Article

Distribution of district heating: 4th Generation

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4^{th} Generation

District heating (DH) is here to stay. Looking back on the history of DH it goes quite some years back. During the years it has developed to fulfill the demands as they came up, typically driven by the demand for reduced investment and heat costs, but also lower equipment space demands, concerns of energy efficiency, environment, longer life-time, and lower fire risks. The development has been categorized in 4 generations which each indicate major changes in the technology. Currently most DH schemes being operated are categorized as being at the stage of 3^{rd} generation DH technology starting its transition to the 4^{th} generation to address the challenge of the future non-fossil and renewable based energy system. To meet the demands of the future energy system, existing DH schemes will develop into the next generation, the 4^{th} and the most advanced generation with more focus on the integrated energy system including buildings and integration of low quality fluctuating renewable energy sources and surplus heat. The intention of this series of articles is to describe the typical principles of each generation and discuss the motivation behind each generation and the main development drivers.

The fourth generation

Transforming the energy system towards a sustainable system, based on high share of fluctuating renewable sources for heating and cooling, and at the same time reduced specific building energy consumption as well as supply and return temperatures, calls for further development of the DH and cooling concept. This development path is characterized as the 4^{th} generation DH.

The concept of DH has to be seen as an integrated part of the future smart energy system, including also district cooling, electricity and gas grids as well as buildings HVAC systems. The technology of DH must develop and be flexible to effectively position DH into the future smart energy system. Even though some aspects of the 4^{th} generation DH concept are applied in existing DH systems today, the general implementation or the period of best available technology is expected to be from year 2020. A graphical comparison between the four generations of DH concepts / technology is shown in figure 1. The figure illustrates the typical applied technologies, operational profile of each generation and the period of best available technology.

In the future a higher pressure will be on utilizing low grade renewable and waste heat sources to a larger extend. A common denominator for renewable low grade heat sources is that they tend to be difficult to access on a building level, either due to location, required investments or in general the economy of scale factor. To overcome the issues with both utilizing the low temperature fluctuating renewable heat sources and the reduced heat demand of buildings the district heating networks can take advantage of the low-energy buildings and operate at even lower supply temperatures than commonly used today or applied for 3^{rd} generation DH systems. The reduced supply and return temperature not only increases the efficiency of the system but also increases the flexibility of the district heating system towards potential new heat sources and towards the whole energy system.

Part of smart energy system

A smart energy system can be defined as a system where electricity, gas, heating, cooling and transport systems in cities are combined and coordinated to utilize synergies between them in order to achieve an optimal solution for each sector as well as the most energy and cost effective solution for the overall energy system. Considering the energy flexibility each sector brings into the system will be a central mindset for the future. The energy flexibility is especially important due to the common intermittent nature of renewable sources and in this respect short and long term energy storage become important.

Sources of energy

The concept of DH allows utilizing any kind of thermal energy, including CHP, surplus heat from industry, heat from waste to energy, geothermal, solar thermal and fluctuating electricity via heat pumps and electric boilers. Besides this, the process of converting e.g. solid biomass fuels into liquid or gas phase fuels for the transport sector produces heat that can be also utilized in DH. In Denmark the high penetration of wind turbines have resulted in overproduction of electricity at periods of high wind speeds. The short term excess electricity could be absorbed by electric boilers and the general high level of wind based electricity could be used to supply large scale heat pumps producing heat for the district heating systems while at the same time utilizing heat storages if the heat

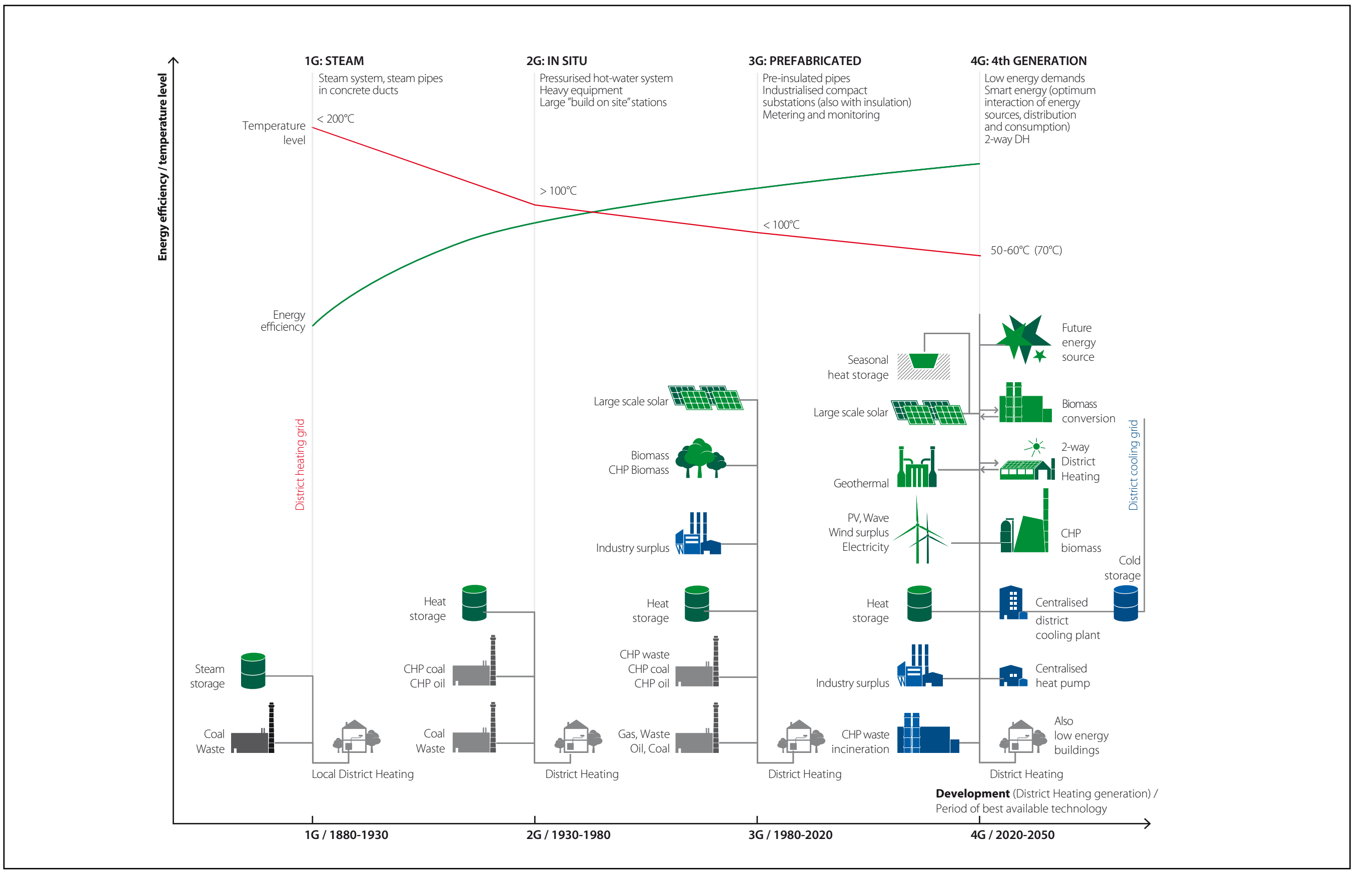

FIGURE 1: Illustration of the concept of 4th Generation DH in comparison to the previous three generations

production is higher than the demand. Thus combined with the existing CHP plants the district heating becomes a "very intelligent electric consumer" responding on the weather conditions.

Geothermal heat at temperature level suitable to 4GDH can be accessed in most places with 2.000 to 3.500 meters deep boreholes. Currently there are more than 240 geothermal DH systems running in Europe. A particularly interesting heat source for DH is district cooling. By developing DH in symbiosis with district cooling the heat extracted from buildings by the district cooling system can be used as an heat source for the district heating system, which results in very high efficiency of the cooling heat pump.

Storages

Large heat storage tanks were introduced in the second generation of DH and it is a natural vital element in all third generation DH systems. In the fourth generation system, they will be more important and even larger and supplemented with several other types of thermal storages.

Large storage tanks can also be designed for cold water for district cooling systems. One advantage of such a chilled water tank is that it can reduce the maximal chiller capacity by leveling the daily fluctuation. Another advantage of large storages is that the electric chillers or heat pumps will be able to respond on the electricity prices and produce the cold or heat at periods of low cost electricity. That is in particular important in warm climate zones. District cooling with chilled water storages benefits from economy of scale and is probably the best way to mitigate brown-outs at e.g. 1 pm due to many uncontrolled electric chillers.

To compensate for the intermediate availability of renewable sources and an increasing share of renewable energy for heat and electricity, even seasonal heat storages can be applied. For instance, Vojens consumer owned district heating company in Denmark, put a 200.000 m^3 underground thermal storage into operation in 2015 to increase the utilization of heat from a solar thermal plant from 20% to 50% of the annual heat demand. Thereby Vojens DH utility is well prepared for installation of electric boilers and heat pumps that can

FIGURE 2: Vojens solar heating plant and the storage pit under construction

take advantage of future fluctuating electricity prices.

In combined DHC systems the Aquifer Thermal Energy Storage (ATES) is of special interest, in particular in case it is designed in a system in which the same heat pump is providing:

1) The cooling peak capacity is supplied by the ground source heat pump, which replaces the peak load chillers and stores heat in the ground for the heating period
2) The heating peak capacity is supplied by the ground source heat pump, which replaces the peak load boilers and stores cool in the ground for the cooling period.

By this four huge benefits are realized:

1. A heat storage of low temperature heat
2. A cold storage at low but use full temperature
3. A district cooling peak plant and
4. A district heating peak plant

In case of low temperature consumers and operation of the DH system at 70°C during peak demand, the efficiency of the heat pump will be fairly high. This further reduces the reliance on fossil based heat sources, which are typically supplying the peak demand.

The combination of:

- Efficient HVAC systems for low temperature heat and high temperature cold
- DH grids with hot water storages, tanks and pits
- DC grids with cold water storages, tanks and pits
- Heat pumps
- Heat pumps with ATES
- Electric boilers
- Fast regulating CHP plants
- Biomass boilers

has the ability to use huge amounts of electricity when the prices are low and avoid using electricity in longer periods of high electricity prices – even weeks. This system has the same impact on the power grid as an electrical battery, but at fraction of the cost, even below one hundredth of an electrical battery. This kind of an innovative idea could be called a thermal/electric battery.

An obvious next stage is that such energy efficient and cost effective battery will be a driver for extending the DH&C grids to replace uncontrolled electricity consumption from small heat pumps, chillers and electric heating.

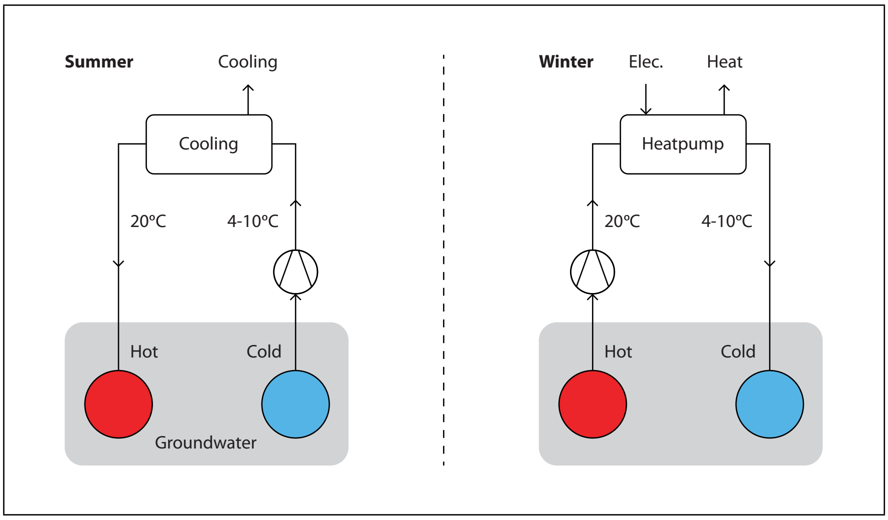

FIGURE 3: Aquifer thermal energy storage with heat pump

Distribution

The introduction of lower supply temperatures will at the one hand increase the needed flow capacity, but at the other hand also energy consumption is expected to decrease due to energy renovation of existing buildings and due to lower energy demands for new buildings. To overcome the hydraulic bottlenecks in the network booster pumps can be located decentral in the network to a higher extend than applied today. The benefit of lower supply temperatures is the reduced thermal distribution losses and the increased integration of low grade energy sources.

Building installations and substations

The main criteria when it comes to the building installation is the ability to operate at low supply temperatures for space heating and DHW and at the same time reduce the return temperature. This is especially important for existing buildings, which will be the majority of buildings many years ahead. For energy renovated and new buildings the building heating installation has to be designed to fulfill the requirements. Heating supply temperature below 40°C for floor heating or supply temperature of 50°C for radiator based space heating could be a relevant future demand. In the period of high heat consumption the supply temperature can be increased. Studies have shown for Danish one family houses build in 1970 the supply temperature for space heating can be as low as 50°C during 79% of the year, without any energy renovation required.

Regarding DHW, one way to reduce DH supply temperature is to reduce the DHW temperature. However, when reducing the DHW temperature special considerations should be put on the hygienic aspect regarding the legionella bacteria. One way to reduce the risk of these bacteria is to minimize the volume of water in the DHW system and make sure there is no still standing water. The best way to achieve this is to use instantaneous heat exchangers for DHW preparation, with special focus on the DHW volume in the piping system. For larger buildings this means decentralized instantaneous preparation of DHW in each flat by the flat station concept. At the same time as the system volume is minimized it becomes important to use highly efficient heat exchangers to reduce the temperature difference between the supply and the DHW temperatures.

FIGURE 4: y-Booster substation installed in a test house in the Northern Copenhagen area.

By introducing the concept of boosting the temperature locally, the temperature link between space heating and DHW preparation can be disconnected and the supply temperature of the DH system can be reduced to the temperature requirement of space heating system. First projects with decentralized electric boosting of the DH supply temperature have been already launched. The temperature can be boosted on the supply side or the DHW side and the boosting can be done either by direct electric heater or by a heat pump. Depending on the chosen solution primary or secondary side storage tanks can be applied.

The concept of boosting the temperature for DHW is very interesting, especially seen in the perspective of flexible use of heat and electricity. But also a number of pilot projects have been made supplying existing and new low-energy buildings with low-temperature DH. One example is the DH system in Lystrup/Denmark. In Lystrup a group of 41 row house flats where successfully supplied with 50°C DH without decentralized boosting of the temperature.

The synergies between heating and cooling can also be utilized in the building HVAC systems. Central hot and cold water pipe systems in a building can e.g. provide heating in winter and cooling in summer by the same ventilation coils and wall, roof and floor tubes and thereby improve thermal comfort and return temperatures.

Intelligent control

The common way of controlling the heating system is by thermostatic radiator valves or thermostatic floor heating valves in combination with a weather compensator (building supply temperature is controlled according to the outdoor temperature).

FIGURE 5: Low temperature DH supply for an area in Lystrup/Denmark. Construction site and area plan.

For the 4^{th} generation DH, the control will not only focus on the static heat demand of the buildings but also on the energy flexibilities, e.g. provided by the passive thermal masses in the building or by a heat storage capacity. The aim is to avoid expensive and inefficient peak load boiler operation, but also to bring the energy flexibilities in to play when dynamically optimizing the energy system operation across the energy carriers. The intelligent control will be based on model predictive control principles, where indirect incentives like variable prices for energy will be a part of it.

Planning, cost and motivation structures

An important aspect in regards to realizing the 4^{th} generation DH concept is to ensure suitable planning, cost and motivational structures in relation to the operation as well as to strategic investments. Beneficially investments could be done by multi-purpose organizations, able to identify the value of integrated smart energy systems. This is often in contradiction to the common situation today, where single-purpose organizations are owning and operating the systems.

Benefits

DHC systems have an important role to play in the future renewable energy system, especially providing the capability of integrating intermittent renewable and low grade energy sources at competitive costs. Further energy flexibility across the energy carriers or sectors have to be integrated, as well as lower heat demands has to be taken into account. To meet these demands of the future, the concept of DHC has to develop. The 4^{th} generation DH is outlining a path to go regarding the needed development for the future.

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