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The benefits of low-temperature district heating and geothermal heat sources

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The benefits of low-temperature district heating and geothermal heat sources

Abstract

In light of the continuous requirements for increased energy efficiency and utilization of renewable energy sources for the future it is relevant to increase focus on the combination of geothermal heat sources and low-temperature district heating (DH) systems, also referred to as the 4th generation DH.

To maximize the utilization of low temperature renewable geothermal heat sources, the DH networks can take advantage of the reduced heat demand of buildings due to renovations by operating at low temperatures. Improving the DH system and building installations to be able to be operated with reduced supply and return temperatures not only increases the efficiency of the DH system but also significantly increases the amount of feasible geothermal sources. Reduced supply temperature will further increase the efficiency of combined geothermal and heat pump plant, where electrical heat pumps are used to enhance the temperature of the geothermal plant. Reduced reinjection temperature will increase the efficiency of the geothermal as less pumping is needed to extract the same amount of heat.

The paper includes a description of the main characteristics of Thisted DH system including the geothermal system. The benefits of operating Thisted DH system at low temperatures are addressed in regards to distribution losses as well as reflected on the efficiency of the geothermal plant.

When reducing the DH network temperatures special considerations needs to be made regarding the design of the DH network and the building installations.

The conclusion is that the concept of low-temperature DH in combination with geothermal heat sources can be an important player for meeting the goals of limiting greenhouse effects set forth at the COP21 meeting and a feasible way towards achieving the future sustainable renewable energy system.

Introduction

Transforming the energy system towards a sustainable system, based on high share of renewable and often fluctuating renewable sources is a challenge. The district heating concept in general holds the key to address the fluctuating nature of renewables as well as utilizing low temperature renewable sources in a large and sustainable way. DH needs to evolve to address the fact that the building energy consumption is being reduced by energy renovations, which puts up challenges for the sustainability of traditional DH systems. To allow maximal utilization traditional DH temperature levels need to be reduced, which conveniently also solves the challenge of reduced energy demand in buildings. This development path is characterized as the 4th generation DH [1-5].

Geothermal energy is a stable and secure renewable energy source. Almost independently on locations, geothermal energy can be found with sufficiently high temperature for fulfilling space heating demands. A great case can be found in Paris where a total capacity installed is 270 MWth. In case of low temperature geothermal sources heat pumps can be used to lift the temperature to suitable levels, as is done in Thisted, Denmark. Currently there are more than 240 geothermal DH systems running in Europe. Perhaps the main challenge with utilizing geothermal energy is that

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it is not enough to find sufficiently high temperatures, it is generally preferred that there is an underground water stream to replenish the extraction well. If possible the geothermal water should be pumped back down to an upstream location to prevent drying up the underground water reservoir as well as getting rid of the geothermal fluid. The process of finding suitable locations for boreholes as well as drilling and building of surface plant is still expensive. Furthermore, the risk of reduced heat potential than estimated by geological surveys still exists. The above-mentioned challenges, among others, have resulted in that utilizing geothermal energy on a grand scale is not main stream, even though geothermal energy has the potential to achieve tremendous reduction in fossil fuels usage. A more industrialized and standardized large scale exploitation will lead to reduced levelized cost of energy (LCOE) in the future.

The way forward for successful grand geothermal utilization can only be achieved in combination with DH networks, preferably of the 4th generation. By applying DH networks the plant capacity can be dimensioned as a base load provider to ensure very high utilization throughout the year, which results in low investment costs per energy unit.

Low-temperature DH cases in DK

Number of pilot projects have successfully been made supplying existing and new low-energy buildings with low-temperature DH. One example is the DH system in Lystrup/Denmark, see Figure 1. In Lystrup a group of 41 new row house flats were successfully supplied with 50°C DH, without decentralized boosting of the temperature. To successfully run with the low supply temperature instantaneous domestic hot water heat exchangers were applied. The heat exchanger applied had sufficient thermal length to be able to produce 47°C domestic hot water at a supply temperature of 50°C, while still having a low primary return temperature. For the heating circuit, radiators were installed with sufficient area for operating at 50/25°C supply/return temperature at design load.

The outcome of the project was very positive with a thermal distribution loss of 17%, which is to be considered low, when keeping the design energy consumption of 6 MWh/year/flat in mind. A contributing factor was the design of the DH network with up to 2 m/s media velocity and pressure head of 6 Bars. In case of traditional design rules for media velocity, operation pressure and temperature levels the thermal distribution loss would have been around 40%.

Another example is a house area located in Sønderby/Denmark. The area includes 75 one-family houses build from 1997, see Figure 2. Before the system renovation, the houses were equipped with domestic hot water storage tanks, which required high temperature supply. The renovation included new building level substations including instantaneous heat exchangers with long thermal length for domestic hot water preparation, replacement of the DH distribution pipe network. To maximize the capacity of existing city wide DH network the supply to the Sonderby area was mainly taken from the return pipe of the existing DH network. The houses were equipped with floor heating with maximum operating temperature of 40°C, which fits well to the low temperature operation. The results showed that it is possible to operate the new system at supply temperature of 55°C, reducing the thermal distribution loss from 41% to 14% compared to the old DH system. On an annual basis 80% of the supplied energy came from the return line of the city DH system.

The main learning from low-temperature DH demonstration projects have been that the DH network must be carefully designed to reduce the distribution heat losses. This includes optimizing the pressure head utilization in terms of high media speeds and specifying pre-insulated DH pipes of a high insulation class [6]. On the building level, the substation should be pre-insulated and domestic hot water should be prepared by instantaneous heat exchanger with a long thermal length. A logarithmic temperature difference of not more than 5-7°C is recommended [7,8]. Besides this, the control valves should include automatic hydraulic balancing, e.g. by means of combination valves. Hereby hydraulic balancing of the DH network is secured. A careful commissioning, both initially and periodically of the system is needed to secure the continuous optimal performance.

The cases above focuses on one-family houses/row houses. In case the buildings are multi-family houses, the concept of flat stations can be applied. The concept is to have a substation in each apartment, where fresh domestic hot water is prepared for each flat at the time of usage. Hereby only a small volume of domestic hot water is hold

FIGURE 1: Low-temperature DH supply for an area in Lystrup/Denmark. Construction site and area plan

FIGURE 2: Typical one-family house and plan of the low-temperature DH network supplying the Sønderby/Denmark area (75 houses).

up in the pipes, leading to a higher level of hygiene e.g. in relation to bacteria growth, such as the legionella bacteria. As can be seen from Figure 3 the flatstation concept reduces the number of distribution pipes in the building from 5 to 3 compared to the traditional distribution system.

A major benefit of the flat station concept is that it makes multi-apartment buildings suitable for operation at low DH supply temperatures, due to the reduced risk of bacteria's in the domestic hot water system. The flat station concept is also a good option when renovating older buildings, leading to energy savings due to reduced hot distribution pipes and better match between supply and demand through individual decentralized control options for the inhabitants [9].

The DH system of Thisted

Thisted is located in the North of the Danish mainland Jylland. The Thisted DH company was established in 1961 and has today an annual heat delivery of 202 GWh and is serving 4500 households, which corresponds to 89% of all households in the city. The peak heat load demand is in the range 60-70 MW. The share of renewable and recycled energy is 99,25%, whereas waste incineration counts for 61,5%, straw incineration 24% and geothermal heat 13,75%. In 2015 the DH net operating temperatures are typically 76/43°C in the summer period and 78/40°C in the winter period, approximately 10°C lower than what it was in 1984. The annual thermal distribution loss was around 13,7%. For increasing the system efficiency the future vision is to reduce the operating temperatures further, along with the expected future energy renovations of the connected buildings.

The geothermal plant in combination with absorption heat pumps, Figure 4, has been in operation since 1984 and was the first of its kind in Denmark. The wells are 1,3 km deep and are entering the Gassum formation. The driving energy for the absorption heat pump is from waste and straw incineration. The geothermal source temperature is 44°C and is typically reinjected at a temperature of 12°C after the heat extraction in the absorption heat pump. There are currently 2 absorption

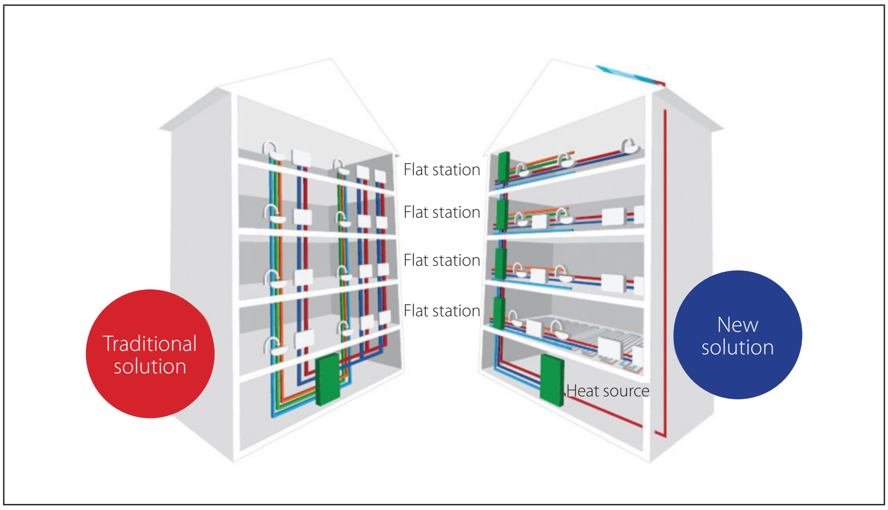

FIGURE 3: Traditional solution and flat station solution. Flat station concept is independent on the heat source type.

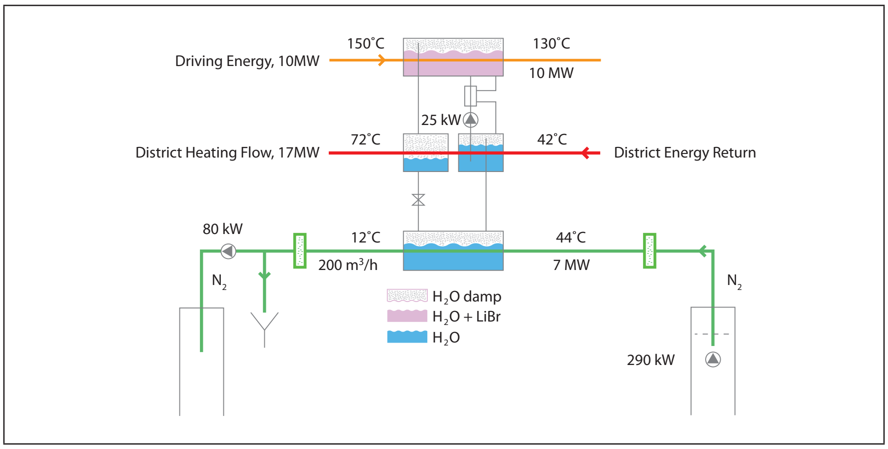

FIGURE 4: The principal layout including main technical data for Thisted geothermal plant including absorption heat pump.

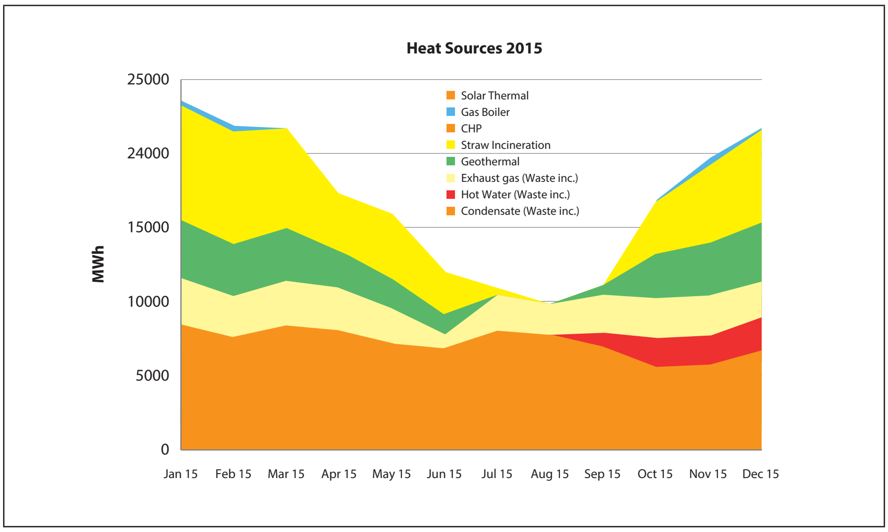

FIGURE 5: Fuel sources and yearly distribution for Thisted DH.

heat pumps installed. The first one has a capacity of 2,6 MW and the second one a capacity of 4,2 MW. A third is planned to be installed in 2017 with a capacity of 2 MW.

As it can be seen from Figure 5, the baseload is waste incineration, and sufficient energy from this source is available during the summer months, leading to the shutdown of the geothermal plant during that part of the year. Besides this the remaining energy is mainly coming from straw combustion and finally a very small share of gas boiler and solar heat contribute to the system.

The DH network design level is PN10 and building heating circuits are directly connected to the DH network. The domestic hot water is prepared by instantaneous heat exchangers, which as mentioned earlier, is the right solution for low-temperature DH operation.

Synergies between Geothermal energy and Low-Temperature DH in Thisted

The synergies between low-temperature DH and geothermal heat can be split into the benefits for the DH network system and the benefits for the geothermal system. In table 1, the focus is on the DH network system, where the impacts of reduced DH net temperatures are in focus.

In this case, it's assumed the DH net temperatures can be reduced in the summer period from 76/43°C to 60/35°C and from 78/40°C to 65/35°C for the winter period. Given the new temperature levels the temperature reduction alone would lead to an annual thermal distribution loss saving of 20%, corresponding to 3% of the total energy demand for Thisted utility. The reduced temperatures also mean a reduced dT between DH flow and return, leading to a higher flow and hence a higher pump energy consumption. Anyhow this higher pump energy consumption is negligible compared to the thermal distribution loss reduction, therefore it's not stated specifically in Table 1.

When reducing the DH return flow temperature, the impact for the absorption heat pump is a reduced reinjection temperature for the geothermal water. Hereby the capacity and the energy extraction from the geothermal plant is increased. By reducing the DH return temperatures as stated in Table 1, the geothermal water will be returned at 3°C lower temperature, which leads to an increase of 10% of the geothermal plant capacity, corresponding to a yearly additional energy of 2 GWh or 1% of the yearly demand for the utility of Thisted. Another potentially positive factor when reducing the DH flow temperature is the minimum needed heat pump driving temperature. This can typically be reduced in the same amount as the DH flow temperature. In the specific case of Thisted this anyhow has no real value, since a high driving energy temperature is available. In other cases it could be more critical, e.g. in case of costs of running the drive energy source at higher temperatures then otherwise would be needed. The impact on the geothermal operation can be seen in Table 2.

Situation Today		**LTDH scenario:**
DH net		
Energy an net	201500 MWh/y	195845 MWh/y
Thermal dist. losses	13,7%	10,9%
Thermal dist. losses	27600 MWh/y	21945 MWh/y
Energy consumed	173900 MWh/y	173900 MWh/y
Geothermal share	13,75%	
Trench length total	220 km	
T DH flow summer	76°C	60°C
DH return summer	43°C	35°C
T DH flow winter	78°C	65°C
DH return winter	40°C	35°C
T soil	8°C	8°C
Thermal distr. Loss saving (factor)		0,20 [-]
Saved therm. dist. loss		**5655 MWh/y**
Saved energy an net (factor)		0,03 [-]

TABLE 1: Impact on energy saving by reducing the DH net temperatures.

Situation Today		**LTDH scenario:**
Absorption HP:		
COP	1,7 [-]	1,7 [-]
Abs. HP driving temp. min.	120°C	105°C
Geothermal extraction temp.	44°C	44°C
Geothermal reinjection temp.	12°C	9°C
Increased capacity from geothermal well		10% 0,7 MW
Additional Energy from geothermal well		**1939 MWh/y**

TABLE 2: Impact low-temperature DH operation has on geothermal system performance, incl. absorptions heat pumps.

Discussion

The main challenge looking forward is the reduction of the DH net temperatures. Looking historically on the temperatures they have been going downwards and it has been shown that it is mainly a matter of continuous focus and efforts on the short and long term. For Thisted utility the DH return temperature has been reduced by approx. 10°C since 1984, and the goal is to reduce the temperatures further.

On the short-term, monitoring of the building energy meter with focus on weighted return temperature is relevant and widely applied. This temperature is the basis for a bonus system, motivating the users to reduce their return temperatures. In case the surface of the radiators is not sufficient for obtaining a low return temperature, the most exposed radiators can be replaced with larger ones. In the case of underfloor heating, the supply temperature is of no issue. Investigations have shown that for a normal Danish one-family house from 1970, only 8,1% of the duration of heating season the radiators need supply temperatures higher than 55°C. In case of installed new windows this is reduced to 1,8% [10]. The general learning has been that existing radiators are sufficient for running with low-temperature supply most of the heating season.

For the preparation of domestic hot water it is a matter of the thermal length of the installed heat exchanger, in case it is not sufficient the heat exchanger can be replaced with a suitable one. Important here is to specify heat exchangers with long thermal length even if the DH supply temperatures are not yet reduced to low temperature level. By starting already today specifying heat exchanger with long thermal length the DH system is made ready for reduced supply temperature once the time comes for lowering the supply temperatures.

In the longer run building energy renovations, like replacement of windows and typically thermal insulation of roof leads to a reduced energy consumption, allowing reduction of the DH net temperatures. Low-temperature DH focuses on the general temperature level, but rising the temperatures in the network when the ambient is very cold is an obvious option to optimize the network investment and operational costs.

Conclusion

The combination of low temperature, or 4th generation DH, and geothermal heat sources is a good match leading to increased efficiency of the system, including reduced thermal distribution losses of the DH network and a higher utilization of the geothermal plant.

In the case of Thisted applying 4th generation DH concept is estimated to reduce the thermal distribution losses by 20%, corresponding to 3% of the yearly heat demand of the utility. Due to the reduced reinjection temperature of the geothermal plant, the capacity is increased and so is the yearly delivered energy from the geothermal plant. The increased capacity is estimated to be 10%, corresponding to 2MWh/year of energy.

More general the conclusion is that the concept of low-temperature DH in combination with geothermal heat sources can be an important player for meeting the goals of limiting greenhouse effects set forth at the COP21 meeting and a feasible way towards achieving the future sustainable renewable energy system.

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