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Energy, economy and exergy evaluations of the solutions for supplying domestic hot water from low-temperature district heating in Denmark

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ABSTRACT

District heating in Denmark is going through the transition from 3rd generation (80/40 °C) to 4th generation (50–55 °C/25 °C) systems in preparation for district heating based completely on renewable fuels by 2035. However, concern about Legionella growth and reduced comfort with low-temperature domestic hot water supply may be discouraging the implementation of low-temperature district heating. Aimed at providing possible solutions, this study modelled various proposals for district heating systems with supply temperatures of 65 °C, 50 °C and 35 °C and for two different building topologies. Evaluation models were built to investigate the energy, economy and exergy performances of the proposed domestic hot water systems in various configurations. The configurations of the devised domestic hot water substations were optimised to fit well with both low and ultra-low-temperature district heating and to reduce the return temperature to district heating. The benefits of lower return temperatures were also analysed compared with the current district heating situation. The evaluation results show that the decentralized substation system with instantaneous heat exchanger unit performed better under the 65 °C and 50 °C district heating scenarios, while the individual micro tank solution consumed less energy and cost less in the 35 °C district heating scenario.

1. Introduction

District heating (DH) is of great importance for the sustainable energy system of the future. In the district heating system, the heat is generated at the heat plant and delivered to the substation by transmission network. In Denmark, most district heating substations are designed and dimensioned to the served buildings. But area substation and flat substation also exist for specific needs. Ultimately, the heat is supplied to the consumer by the distribution network. The schematic of the common conventional district heating system is shown in Fig. 1.

In most European countries including Denmark, the heat supply covers the demand of both space heating and domestic hot water (DHW). To make the utmost use of industrial excess heat and renewable energy sources, as well as to improve the efficiency of the DH system, Danish district heating is undergoing the transition from the current 3rd generation district heating (80/40 °C) to 4th generation district heating (55/25 °C) without violating any comfort or hygiene requirements [1]. Moreover, the savings from a more efficient heating system can results in more significant benefits in the entire energy system by synergy effect with the electricity system, gas system, etc. [2]. For heat supply to energy-efficient buildings in low heat density areas, it will be even possible to apply the ultra-low-temperature district heating (ULTDH) with supply temperature at 35–45 °C to make the utmost use of the low-temperature excessive heat, and improve the efficiency of the heat pump as heat production.

The demand for domestic hot water (DHW), an important part of the total heat demand, will play a yet bigger role in the energy-efficient buildings of the future. Over the past 20 years, personal consumption of DHW has increased almost 50% [3], and, to prevent Legionella, the DH supply for DHW preparation is always operated at high temperatures. This leads to even larger energy consumption for DHW supply and more heat loss during transmission and distribution. Therefore, to improve the efficiency of the DH system, suitable solutions of supplying domestic hot water from low-temperature district heating are in need.

1.1. Comfort and hygiene requirements for domestic hot water supply

With careful design and operation, space heating can work properly at low DH supply temperature without supplementary heating. DHW production from LTDH, however, requires more attention, because of the hygiene and comfort requirements which

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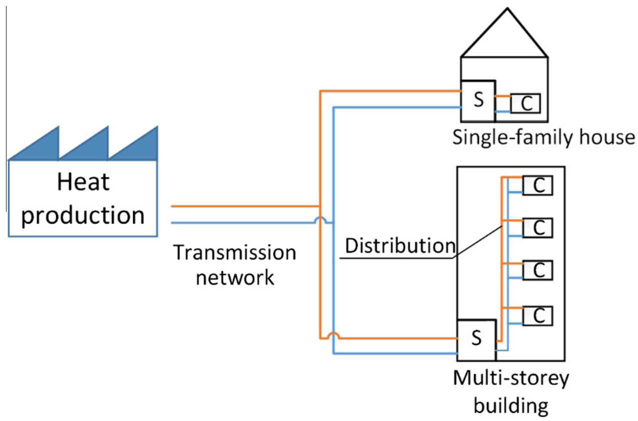

Fig. 1. Schematic of conventional district heating system. * S represents for substation, C represents for consumer.

can differ in different situations. According to the building regulations in Denmark, the temperature requirements for DHW comfort and hygiene vary depending on the size of the heating system. For systems with large DHW volumes, a high temperature regime is required to inhibit Legionella, while the temperature requirements for systems with no DHW storage or circulation are less strict. The specific comfort and hygiene requirements for DHW temperatures are summarised in the Table 1, in which both Danish and EU standards are taken into account [4].

1.2. Existing DHW system configuration with medium-temperature district heating

The conventional DHW system for medium-temperature district heating (MTDH) can be different in single-family houses and multi-storey buildings. Both building topologies can have small or large DHW volume depending on their substation configurations.

1.2.1. Conventional DHW configurations in single-family houses

Usually, DHW circulation is unnecessary for the single-family house to guarantee the acceptable (10 s) waiting time, since the distribution pipe length from the substation to the tap is short. Currently, a storage tank or an instantaneous heat exchanger unit (IHEU) are most commonly used for DHW production in single-family house. The schematics of the DHW system configurations are shown in Fig. 2.

If the DHW is stored in a tank, the tank has to be maintained at no less than 60 °C to avoid the risk of Legionella. Where an IHEU is used, bypass flow is required to ensure the 10 s waiting time for comfort reasons. These two existing methods can work properly with medium-temperature district heating without supplementary heating.

Table 1
Temperatures required for hygiene and comfort in different building typologies.

	Systems with no circulation or storage tank	System with large DHW volume
Requirements for Legionella prevention	–	Storage tank 60 °C Circulation pipes > 50 °C
Requirements for comfort	45 °C for kitchen use	45 °C for kitchen use
	40 °C for other uses Waiting time < 10 s	40 °C for other uses Waiting time < 10 s

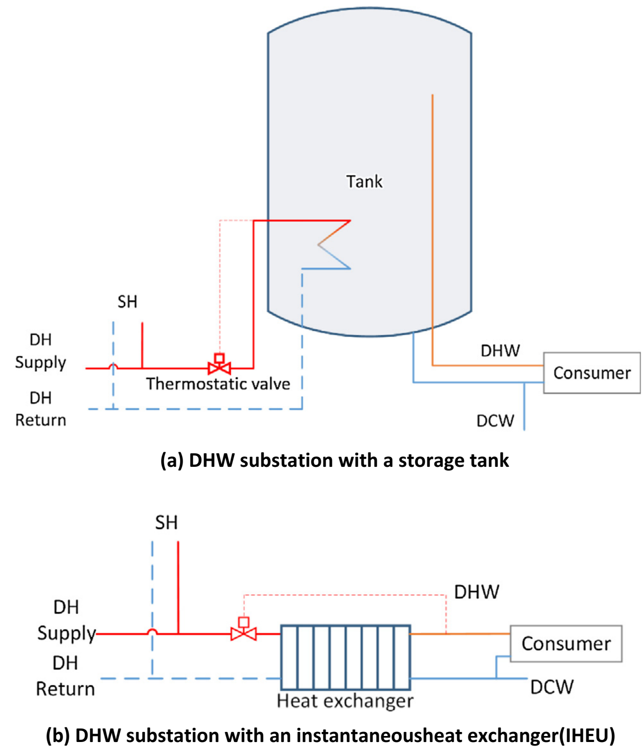

Fig. 2. Existing DHW configurations for single-family house. * SH represents for space heating.

1.2.2. Conventional DHW configurations in multi-storey building

For multi-storey building, depending on whether the DHW is prepared in the central substation or locally, the configurations can be divided into mainly two types. The schematics are shown in Fig. 3.

To take account of the overall DHW peak load and the comfort requirement, the DHW shown in Fig. 3(a) requires a storage tank to shave the peak load and circulation pipes to ensure the 10 s waiting time. The cold and hot water are mixed at the faucet to reach the desired temperature by the consumer. This study did not include systems only with a main heat exchanger and circulation in the analysis for multi-storey buildings because they are uncommon in Denmark. According to the standard for Legionella prevention [4], a centralized system with DHW circulation requires the tank to be maintained at 60 °C and the DHW circulation to be at least 50 °C. Consequently, the heat loss from such systems can be substantial. In Denmark, it has been found that the circulation system can waste up to 70% of the total energy delivered for DHW use [3]. Moreover, the high temperature regime for the circulation obstructs the implementation of LTDH/UTLDH. In comparison, DHW can be prepared locally by the individual heat exchanger as shown in Fig. 3. It is feasible to apply such a system with LTDH, but to ensure the 10 s waiting time for comfort, bypass flow is always needed, which increases the return temperature to district heating.

1.3. DHW preparing technologies

There are some investigations of different technologies for DHW preparation. Cholewa et al. [5] test the performances of three different heating systems for multi-storey buildings: a system with centralized condensing gas boiler, a system with flat-based heat exchanger supplied by district heating, and a system with flat-based gas boiler. The results show that both the decentralized