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Decentralized substations for low-temperature district heating with no Legionella risk, and low return temperatures

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ABSTRACT

To improve energy efficiency and give more access to renewable energy sources, low-temperature district heating (LTDH) is a promising concept to be realized in the future. However, concern about Legionella proliferation restricts applying low-temperature district heating in conventional systems with domestic hot water (DHW) circulation. In this study, a system with decentralized substations was analysed as a solution to this problem. Furthermore, a modification for the decentralized substation system were proposed in order to reduce the average return temperature. Models of conventional system with medium-temperature district heating, decentralized substation system with LTDH, and innovative decentralized substation system with LTDH were built based on the information of a case building. The annual distribution heat loss and the operating costs of the three scenarios were calculated and compared. From the results, realizing LTDH by the decentralized substation unit, 30% of the annual distribution heat loss inside the building can be saved compared to a conventional system with medium-temperature district heating. Replacing the bypass pipe with an in-line supply pipe and a heat pump, the innovative decentralized substation system can reduce distribution heat loss by 39% compared to the conventional system and by 12% compared to the normal decentralized substation system with bypass.

1. Introduction

District heating is an efficient method of supplying heat to consumers in many regions, especially in high heat density areas. Compared with other heating systems, district heating is flexible in using various forms of energy, such as surplus heat from industrial processes, geothermal energy, solar energy, and also residual resources, which might be used increasingly in the future. Therefore, district heating can play an important role in realizing a system of sustainable energy with 100% renewable energy supply [1].

After long-term development, the current temperature level of most district heating systems is often below 100 °C, but still high. To meet the lower heating demand of energy-efficient buildings in the future and give access to more low-temperature heat sources, the concept of 4th Generation District Heating [1] has been proposed, with the aim of developing a district heating system with lower supply temperature. A recent study investigated the feasibility of supplying space heating with low-temperature district heating (LTDH) without compromising on comfort [2], which indicates that with extensive renovation and efficient heating equipment, LTDH supply is sufficient to provide an indoor temperature of 22 °C.

However, one obstacle to realizing LTDH is the conflict with hygiene requirements. Artificial aquatic systems are easily colonized with Legionella, which is the causative agent of Legionnaire's disease. Temperatures in water below 50 °C and stagnancy are considered the main factors that promote the growth of Legionella. The common solution is to use a high-temperature regime and domestic hot water circulation. Most countries require the district heating supply temperature to be at least 60 °C for large systems with circulation. Unfortunately, previous research has shown that the heat loss of a conventional system with domestic hot water circulation and a storage tank can be as much as 50% of all the energy delivered [3]. However, if the water volume can be limited, the proliferation of Legionella can be much restrained. According to the regulations of CEN/TR 16355 [4], a hot water system without a tank and circulation system has no need to be kept at a high temperature. So a system of decentralized substations can limit both the heat loss and the risk of Legionella. The domestic hot water can be produced in each apartment in a building using a compact flat-

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plate heat exchanger and distributed to the taps in the apartment with small-dimension pipes. In this way, the volume of the indoor domestic hot water system is so small that the risk of Legionella is eliminated without maintaining high temperatures.

Some articles have presented investigations of the benefits of applying the decentralized substation system, but with medium-temperature district heating. Breuer and Loose [5] point out that decentralized supply of domestic hot water can save approximately 30% of heating energy consumption comparing to the conventional circulation system, making it an economically efficient alternative method for DHW production. Cholewa and Siuta-Olcha [6] conducted an practical measurement for a 4-storey building with decentralized substations in Poland. By comparing the readouts of the heat provision and heat consumption (both space heating and DHW), they find the decentralized substation can achieve the efficiency of 67.1%, and motivate the consumer to reduce their heat consumption by 19.2%. In another article, Cholewa et al. [7] compare the measurements of a centralized heating system with gas boiler, a decentralized substations system with district heating, and a decentralized heating system with individual gas boiler for each dwelling. The decentralized substation system with district heating has 10.5% higher efficiency than the centralized system on annual average, but lower than the individual gas boiler system. However, more equipment for ventilation is required by the individual gas boiler system. Thorsen [8] provides a parametric study about the decentralized substation concept. According to the practical data, the investment of the decentralized substation system is on break-even level as the conventional system. And it can save 2–4 kWh/m^2·yr energy without violating the comfort and hygiene requirements.

In this study, we explored the feasibility and benefit of realizing LTDH by applying the decentralized substation unit. In addition, we proposed and investigated an innovative decentralized substation system with an in-line supply pipe and a heat pump, which aims to further reducing the return temperature. Three models were built up to simulate the scenarios of the conventional system supplied by 3rd generation district heating, the decentralized substation system supplied by LTDH, and the innovative decentralized substation system supplied by LTDH respectively. The design information of the models was obtained from a case multi-storey building with decentralized substation system supplied by medium temperature district heating (70 °C). The model of decentralized substation system was compared with measurements of the case system to ensure accurate settings and parameter input, and is used to simulate the LTDH scenario by converting the supply temperature to 55 °C. The annual distribution heat loss, the resulting operation costs, the seasonal variation of the three scenarios, and the benefit of low return temperature were analysed and compared. The results provided by this study can be used to promote LTDH in the planning stage, and to improve the efficiency of the decentralized substation system.

2. Materials and methods

This section describes the methods for setting up the models that were made to investigate the energy performance of the heat distribution process. The distribution heat loss of three scenarios, as one crucial indicator of the efficiency for the heat distribution process, was simulated and compared. In this study, the distribution heat loss focused on is the heat loss from the building inlet to the apartment inlet. Distribution heat loss inside the apartments and in the network was not taken into account. In addition, the economic performances of different systems related to the heat distribution process were analysed and compared. The investment costs were not included in this study, since the price of the equipment varies a lot among manufacturers. The benefit of a lower return temperature was also investigated from both energy and economy points of view. To make a common basis for the comparison, the conditions on the consumer side for three scenarios, such as heating demand, building insulation level, heating equipment, were all assumed to be the same.

2.1. Information of the case system

2.1.1. Building information

The case building is a six-floor residential building located in Denmark. The ground floor comprises two commercial stores. Each of the other floors has three apartments. The basement has a storage room and a technical room which only have space heating demand, while the rest of the basement is used for parking and is neither heated nor supplied with hot water.

The case building and the floor layout of the residential storeys are show in Fig. 1.

The apartment area is about 110 m^2. As shown in Fig. 1, each apartment has typical domestic hot water use with one kitchen, one shower head, and one hand basin. Floor heating in the bathroom is used all the year round for comfort. The building was constructed in 2006 and is well-insulated. The design space heating and domestic hot water demands are assumed to follow the Danish building code BR95 [9], which requires the total energy supply should be less than 70 kWh/m^2 per year plus 2200 kWh divided by the heated floor area.

2.1.2. Decentralized substation system in the case building

The reference heat distribution system in the case building is the decentralized substation heating system, which is not very common in multi-storey residential buildings in Denmark. However, to promote the utilization of LTDH, the local district heating company decided to apply decentralized substation systems in some new residential buildings. Each flat in the case building has its own decentralized substation installed in the cabinet inside. The substation is connected with the district heating service supply and return pipes installed as risers in the cabinet. There are three risers in the building. The substations of the three flats on the same floor are connected to different risers. The heat demand for both space heating and domestic hot water is supplied by the individual decentralized substations.

The type of substation unit used in the reference building is shown in Fig. 2.

Fig. 3 shows the installation and connection of the decentralized substation unit.

The thermostatic valve (2’) of the domestic hot water heat exchanger also serves as a bypass to keep the supply line warm if necessary, so that an acceptable waiting time for domestic hot water can be guaranteed. Temperature and energy meters in the decentralized substation of each apartment record the accumulated heat consumption of the apartment. Normally, the time step of the meters was set to a daily or monthly basis. In this study, the meters were reset to save the data with a shorter time step (0.5 h) for a two-day test for more accurate measurements. At the building inlet, an energy meter is installed to measure the overall heat supplied to the building from the district heating network and the district heating supply and return temperatures. The distribution heat loss of the case building was calculated as the subtraction between the measured total heat supply by the district heating network and the total heat consumption of the consumers. It was compared to the simulation results by the model. The measured return temperature was also compared to the calculated return temperature of the decentralized substation model.

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