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Field experience with ULTDH substation for multifamily building

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Abstract

Ultra-low temperature district heating (ULTDH) substations may be an important enabler for integrating higher shares of renewables and waste heat in the district heating (DH) network. In the paper, we describe a concept and first experimental results for producing domestic hot water (DHW) at DH supply temperatures of 45°C. The substation utilises a heat pump for boosting the DH temperature up to approximately 60°C to an accumulation tank, after which the DHW can be produced on demand for temperatures up to 55°C. Additionally, the system included a separate heat pump to supply the DHW circulation heat demand. The DH accumulator tank provides load shift opportunities, which is important going towards the integrated, flexible and renewable based future energy system. The two heat pumps operate with a COP of approximately 5, which results in representative share of approximately 11-13 % electricity to supply the DHW including circulation.

Keywords: Heat Booster Station, Ultra Low Temperature District Heating, Load Shift, Heat Pump, 4th Generation District Heating

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1. Introduction

To achieve the goal of 100 % renewable (RE) heat and power supply and increased energy efficiency, utilization of available RE resources is important. In this context, the benefits of ultra-low temperature district heating (ULTDH) are multiple. First, heat losses from the DH network can be reduced, which also becomes increasingly important in the future heat supply to low energy buildings, in order to keep relative and absolute network heat losses at an appropriate level. Second, ULTDH enables the use of a higher share of low temperature renewable energy resources such as solar, geothermal and industrial waste heat. If a heat pump is needed in order to utilize such heat sources, the low supply temperature allows significantly improved coefficient of performance (COP) of the utility plant [1]. Lowering the supply temperature may further facilitate individual customers to act as prosumers in case of waste heat generation at an appropriate temperature level. Moreover, ULTDH in local networks opens for possibility to connect new users to existing DH systems without large additional capacity investments. The ULTDH concept, with it the option of thermal and electric load shift, is one of the possible solutions going towards the 4 generation DH system [2].

The viability of low temperature district heating (LTDH) consumer with around 55 °C supply temperature has been proven and demonstrated in Denmark [3]. With it, it is possible to prepare DHW water at 50 °C without any additional energy source for boosting the temperature. However, the lower temperature heat sources down to 40-45 °C, which are sufficient for space heating most of the heating season and for floor heating in general, cannot be utilized directly in LTDH systems due to DHW temperature requirements. A reduction of supply temperature to 40 °C would in Denmark allow additional 10.000 TJ from waste heat sources, if solar thermal waste heat is excluded [4].

For these reasons, the ULTDH has attracted significant academic interest in recent years. Several studies show that the use of booster heat pumps allows reduced supply and return temperatures in the network and thereby provide a decrease in transmission losses and a different optimal relation between heat and pumping losses [5–7]. Assuming the ULTDH supply at 44 °C to originate from centralised heat pumps, the use of booster heat pumps results in an increase of 12 % in the overall performance compared to direct supply at above 60 °C [5]. By further improving the booster technology, the performance potential increase is approximately 17 % [8]. In case the DH was produced by CHP plants, the ULTDH resulted in a decrease of approximately 20 % compared to LTDH.

In order to take advantage of the multiple benefits of the ULTDH system, a substation was developed for multifamily buildings, based on a micro-booster concept for individual single-family houses [9,10]. The consumer DH unit boosts the temperature of the district heating water for DHW preparation and circulation, whereas the space heating is supplied directly by the ULTDH. In the paper, we present the integration methodology of the high efficiency heat pump as well as the layout of the substation. Further, the case study of the building and the implementation of the system is presented. The results show the first operational experience from the test installation site in Copenhagen, as part of the EnergyLab Nordhavn project.

2. Methods

2.1. The ULTDH concept

With the supply temperatures of DH below the needed temperature for producing DHW at 55°C by a direct heat exchange process, the temperature had to be raised or boosted. For this purpose, an electric driven heat pump was applied. In the developed heat booster station, this increase was obtained by use of heat pumps at the primary side, which utilized the supply of DH as the heat source. In cases where the DH network is used as the heat source, it is important that a significant amount of the heat originates from natural resources, such as heat pumps utilizing RE or solar thermal units, or waste heat, such as flue gas condensation, in order for the ULTDH system to exceed the performance of systems with LTDH. The conceptual layout of the system was chosen from a range of designs, in order to obtain the best thermodynamic performance of the HBS, and with it the highest coefficient of performance of the heat pump, for any DH supply between 35°C and 47°C [11].

2.2. The basic principles for the installed heat booster station

Due to capacity costs and the start-up dynamics of a heat pump, a tank for heat accumulation was introduced. The tank itself also enables load shifting in relation to electricity consumption as well as DH consumption. Due to legionella risks, it was decided to place the tank on the primary side and utilise an instantaneous heat exchanger for heating the DHW when tapped. The heat booster station (HBS) was designed and sized for operation in a multifamily building.

The overall concept of the HBS is shown in Fig. 1. Pls. note the system is simplified, which means systems related to heat pumps, control equipment and additional hydraulic and electric systems are not shown.

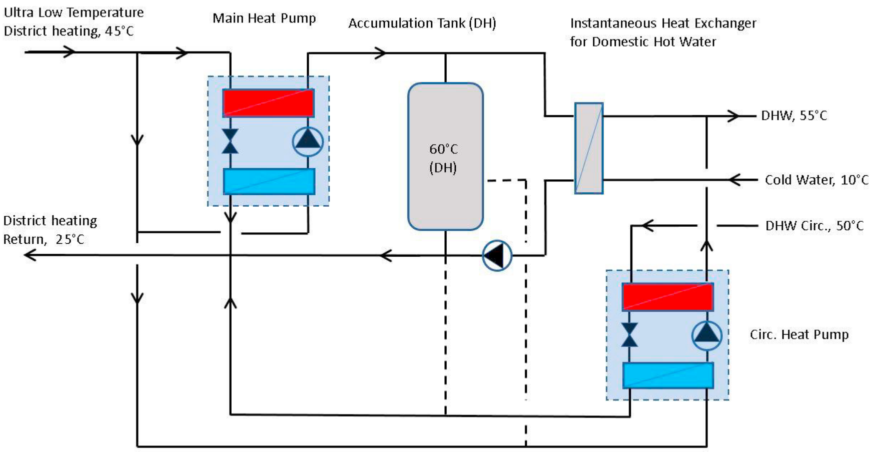


Fig. 1. Basic layout of the heat booster substation

The principle for the main heat pump is that the DH supply flow is split into two. The first part is led trough the condenser of the heat pump, where it is heated or boosted to 60°C-65°C and let into the DH accumulation tank. The second part is led trough the evaporator, where it's cooled down to e.g. 25°C and thus acts as the heat source for the heat pump.

To avoid the DHW circulation impacting the DH accumulation tank, by means of fast discharge and loss of the thermal stratification, a separate heat pump was applied for maintaining the DHW circulation temperature. The heat source was chosen to be the ULTDH supply, or from the bottom of the accumulation tank, in case the temperatures are suitable. The buildings space heating circuit was operated in parallel to the DHW system and is not a part of the HBS.

2.3. Installation in the Building

The HBS unit was installed in Havnehuset located at the Nordhavn area of Copenhagen. The heat demand originated from supplying DHW and DHW circulation to 22 flats by 8 risers.10 flats are in a 5-storey setup, and 12 flats are in a 3-storey setup, where the upper flats are in 2 storeys. The building is shown in Fig 2.

Fig. 2. Havnehuset located at the Nordhavn area of Copenhagen

The HBS consists of 4 parts; the prefabricated station or HBS module (including valves, meters, sensors, controllers, pump, pipes, heat exchanger for DHW and electrical cabinet), a prefabricated large heat pump (main) for the DH tank charging, a prefabricated (small) heat pump for the DHW circulation and two DH storage tanks of each 750 litres volume. The HBS concept can be realised with only one tank, but two was decided due to available space.

Fig. 3. (a) HBS installed in technical room; (b) Part of HBS unit with both tanks

The 4 modules are shown on Fig. 3.**Error! Reference source not found.**, where the heat pumps are placed in the front of the left figure.

For the purpose of the field evaluation, the HBS system was installed as add-on to the existing DHW system of the building. The existing space heating system was operated in the usual way, but supplied by ULTDH. For the sake of obtaining field experience, the ULTDH was established by a mixing loop, see Fig. 4.

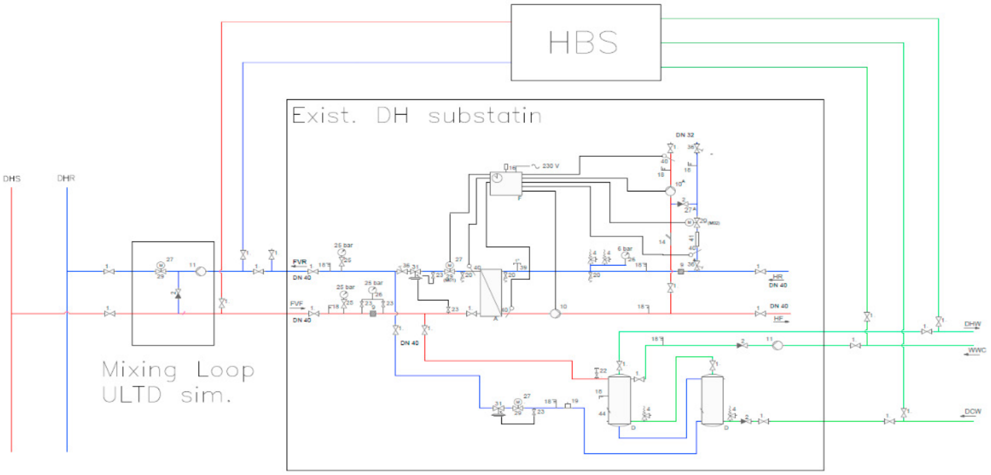
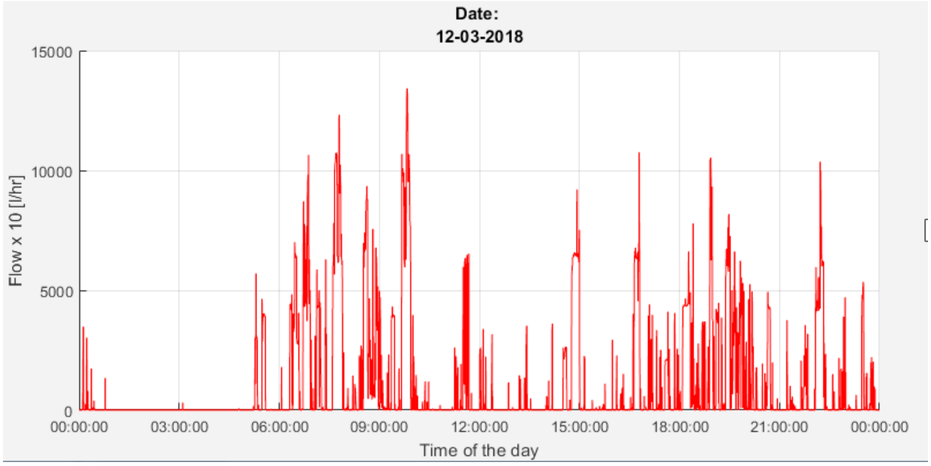


Fig. 4. HBS parallel integration into existing heating/DHW system

3. Results and discussion

3.1. Field Experience

The main field experience and operational data are presented and discussed in this section. The data is time varying and they are presented as plots with the time as the x-axis. The analysis was based on two months of operation, but data examples are specifically given for Monday 12.03.2018 and Sunday 18.03.2018. Fig. 5 shows the DHW tapping profile for two days. Maximum tapping flow is approx. 1,5 m^3/hr, corresponding to a capacity of 78 kW. The HBS can keep the DHW temperature of approx. 55°C during all tapping's and no shortages of the DHW supply has been seen.



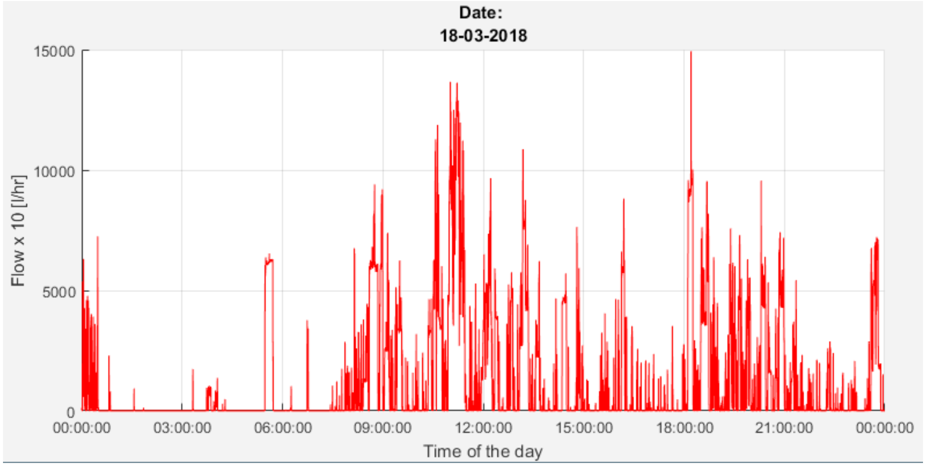


Fig. 5. DHW tapping during the day, a week day and a week-end day

It can be seen, that the amount of tapped DHW at 55°C was lower on the week days compared to the week-end days. In this example, for the week day it was 2.540 liters, where it was 2.905 liters in the week-end day. Further, during the week-day the tapping was more concentrated around the morning and evening hours, whereas the tapping was spread out during the week-end day and with a time delay in the morning.

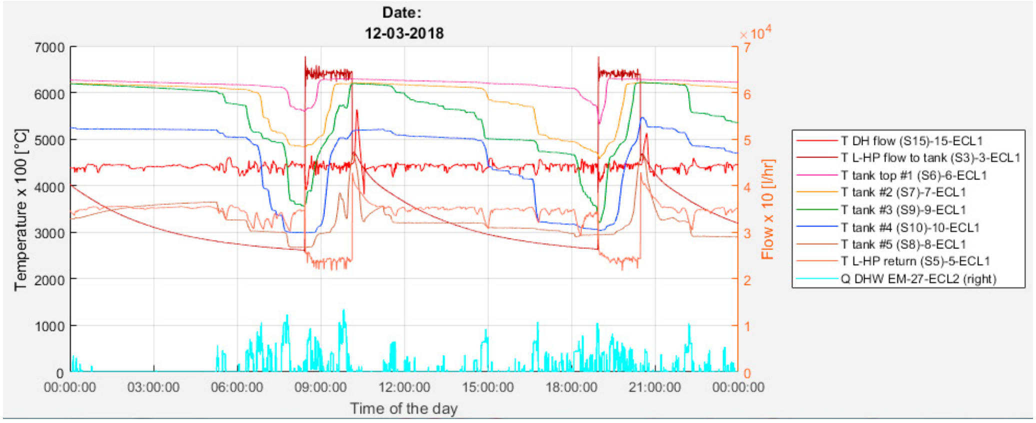


Fig. 6. Charging profile of HBS

The charging profile for the HBS of the 12.03.2018 can be seen on Fig. 6. The DH tanks were charged twice this day, at around 9 o´clock and 19 o´clock. When the tank top was below 56°C (T tank top #1) a charging was started and when the tank bottom temperature (T tank #5) was above 46°C, the charging was stopped. The main heat pump condenser boosts the charging temperature from approx. 45°C (T DH flow) to 63°C (T L-HP flow to tank), where the evaporator returns the DH water at a temperature of approx. 24°C (T L-HP return). The tapped DHW is shown as well (Q DHW). During charging of the DH tank, the flow through the condenser was approx. 730 l/hr, whereas the flow through the evaporator was 530 l/hr. DH temperatures in different vertical locations of the tank are shown as T tank top #1 to T tank #5.

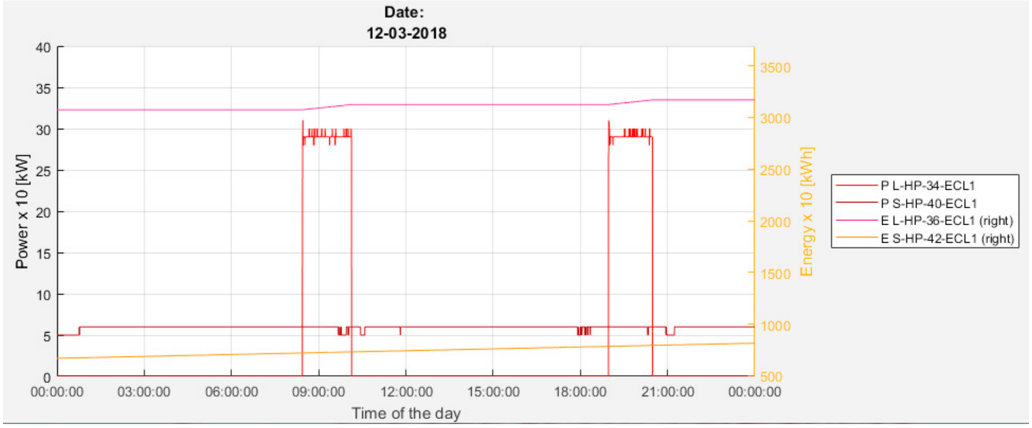


Fig. 7. Electric consumption of heat pumps

The electric power for operating the main heat pump was approx. 3 kW (P L-HP) and the power for operating the circulation (small) heat pump was 0,6 kW (P S-HP). The accumulated electric consumption for the two heat pumps are shown as well (E L-HP and E-S HP). The operation time of the main heat pump, based on the figures above, was 3,25 hr pr. day, resulting in consumption of 9,3 kWh, whereas the consumption for the small heat pump was 14,2 kWh. Totally the daily electric consumption this day was 23,5 kWh. On a yearly basis this adds up to 8.600 kWh of electricity.

The main heat pump condenser was boosting the temperature from 45°C to 63°C, at a flow of 730 l/hr. This corresponds to a capacity of 15 kW. With an electric consumption of 3 kW, the COP was 5,0, which is as expected. Other operational modes occur, e.g. when DH supply temperature or the HP evaporator outlet temperature is changed.

The small heat pump condenser was heating the DHW circulation temperature from 50°C to 55°C, at a circulation flow of 540 l/hr, this corresponds to a capacity of 3,1 kW. With an electric consumption of 0,6 kW, the COP was 5,2, which is as expected. Other operational modes occur.

Table 1. Essential performance of HBS based on two days

HBS data pr. Day	Monday 12.03.2018	Sunday 18.03.2018
Vol DHW [liters]	2.540	2.905
DHW Energy [kWh]	133	152
DHW Circ. Energy [kWh]	78,1	77,5
DH Energy [kWh]	181	204
Main HP Electric cons. [kWh]	9,3	11,7
Circ. HP Electric cons. [kWh]	14,2	14,2
Electric share [%]	11,1	11,3
DH weighted flow temp. [°C]	44,0	44,0
DH weighted return temp. [°C]	30,5	29,1
Energy Bal. (In – Out) [kWh]	-6,5	0,4

Table 1 includes the essential performance of the HBS for the two days. The main performance data relates to the share of electric consumption, which was approx. 11% of the used electric and DH energy, the DH inlet temperature of 44°C and DH return temperature of approx. 30°C. To understand the low electric share, it should be noted that e.g. out of 133kWh for DHW, the 49 kWh were boosted via the main heat pump condenser and the remaining 84kWh were directly from the DH supply. This also explains why the main heat pump electric consumption is lower than the circulation heat pump, even the DHW energy consumption is higher than the DHW circulation heat loss. The electric share depends on the use of DHW, in case of no DHW use at all, and still considering the tank to be charged, the electric share would be approx. 30%. In case the DH tank is not charged the electric share would correspond to the cop of the circulation heat pump, approximately 20%. In case of a low DHW consumption, e.g. one measured day of 1.318 liters of DHW, the electric share was 15,7%.

3.2. Load shift potential

Based on the field experience so far, the capacity during charging of the tank is 3,0 kW electric and 30 kW thermal from DH net. Based on 4 hrs. charging time pr. day, the load shift potential becomes:

Electric load shift potential:	12 kWh/day
DH load shift potential:	120 kWh/day

Comparing this to the heat demand pr. day of the building, which is in the design peal load range of 50 kW, and considering shifting this 5 hrs, the load shift potential for heating becomes 250 kWh/day, and this for peak load. On a yarely basis the average load shift potential is less than half, meaning that for a new building of this type, the load shift potential of DHW is in the same range as for the heating system. No load shift potential is present for the circulation heat pump, since its running continuously.

4. Conclusion

Based on the first field experience for the HBS, it can be concluded that the HBS unit is successfully installed, tested and operating. The DHW is produced at 55°C, DHW circulation is made at 50-55°C, with a DH supply temperature of approx. 45°C and a DH return temperature of approx. 30°C. The share of electric energy consumption for DHW and DHW circulation is 11-16%, depending on the measured DHW consumption. The representative electric share is around 11-13 %. The electric load shift potential is limited to approx. 12 kWh/day, whereas the DH load shift potential is approx. 120 kWh/day. On a yearly basis this is the same range as the load shift potential based on the buildings passive thermal capacity. The DH return temperature could be reduced further, e.g. by compromising the cop of the heat pumps and added heat pump capacity.

Acknowledgement

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