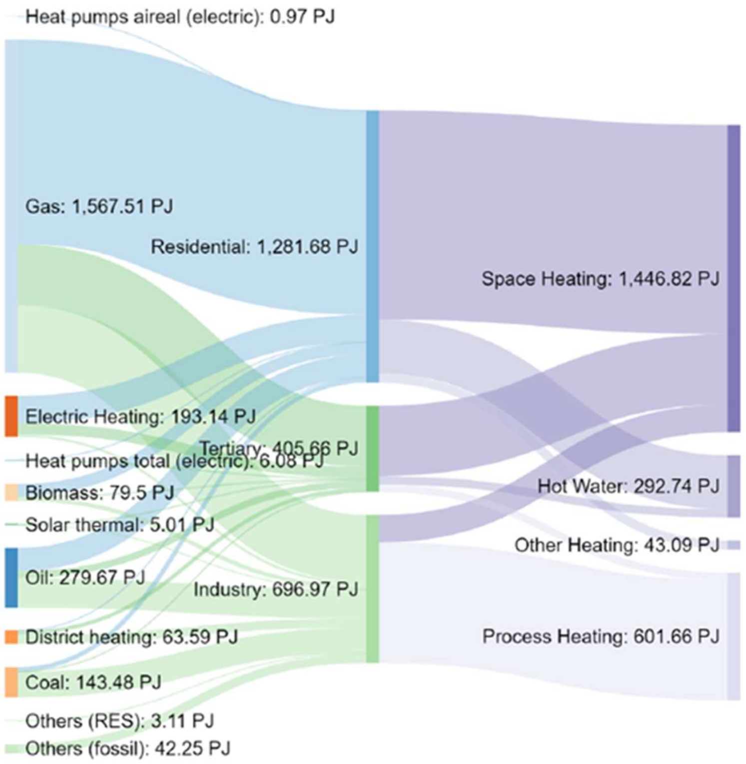


Figure 6-1 Sankey diagram of energy flows for heating purposes in United Kingdom in 2015 from We district D2.3 District Heating and Cooling Stock at EU level

Due to low gas prices, the building stock has not been energy renovated as much as in Denmark, and the thermal comfort is in general of lower quality due to extensive use of night set back in buildings with little insulation. This is one of the greatest barriers against efficient use of low temperature heat sources via low temperature district heating in the UK.

However, there are a growing number of new small-scale district heating projects based on various low temperature heat sources, e.g., large heat pumps which deliver cooling to the metro system and thereby utilize low temperature surplus heat. District heating is of interest for campus owners and developers, which can see the benefit of optimizing the use of energy for the buildings and the district heating infrastructure at the campus.

6.2 Poland

The district heating in Poland covers 25% of the total demand for space heating and domestic hot water, and individual coal boilers cover most of the remaining heat demand.

Around 66% of the district heating is supplied from efficient coal fuelled CHP plants in the larger cities. Therefore, Poland has like Danmark had an incentive to establish central heating in the buildings to use the district heating and the coal, and there have due to the CHP been incentives to operate buildings and district heating at low temperatures most of the year.

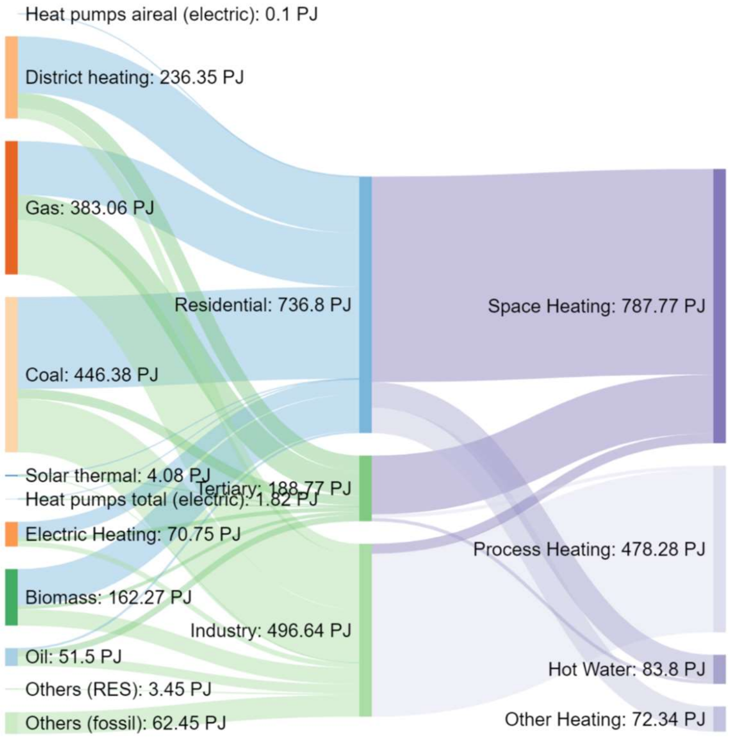


Figure 6-2 Sankey diagram of energy flows for heating purposes in Poland in 2015 from We district D2.3 District Heating and Cooling Stock at EU level

The district heating in Poland was before 1990 established in most urban areas. This was very efficient and clean compared to individual coal boilers, but the district heating operated at high temperatures and the quality of the network and substations were bad, characterized by short lifetime and large water and heat losses. The insulation standard of buildings was also poor, which is a prerequisite for lowering the district heating temperatures.

Since 1990 the district heating systems and the buildings have been renovated and the district heating is in a transition towards lower temperature and further expansion. Poland currently has several projects for large heat pumps, from industries and wastewater in the pipeline and this stimulates a measure for lowering the temperatures in buildings and for integrating the low temperature sources in the district heating. Moreover, there is a strong motivation for increasing the market share of district heating to use coal an efficient and clean way in the short term and to introduce renewable sources like biomass and large heat pumps.

The energy consumption of domestic buildings is high. Only 5% of residential and public buildings achieve the energy standard allowed by modern construction and heating technologies, see the figure below.

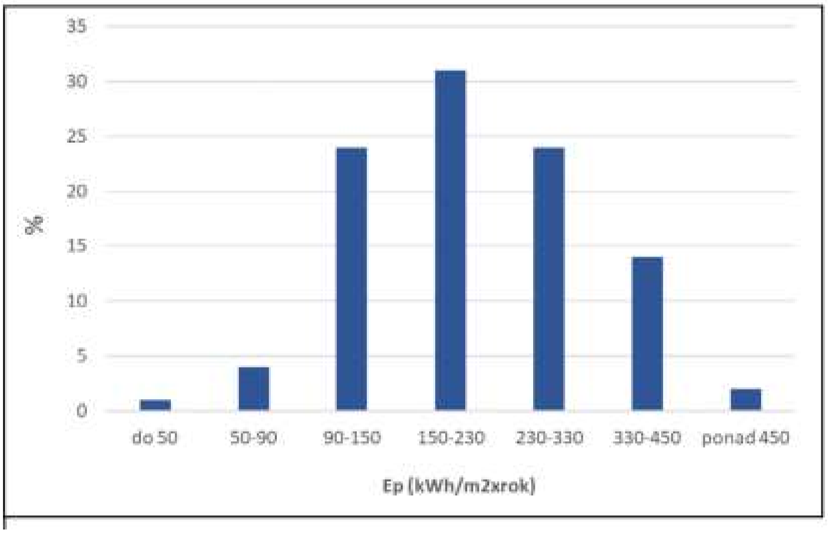


Figure 6-3 Estimated distribution of number of buildings vs energy efficiency ranges Source: KAPE | Ministry of Development and Technology

The current supply and return temperatures for more than 350 district heating companies can are registered in Figure 6-4 and Figure 6-5, which shows that there is currently great variations in supply temperatures in Polish district heating systems, however the return temperature is fairly stable between 45-55°C. This proves that there is great potential for further optimization of the district heating temperatures in Poland.

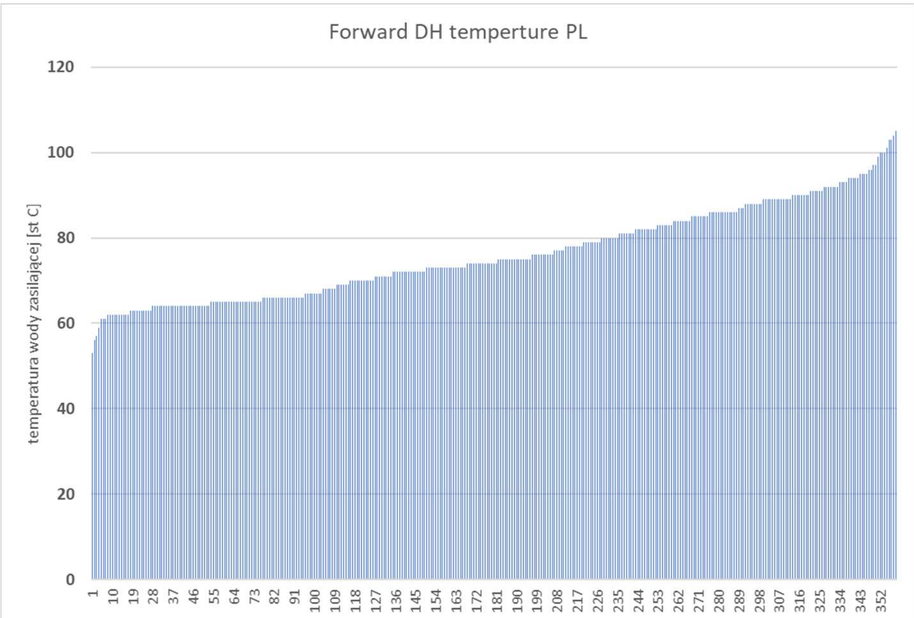


Figure 6-4 Supply temperatures in Polish district heating

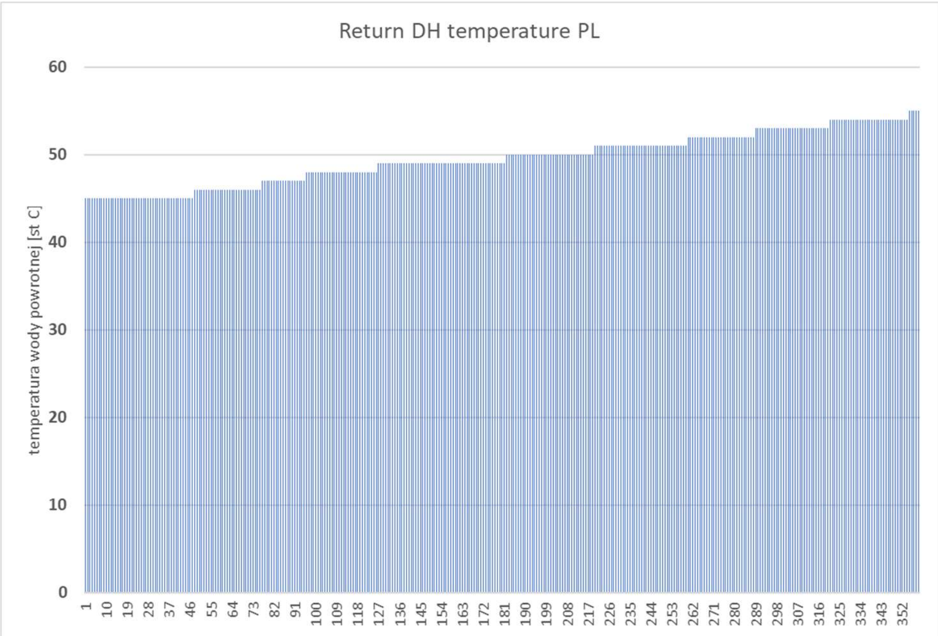


Figure 6-5 Return temperatures in Polish district heating

6.3 The Netherlands

The district heating in the Netherlands covers only a few percent of the market for space heating, which is around 550 PJ. However, the market for process heating, mainly greenhouses is around 400 PJ and around 15% of this market is registered as district heating see Figure 6-6.

The Netherlands was, like Denmark, hit hard by the first oil crisis but decided to replace oil with mainly domestic natural gas from Groningen. Therefore, the market share of district heating is low, and some apartment buildings are still heated by individual gas boilers in apartments.

However, the Netherlands are leading in utilizing the ground water for heating and cooling in combination with heat pumps. This has paved the way for low temperature heating systems in buildings and many ATES plants at the building level.

The Netherlands is also leading in efficient greenhouse infrastructure. A Typical greenhouse cluster includes several huge greenhouse industries, who have formed a co-operative to take care of services which are of common interest, e.g., a local power grid, a local district heating grid and other services. The co-operative operates the grids and can take care of large base load plants, e.g., deep geothermal. Each industry has own back up with gas boilers and gas engine.

The frequency of earthquake due to gas extraction in Groningen increased dramatically after 2010 and was the main reason for changing the energy policy with the aim to half the gas consumption. The Paris agreement and the shortage of natural gas has recently added one more reason to reduce the consumption of gas.

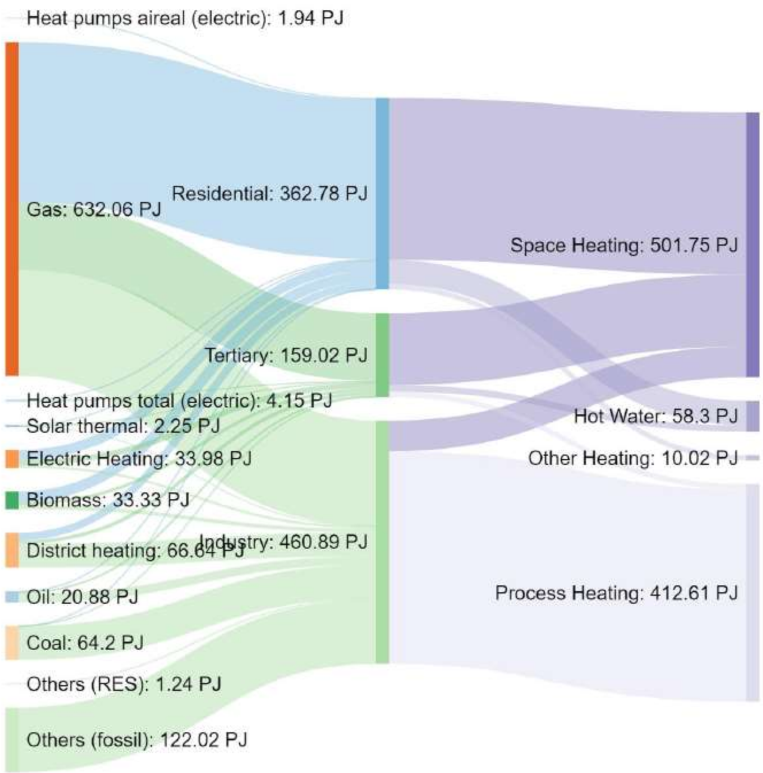


Figure 6-6 Sankey diagram of energy flows for heating purposes in the Netherlands in 2015 from We district D2.3 District Heating and Cooling Stock at EU level

This has stimulated the development of district heating based on CHP and large heat pumps. A good example is the district heating company in Groningen.

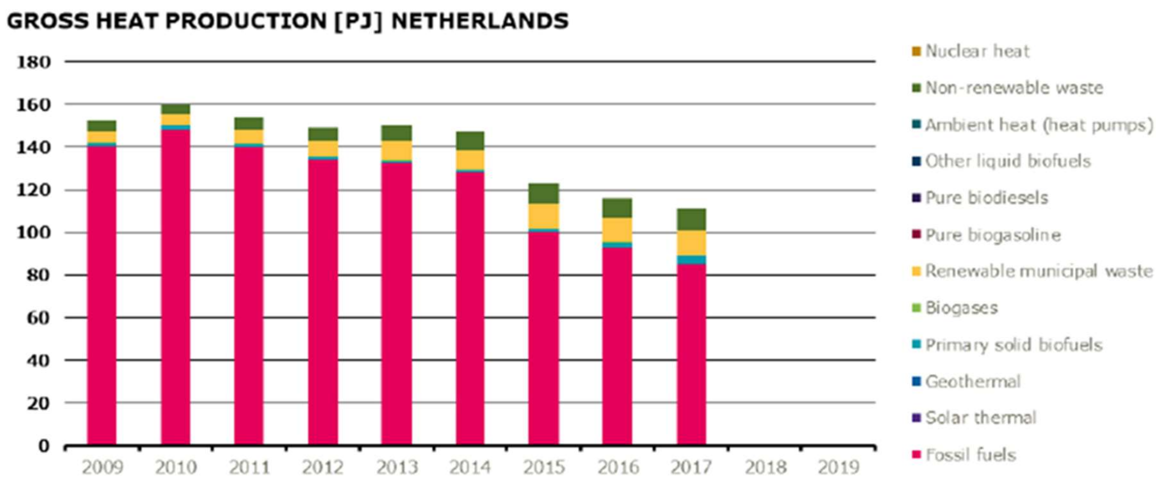


Figure 6-7 Gross heat production by fuel and year in The Netherlands