District heating (DH) systems supplied by renewable energy sources are one of the main solutions for achieving a fossil-free heating sector in Denmark by 2035. To reach this goal, the medium temperature DH used until now needs to transform to a new concept reflecting the requirement for lower heat loss from DH networks required by the reduced heating demand of low-energy and refurbished buildings combined with the lower supply temperatures required by using renewable heat sources. Both these needs meet in the recently developed concept of low-temperature DH designed with supply/return temperatures as low as 50°C/25°C and highly insulated pipes with reduced inner diameter. With this design, the heat loss from the DH networks can be reduced to one quarter of the value for traditional DH designed and operated for temperatures of 80°C/40°C. However, such low temperatures bring challenges for domestic hot water (DHW) and space heating (SH) systems, from the perspective of both DH customers and the DH company. The aim of this work was therefore to identify, evaluate and suggest solutions.

The first part of the research focused on the feasibility of supplying DHW with no increased risk of Legionella and on the performance of low-temperature DH substations.

The Danish Standard DS 439 for DHW requires that DHW should be delivered in reasonable time, without unwanted changes in desired temperatures (comfort) and without increased risk of bacterial growth (hygiene). While the comfort requirements set the minimum DHW temperature to 45°C, the hygiene requirements set it to 60°C, which is simply not reachable for low-temperature DH. However, the German DHW standard DVGW 551 makes no requirement about minimum DHW temperature if the overall DHW volume is below 3L. This rule was adopted as a cornerstone for the research and for the whole low-temperature DH concept in general, so the minimum DHW temperature is defined by a requirement for 45°C at the kitchen tap.

The performance of a low-temperature DH substation with instantaneous DHW preparation was evaluated based on the results from laboratory measurements supplemented with results from the verified numerical model developed in MATLAB-Simulink. The laboratory measurements showed that the low-temperature substation can heat the required flow of DHW to 47°C with 50°C DH water while keeping the return temperature as low as 20°C. The results of numerical simulations considering the influence of the DH network, represented by a 10 m long service pipe connection for the substation equipped with an external bypass with a set-point temperature of 35°C, showed that the time needed to produce 40°C DHW was 11 s with and 15 s without the external bypass, respectively. DS 439 suggests 10 s as the reasonable waiting time for DHW, so a low-temperature DH substation based on the instantaneous principle of DHW preparation should be equipped with bypass solution keeping the service pipe warm and reducing the waiting time. Traditional bypass solutions simply redirect the bypassed water back to the DH network without additional cooling, but bypassed water can instead be redirected to floor heating in the bathroom to be further cooled and thus reduce heat loss from the DH network while improving comfort for occupants and still ensure fast DHW preparation. Various solutions for the redirection and control of bypass flow were developed and their detailed performance tested on the example of a low-energy single-family house modelled in building energy performance simulation tool IDA-ICE 4.22. The effect on the DH network was simulated with the commercial program Termis on a case study of 40 single-family houses supplied by low-temperature DH. In comparison to the reference case with a traditional external bypass, the proposed solution resulted in average cooling of bypassed water by 7.5°C, reducing the heat loss from DH network during non-heating period by 13% and increasing the average floor temperature by 0.6-2.2°C without causing overheating. The price for heating the bathroom floor during the non-heating period depends on the location of the house and was between 98 and 371 DKK/house, but it seems reasonable to bill all customers with an even and discounted price, reflecting the fact that 40% of the heat delivered to the bathroom floor is covered by reduced heat loss from the DH network. It can be concluded that low-temperature DH with a supply temperature low as 50°C can be used for the delivery of DHW with a supply temperature as low as 47°C and without increased risk of Legionella if the DH substation and DHW system are designed for the low-temperature supply conditions. To ensure the fast provision of DHW during non-heating periods, the supply service pipe should be kept warm, preferably with the bypass solution redirecting the bypass flow to bathroom floor heating and thus at least partly exploiting the additional heat loss caused by keeping the DH network ready to use. The second part of the work focused on SH systems in low-energy and existing buildings supplied by low-temperature DH.

The feasibility of supplying existing buildings with low-temperature DH was investigated using the IDA-ICE program by modelling the example of single-family house from the 1970s, representing a typical example of Danish building stock. The results show that, to maintain the desired indoor temperature and not exceed the originally designed flow rate from the DH network, the DH supply temperature would need to be increased above 50°C in cold periods. In its original state, the house would need to be supplied with a DH temperature above 50°C for 21% of the year and above 60°C for 3% of time, with the highest temperature being 73°C. But if the windows are replaced, which can be expected because their lifetime is coming to an end, the maximum supply temperature is reduced to 62°C and the periods are reduced to 7% and 0.2% respectively. Further improvements, such as the addition of ceiling insulation or the installation of low-energy windows and low-temperature radiators, will allow DH water supply at 50°C the whole year around. The results show that supplying existing buildings with low-temperature DH is not a serious problem and that DH companies should be stricter in reducing the supply temperature, which is very often kept high just because of the malfunctioning of the in-house systems of customers. Moreover DH companies should require that all newly installed and refurbished DH substations should be designed for low-temperature DH to ensure the gradual transition to a temperature level of 50°C in the shortest possible period.

The IDA-ICE program was also used to model the performance of a space heating system with radiators in the low-energy single-family house. The space heating system was investigated from the perspective of the customer, represented by
thermal comfort, and the DH company, represented by a smooth heat demand and low return temperature. To accord with the literature, the modelling of internal heat gains reflected the improved efficiency of equipment by reduction of value from 5W/m² to 4.2W/m², also modelled as intermittent heat gains based on a realistic week schedule. Furthermore, the indoor set-point temperature was increased from 20°C to 22°C to reflect a temperature level preferred by occupants. The results showed that an SH system with radiators can provide the desired indoor temperature while ensuring a smooth heat demand from the DH network and proper cooling. However, using input values suggested by the literature leads to up to 56% greater heat demand than values suggested in the Danish national calculation tool Be10, and in 40% lower connection power than for an SH system dimensioned in accordance with DS 418. Use of Be10 input data in cost-effectiveness analyses for DH networks therefore means worse results, because less heat is sold to customers and there is higher heat loss in the network. Similarly, higher connection power than needed means bigger pipe diameters are needed, resulting in higher heat losses as well. Using realistic values is therefore very important for feasibility calculations of DH.