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District heating substation
with electrical heater supplied by 40°C ultra-low district heating

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District heating substation with electrical heater supplied by 40°C ultra-low district heating

It is a fact there is abundance of low-temperature renewable energy sources that are waiting to be utilized. The limiting factor for taking advantage of those heat sources has historically been the temperature requirements of space heating installations. With the increased number of low-energy buildings and floor heating installations the requirements to the supply temperature has been decreasing, which opens up the possibilities for exploiting the unused low-temperature energy sources. In fact it is expected that in the near future the limiting factor for reducing the district heating supply temperature will be the temperature requirements of the domestic hot water systems. In this respect, Danfoss along with consortium of partners developed an innovative solution for district heating with 40°C supply temperature. The concept includes an instantaneous DHW preparation unit with an electrical heater for boosting the last few degrees of the DHW. The concept has been tested in the city of Odder in Denmark for nine months. The results show that the concept is working, keeping the same level of comfort as customers would expect from traditional district heating, while enabling use of new low-temperature renewable or waste heat sources and reducing heat loss from the district heating network.

Key words: ultra-low-temperature district heating, electrical heater, low-grade waste heat

Introduction

District energy has for the last couple of years been receiving increased awareness in energy strategy plans of governments and cities and is seen as one of the key drivers for reducing CO_2 emissions by opening up for large-scale application of renewable heat sources. When looking on the generations of DH it is clear that the supply temperature has been continuously decreasing. With the increased share of energy efficient buildings this trend is becoming a must to ensure the cost efficiency of DH systems. Lower supply temperature means not only reduced heat loss from the DH network but mainly easier exploitation of low-grade renewable sources with higher efficiency and thus better economy or utilization of huge potential of low-grade waste heat being otherwise lost.

The minimal supply temperature

The minimal supply temperature of district heating is normally defined by the requirement of customers to get domestic hot water (DHW) at certain comfortable temperature and/or the heating system to provide required indoor temperature. In Denmark, the minimal DHW temperature is, from comfort perspective, 45°C at the kitchen sink and 40°C at other tapping points. Beside this, requirement exists for the minimal DHW temperature from the perspective of hygiene issues of 50°C. However, if the overall piping volume of DHW system is below 3L it allows up to 40 m of piping without any limitations from hygienic perspective [1]. By applying high efficient heat exchangers the minimal DH supply temperature to provide 45°C DHW without additional on-site heat source is 50°C (see Figure 1). This temperature level is also high enough for space heating system with floor heating or low-temperature radiators. This concept is generally called the 4th generation DH. Examples of 4th generation DH systems in Denmark can be found in Lystrup [2], for low-energy houses built 2010 and in Sønderby, for existing single family houses built in late 1990s.

However, as there is a big potential in using low-grade renewable and waste heat and it exists throughout whole Europe it is interesting to explore possibilities of direct use of heat sources with even lower temperature levels than 50°C. Beside this, lower supply temperatures will further reduce the heat loss from DH networks and in many areas enable use of DH return water as a heat source. This idea was a starting point for the project "Development and testing of district heating substation with electrical

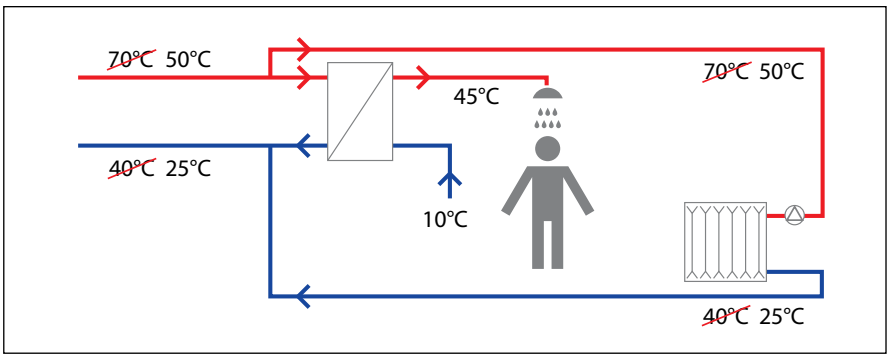

FIGURE 1: Low-temperature district heating principle

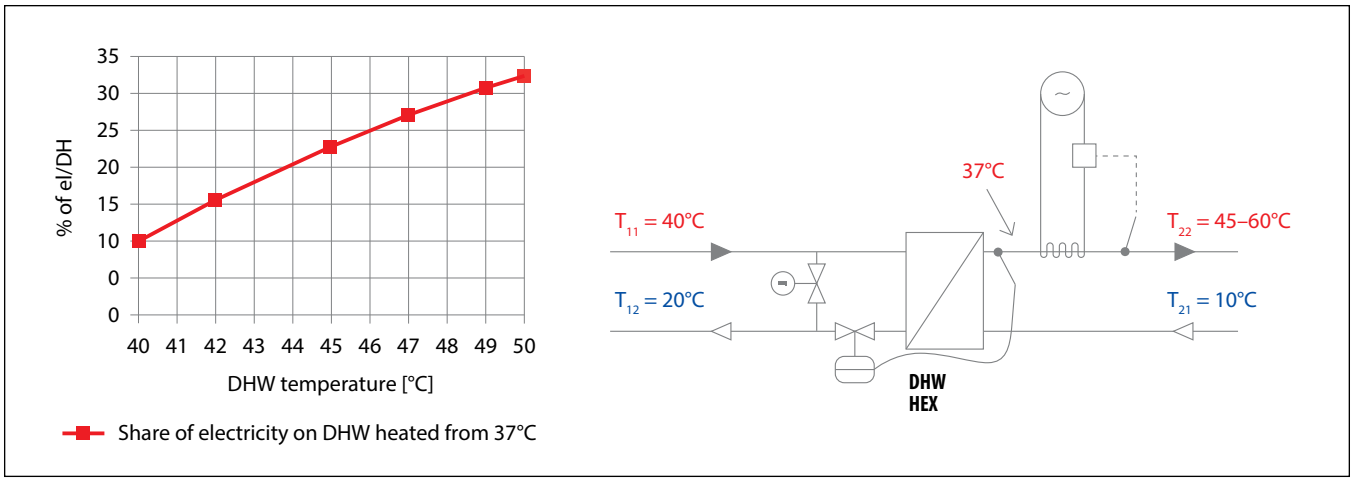

FIGURE 2: left: Share of electricity theoretically needed to heat DHW from 37°C to certain temperature level; right: Scheme of electrical booster

heater for ultra-low-temperature district heating", joined by consortium of partners: Danfoss, COWI, Danish Technological Institute and Odder District Heating, supported by research and development project EUDP sponsored by The Danish Energy Agency. In the project a supply temperature of 40°C was considered since 40°C was seen as minimal temperature required to supply houses with floor heating all year around without need of additional temperature boost. With high efficient heat exchangers and 40°C DH water the DHW water is heated up from 10°C to 37°C, while keeping the return temperatures of DH water at level below 20°C. However, as 37°C DHW is not warm enough, the last 8°C need to be boosted by another heat source, in this case by instantaneous electrical heater. Figure 2-left shows the share of electricity to heat up the DHW from 10°C to the temperatures between 40 and 50°C. It can be seen that the theoretical share of the electricity for DHW with temperature 45° is 23%, but the share is increasing up to 33% for DHW with 50°C.

The substation

During the project it was discussed whether to place the electric heater on the DH side or the DHW side. Figure 2-right shows the final concept of the DH substation with the electrical heater added on the DHW side just after the DH to DHW heat exchanger. The DHW side was chosen because it results in reduced electricity consumption, lower DH return temperature and DH reduced flow rate of DH water. Furthermore the additional pressure drop caused by the electrical heater is not increasing requirement for differential pressure in the DH network and the waiting time for DHW is shorter. Instantaneous principle is chosen to exclude storage tank and thus reduce the space requirements, stand-by heat loss and cost of the unit. On the other hand, instantaneous principle results in additional requirements on the electrical connection.

The requirement for DHW of 32,3 kW at 45°C [3] requires electrical heater with power of 7,4 kW, protected by 3x16 A fuses, which is seen sensible additional electrical load for the existing house originally not designed with electrical heating. However, in case DHW delivery with the same power but at 60°C the design power of the heating increases to double, 14,9 kW requiring 3x26 A fuses, which will result in needed upgrade of main fuses and it is still not sure that the electricity network supplying the house can withstand it. To make the concept applicable in existing buildings, we chose the electrical heater with 7,4 kW, with temperature setting range 30-60°C. However due to the missing commercially available electrical heater with power 7,4 kW and required flow characteristic we used for proof of the concept commercially available electrical heater with 11 kW heating coil.

The DH substation used for the concept was a traditional low-temperature DH substation for space heating and DHW heating with modified self-acting DHW controller with adaptive set point. The adaptive set-point DHW function ensures that in case the DH supply temperature increases (e.g. winter peak load) the substation will preheat the DHW as much as possible before it switches on the electrical heater. Additionally, to minimize the share of the electricity at the beginning of each tapping, bypass function in the substation keeps the supply pipe at 40°C.

Testing area

We installed the units into five single-family houses in city of Odder, Denmark (see Figure 3-left). The houses were built around year 2000 and they are heated mostly by floor heating. Two of them have few additionally radiators originally designed for supply/return/room temperature 70/40/20, those were replaced with ones with larger heating surface to enable the use of 40°C supply temperature as long as possible. All five houses are situated

Figure 3: left: One of the houses in Odder project; right: Mixing shunt for experimental loop

at the end of one street in Odder. A mixing shunt was installed prior to the five houses to reduce the supply temperature in the DH network to 40°C. The mixing shunt (see Figure 3–right) was equipped with pump providing 1,2 bar at 2,5 m^3/h, with online heat meter and electronical controller enabling monitoring and changing of settings remotely . Under the original condition, there was no bypass in the individual DH substations, only one bypass at the end of the street with set point temperature 60°C, resulting in considerable high bypass flow. The street bypass was closed when we started operation of the mixing shunt. Due to the electrical heater with peak power of 11 kW (without possibility to limit the maximal power) and existing electrical installations in the houses, all main fuses had to be increased from 25 A to 35 A. The normal cost for this upgrade will be 135€ (1000 DKK) for each A of additional fuse capacity. However, electricity provider Aura Energy sponsored this change for the period of testing. The concept was tested for period of eleven months, from March 2015 to middle January 2016. The electricity used by the electrical heaters was paid back to the customers by Odder District Heating company. The DH supply temperature to the houses was kept 40°C, but during June and July we increased the temperature to 60°C to confirm functionality of adaptive set point of the DHW controller. The DHW set point temperature on the electrical heaters was kept in all cases at 45°C.

Evaluation of the concept was made based on extensive measurements. In each of the substation we installed two heat meters, measuring with time step of five minutes flow, temperatures and energy on primary and secondary side of the DHW heat exchanger, temperature of DHW produced by electrical heater and also electricity used for electrical heater and inlet pressure of cold water. Data from main DH meter used for billing the DH customers were logged every 24 hours to track the heat demand and the average supply and return temperature. We measured also indoor temperature in the living rooms, to ensure that the reduced DH supply temperature did not compromise thermal comfort of the occupants. Both data sets were available online. Furthermore, we equipped the showering heads with simple digital thermometer with display to let the occupants see their preferred DHW temperature for showering to prove to them that DHW temperature of 45°C is enough to satisfy their DHW comfort requirements.

Results of the measurements

The most important result is that there were no justified complaints neither about comfort of DHW nor about indoor temperature, even the outdoor temperature during January went down to -10°C. The only complain was about low indoor temperature, but the problem was identified in wrong adjustment of the electronical controller by the house owner and by wrong adjustment of the differential pressure controller in the substation. These results are very valuable for the DH company because it confirms that 40°C supply temperature is enough to keep the houses on the comfort temperature levels desired by customers. From the indoor temperature measurements it can be furthermore seen that the preferred indoor temperature in the heating season is around 24°C, and in some case it goes up to 26°C. DHW temperature preferred by the occupants for showering was 39-40°C, confirming that 45°C DHW is enough for their comfort.

The measurements performed on the tested units revealed that the real share of electricity on DHW production was in average 30% compared to the theoretical 23%. The higher electricity share can be explained by the nature of the electrical heater operation. During long idling periods the heat exchanger is cooled down which increased the DHW volume needed to be heated. One hand it increases comfort for the users by reduced waiting time for DHW, but on the other hand it increases share of the electricity for DHW production. The unit can be modified to delay start of the heater to the moment when the water front with proper temperature, i.e. 37°C, reach the electrical heater, at the cost of extend waiting time for the DHW with required temperature. This option might in the future be controlled by the user. The adaptive set point of the DHW controller worked as expected and maximized the DH share for DHW heating for periods with DH supply temperature over 40°C.

It should be noted that the share of electricity of the total annual heat used in the house, for space and DHW heating, is very low, only 3%. The relative share of the electricity will however increase in case of house with lower heat demand for space heating, because the DHW part will account for higher relative share of all needed heating energy. And opposite, for houses with higher heat demand, the share of electricity will drop, as shown in Table 1. However, it should be kept in mind that concept of combining DH substation with electrical DHW heater is mainly aimed for buildings with space heating system designed for maximal supply temperature of 40°C, which in most cases will not fit older existing buildings.

The average supply and return temperature from the testing area was 42°C and 34,4°C respectively, while for the adjacent area operated on the normal conditions it was 63,8°C and 52°C for non-heating period (1.4. – 15.10) and 67,2°C and 46,4°C for rest of the year. By simple calculation of heat loss based on the average soil temperature of 8°C, the annual heat loss was reduced by 40%, which is in agreement with predicted value. However, foreseen economical

Building area: 120 m^2	Construction year	Heat demand for space heating [MWh/y]	Heat demand for DHW [MWh/y]	Share of el. for DHW heating on total heating energy [%] DHW 45°C	
				Theoretical (23%)	Measured (30%)
Low-energy house	2010	6.3	1.8	5.1%	6.7%
Existing building – newer	**1997**	**16.4**	**1.8**	**2.3%**	**3%**
Existing building – old	1970	20	1.8	1.9%	2.5%

TABLE 1: Heat demand for space heating and DHW and share of electricity for DHW heating

contribution of reduced heat loss to the concept is reduced by fact that the cost of low-grade heat is quite low.

DH network

Lower temperature difference between supply and return results in higher DH water flow compared to the traditionally used DH concepts. Therefore, when applying the concept of DH substation combined with the electrical heater it should be considered if we are dimensioning a new DH network or if we want to apply the concept to already existing DH network.

- For designing of a new DH network it means that dimensions of the pipes should be bigger than in case of traditional medium-temperature or low-temperature DH system and it will result in higher investment cost for the DH pipes. On other hand it will be compensated by lower price of low-grade 40°C heat and by reduced heat loss coming from reduced temperature levels.
- In case of applying the concept to the existing DH network the limitation might be hydronic capacity of the pipes because the network was originally designed for higher temperature difference between supply and return flow. The solution is to operate the DH with 40°C supply during non-heating and low heat demand periods. When the flow of DH water reaches the maximal hydronic capacity, the auxiliary medium-temperature heat source is needed to increase the supply temperature. However, medium-temperature heat source will result in increased cost for the heat.

Economy

The following economical analyze is made for existing DH network, considering the average DHW use of 1,8 MWh/y per house, electricity price of 0,29€/kWh and expected price of low-grade 40°C waste heat supplying district heating at 50% of traditional medium-temperature DH. We assume that installation of the electrical heater doesn't require upgrade of the main fuses. In case the existing DH network does not have enough capacity to cover heating demand of the buildings with supply temperature of 40°C the supply temperature will be increased. The share of low-grade and medium-temperature heat at annual heat demand is considered 50%, resulting in price level of 75% of medium-temperature heat. However at the same time, increased DH supply temperature reduces need of electricity for DHW heating and thus we assume share of electricity on the DHW heating of 15% instead of 30%. The cost of DH substation with electrical heater is expected to be 585€ more compared to new state-of-the-art DH single-family house substation and additional cost for connecting the electrical part of the substation to the three phase electrical connection in the house is 135 €. Beside this, we assume 10€/year contribution from reduced heat loss from the DH network. All prices are with VAT.

Realizing the concept for existing building with annual heat demand for space heating of 16,4 MWh/y and with 7,4 kW electrical heater the annual saving compared to the traditional medium-temperature DH solution is 455 €/y (3400 DKK/y) and simple payback time is one and half years for DH area with high heat price (see Table 2). In the area with low DH price the savings accounts for 170€/y and payback time for four and half year. When applied in low-energy house with annual space heating demand of 6,3 MWh/y the annual saving drops to 150€/y and payback time is increased to almost five years in case of DH area with high price. However for an area with low DH price the simple payback time increases to forty three years and thus the concept doesn't fit to these conditions.

Conclusions

The pilot project showed that the developed substation combined with the electrical heater is working and the concept can under certain conditions be applied with positive economy in buildings with space heating system designed for maximal temperature of 40°C. It should be stressed that using the electricity to cover small part of DHW heating should be seen in perspective of increasing share of renewable energy in the electrical grids and also as an enabler to exploit low-grade waste heat. The amount of available low-grade industrial and renewable heat is huge and the concept is therefore seen as very promising due to the fact that it decouples DH supply temperature from required DHW temperature and thus allows utilizing abundant sources of low-grade heat sources being otherwise lost. The next step is to investigate possible implementation on a bigger scale.

	DH price [€/MWh]		Existing building-newer (space heating 16,4 MWh/y)			Low-energy building (space heating 6,3 MWh/y)		
Case	Medium-temperature	Ultra-low-temperature (40°C)	Annual cost for heating energy (DH + el.) [€/y]	Annual savings [€/y]	Simple payback time [y]	Annual cost for heating energy (DH + el.) [€/y]	Annual savings [€/y]	Simple payback time [y]
Reference: DH – LOW price	60	-	1090	-	-	485	-	-
DH + el. heater – LOW price	60	30	925	170	4,3	470	15	43.3
Reference: DH – HI price	120	-	2185	-	-	970	-	-
DH + el. heater – HI price	120	60	1730	455	1,6	820	150	4.8

* For existing network, the share of el is considered 15% instead of 30%, because one half of electricity is covered by medium-temperature heat.

TABLE 2: Simple payback time and annual savings for existing DH network, various DH prices and existing and low-energy single-family house

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References

[1] DVGW. W551 e Trinkwassererwärmungs- und Trinkwasserleitungsanlagen; 1993. Bonn. [in German].

[2] Christiansen CH, Rosa AD, Brand M, Olsen PK, Thorsen JE. Results and experiences from a 2 year study with measurements on a new low-temperature district heating system for low-energy buildings. In: Proceedings of 13th international symposium on district heating and cooling, September 3-4, 2013, Copenhagen, Denmark.

[3] Dansk Standard, "DS 439 - Code of Practice for domestic water supply installations". 2009. [in Danish].

More information

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