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

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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 CO₂ 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 DHCP 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**
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 theoretically needed to heat DHW from 37°C to certain temperature level; right: Scheme of electrical booster 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...
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 m³/h, with online heat meter and electronic 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 complaint was about low indoor temperature, but the problem was identified in wrong adjustment of the electronic 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

<table>
<thead>
<tr>
<th>Building area: 120 m²</th>
<th>Construction year</th>
<th>Heat demand for space heating [MWh/y]</th>
<th>Heat demand for DHW [MWh/y]</th>
<th>Share of el. for DHW heating on total heating energy [%]</th>
</tr>
</thead>
<tbody>
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<td></td>
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<td>Theoretical (23%) Measured (30%)</td>
</tr>
<tr>
<td>Low-energy house</td>
<td>2010</td>
<td>6.3</td>
<td>1.8</td>
<td>5.1% Measured (6.7%)</td>
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<tr>
<td>Existing building – newer</td>
<td>1997</td>
<td>16.4</td>
<td>1.8</td>
<td>2.3% Measured (3%)</td>
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<tr>
<td>Existing building – old</td>
<td>1970</td>
<td>20</td>
<td>1.8</td>
<td>1.9% Measured (2.5%)</td>
</tr>
</tbody>
</table>

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

![Image](image-url)
In case of applying the concept
For designing of a new DH network it
already existing DH network.
if we want to apply the concept to
dimensioning a new DH network or
it should be considered if we are
combined with the electrical heater
applying the concept of DH substation
used DH concepts. Therefore, when
water flow compared to the traditionally
supply and return results in higher DH
Lower temperature difference between
DH network
of low-grade heat is quite low.
concept is reduced by fact that the cost
contribution of reduced heat loss to the
 DH – LOW price 60 - 1090 - - 485 - -
 DH – el. heater
Low energy building
(DH + el.)
energy
[€/y]
15
43.3
 Existing building-newer
(supply heating 16,4 MWh/y)
Annual cost
for heating energy
(DH + el.)
[€/y]
Simple
payback
time
[y]
4,3
470
Annual savings
[€/y]
170
Annual cost
for heating energy
(DH + el.)
[€/y]
190
Reference:
Low-energy building
(supply heating 6,3 MWh/y)
Simple
days
payback
Time
Low-energy building
(supply heating 6,3 MWh/y)
Simple
payback
time
[y]
820
150
4.8

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.

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<tr>
<td>DH – LOW price</td>
<td>60</td>
<td>-</td>
<td>1090</td>
<td>-</td>
<td>-</td>
<td>485</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>DH + el. heater – LOW price</td>
<td>60</td>
<td>30</td>
<td>925</td>
<td>170</td>
<td>4,3</td>
<td>470</td>
<td>15</td>
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<td>DH – Hi price</td>
<td>120</td>
<td>-</td>
<td>2185</td>
<td>-</td>
<td>-</td>
<td>970</td>
<td>-</td>
<td>-</td>
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<tr>
<td>DH + el. heater – Hi price</td>
<td>120</td>
<td>60</td>
<td>1730</td>
<td>455</td>
<td>1,6</td>
<td>820</td>
<td>150</td>
<td>4.8</td>
</tr>
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* 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
References


More information

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