Supply of domestic hot water at comfortable temperatures by low-temperature district heating without risk of Legionella - DTU Orbit (28/07/2019)

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In Denmark, about 25% of the primary energy is consumed for covering the heat demand in the buildings. To achieve a complete renewable energy system by 2050, which is the goal set by the Danish government, methods that are more efficient and economical for heat supply are urgently needed. Considering the overall energy efficiency and environment effect, the district heating (DH) is a cost-effective way of supplying heat to high heat density area. Currently, the DH systems in most countries are still with supply and return temperature at 80/40 °C. The efficiency of the DH system can be improved by applying lower supply/return temperatures (55/25 °C), which has been defined as the 4th generation district heating (4DH) or low-temperature district heating (LTDH). Compared to the current district heating, LTDH can give more access to the renewable energy sources (RES) with low heat quality, increase the recovered heat from industrial process and geothermal heat exchanging process, increase the heat recovery of flue gas condensation and increase the coefficient of performance (COP) of the heat pump if applied. Moreover, the low supply/return temperature in the network can also reduce the heat loss. To make utmost use of low-temperature energy sources, it can be beneficial to apply ultra-low-temperature district heating (ULTDH) in the future energy-efficient buildings, especially when heat pump is used for heat production. The supply temperature of ULTDH should be sufficient to ensure the comfort indoor temperature for space heating but lower than LTDH. Therefore, to meet the comfort and hygiene requirements for DHW supply, supplementary heating methods should be combined.

However, one obstacle to realize the LTDH/ULTDH is the concern of the violation of the comfort and hygiene requirements of DHW supply. According to the Danish standard, the supply for DHW should be able to reach 45 °C for the kitchen use and 40 °C for other uses for comfort. Regarding to the hygiene requirements, large DHW system with DHW storage tank and circulation has to use high temperature regime to get rid of Legionella. The storage tank should be able to reach 60 °C and the circulation should be operated no lower than 50°C. While the DHW system with small DHW volume has very low risk of Legionella. This study investigated available solutions for supplying DHW with LTDH or ULTDH meeting the comfort and hygiene requirements. Both the sterilization methods and optimized DHW system design methods are included. For the sterilization methods, we selected the most widely used treatments, and analyzed the feasibility of applying them in the LTDH scenario, the installation and operation difficulty, and the economy based on the review of substantial documents and relevant standards. In terms of the DHW system design methods, the optimal system configurations and operation methods were designed and evaluated with respect to the different DH scenarios and building typologies. Model studies were built to simulate the performances of the proposed systems under ideal situations. Some case studies were used as reference works to compare with the model results.

Considering the disinfection mechanism of different sterilization methods and the regulation for water quality in Denmark, the approaches of photocatalysis, UV light and filtration have good disinfection efficacy for Legionella if supplied by LTDH, and inject no additives into the water. Thus, they can be considered as feasible sterilization solutions.

In terms of the DHW system design methods, in addition to ensure the safe and hygiene DHW supply, the potential DHW systems should also be optimized for better energy and economy performances. Therefore, targeting to different DH systems and building typologies, the optimal solutions can be different. This research investigated a variety of potential solutions by classifications.

For the LTDH scenario, the decentralized substation system is an optimal solution for buildings with new or deep-renovated DHW substations. The decentralized substation system eliminates the risk of Legionella by minimizing the total DHW volume in use. Large amount of the equipment heat loss can be saved by the local DHW preparation and the supplementary heating is unnecessary. As a result, the energy and exergy efficiency of the decentralized substation system are higher than other solutions, while the energy cost of decentralized substation system is the lowest. To fit the LTDH scenario better, two improved forms of the decentralized substation system were devised by replacing the bypass function, so that lower return temperature can be reached. One form is to replace the bypass by an in-line supply riser with a micro heat pump covering the generated heat loss and ensuring the acceptable waiting time for DHW. The improved decentralized substation system has the potential of saving 13% heat loss compared to the decentralized substation system with bypass. The other form is to redirect the bypass flow to the bathroom heating during the non-heating season. With well insulated supply pipe, the bathroom heating flow can substitute for the bypass function and be efficiently cooled down to room temperature by floor heating. The electric heat tracing system can be applied in multi-storey buildings where the DHW circulation pipes can be replaced and in buildings that have special requirements for DHW hygiene, such as hospitals or nursing homes. The electric heat tracing system guarantees the comfort and hygiene DHW supply by supplementary heating locally using electricity. Being improved by the smart control method which can response to the dynamic DHW load profile, the electric heat tracing system can save 50% energy for covering the heat loss compared with the conventional DHW circulation system.

In terms of ULTDH scenario, one solution is the instantaneous heat exchanger unit (IHEU) combined with a micro electric storage tank. The solution can be easily installed in a new building or an existing building with IHEU. The micro tank solution has less heat loss than the substations with normal heat storage. Moreover, the micro tank helps to reduce the peak load of the electric heater, and ensure the acceptable waiting time. Thereby, the bypass function of the heat exchanger can be replaced, which results in lower return temperature and less heat loss. Another solution for ULTDH is the micro heat pump system. Compared to the micro tank solution, the micro heat pump system requires more energy for equivalent DHW preparation, but less electricity. However, the heat loss of the heat pump unit should be taken into account when planning the system. The exergy efficiency of the two solutions are similar, but the micro tank solution has lower energy consumption and energy cost.

In summation, the decentralized substation system with instantaneous heat exchanger unit (IHEU) performed better under the medium-temperature district heating and low-temperature district heating scenarios, while the individual micro tank solution consumed less energy and cost less in the ultra-low-temperature district heating scenario.