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Renewable-based low-temperature district heating for existing buildings in various stages of refurbishment

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ABSTRACT

Denmark is aiming for a fossil-free heating sector for buildings by 2035. Judging by the national heating plan, this will be achieved mainly by a further spread of DH (district heating) based on the renewable heat sources. To make the most cost-effective use of these sources, the DH supply temperature should be as low as possible. We used IDA–ICE software to simulate a typical Danish single-family house from the 1970s connected to DH at three different stages of envelope and space heating system refurbishment. We wanted to investigate how low the DH supply temperature can be without reducing the current high level of thermal comfort for occupants or the good efficiency of the DH network. Our results show that, for a typical single-family house from the 1970s, even a small refurbishment measure such as replacing the windows allows the reduction of the maximum DH supply temperature from 78 to 67 °C and, for 98% of the year, to below 60 °C. However for the temperatures below 60 °C a low-temperature DH substation is required for DHW (domestic hot water) heating. This research shows that renewable sources of heat can be integrated into the DH system without problems and contribute to the fossil-free heating sector already today.

1. Introduction

To reduce CO_2 (carbon dioxide) emissions and increase security of supply, Denmark has decided that all buildings will have 100% fossil-free heating by 2035. To reach this goal, Denmark needs to implement energy-saving measures on the demand side, increase efficiency on the production side, and replace fossil fuels with various sources of renewable energy [1]. DH (district heating) is seen as the main solution for achieving the goal because it offers faster and cheaper integration of renewable sources of heat than individual heating sources. Based on the study, Heat Plan Denmark 2008 [2], it is planned to increase the share of DH from the current figure of 46% to 53–70%, with the remaining heating demand, which is mostly in areas with low heating demand density, being supplied by individual heat pumps.

However, this widespread integration of renewable sources of heat with high efficiency and thus reasonable cost will require further reductions in DH supply and return temperatures [3]. Moreover, it will also be necessary to reduce the ratio between DH network heat losses and heat consumption in buildings. This is currently increasing due to reductions in heating demand thanks to [4] the refurbishment of existing buildings and the increasing number of low-energy buildings. The solution is to reduce DH heat losses by using twin-pipe geometry (two media pipes in one casing), thicker insulation, and reduced supply and return temperatures. This philosophy lies behind the concept of low-temperature DH, in which the supply temperature is reduced to 55–50 °C and the return temperature to 30–25 °C [5,6]. The minimum supply temperature of 50 °C is defined as the lowest primary temperature needed to supply the required 45 °C DHW (domestic hot water) at tapping points [7]. Low-temperature DH is the optimal concept for the integration of 100% renewable sources of heat.

Reducing heat loss from DH networks makes economic sense for the whole system and also enables supply to areas with low heating demand density, e.g. low-energy housing areas. The economic feasibility and high level of comfort for occupants have been demonstrated in a pilot low-temperature DH project in Lystrup, Denmark, where low-temperature DH supplies an area with 42 low-energy single-family houses [8]. The heat loss from the Lystrup DH network, with design supply/return temperatures of 50/25 °C, is only one-quarter of what it would be if the network had been designed with the traditional temperatures of 80/40 °C [9,10]. The

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houses are equipped with radiators designed for 50/25 °C supply/return temperatures. The 50 °C supply temperature to the SH (space heating) system is enough for newly built buildings, designed mainly with floor heating or low-temperature radiators, and there is still the option to boost the supply temperature during the coldest periods. In fact, the DH supply temperature can be even lower, but then it needs an additional system to heat up DHW to the desired temperature level. Such a system has been recently tested in Birkerød in Denmark, where four single-family houses are supplied with DH with a temperature of 40 °C. This temperature is enough for the space heating system, but the DHW is additionally heated by a newly developed micro heat pump supplied with heat from the DH network [11].

However, low-energy buildings still comprise only a small share of the building stock while the majority are older buildings with considerably higher heating demand. Existing buildings are usually equipped with SH and DHW systems designed with supply temperatures of around 70 °C or higher, so a reduction of DH supply temperature would be expected to cause discomfort for the occupants. These buildings will continue to make up a large share of the building stock for many years (in Denmark, about 85–90% in 2030 [3]), so the question arises as to whether such buildings can cope with low-temperature DH with supply temperatures of 55–50 °C and, if not, what renovation measures need to be carried out on the building envelope and the building heating and DHW systems, or how the DH network should be operated.

Some scientific research has focused on DH in relation to the refurbishment of existing buildings and reporting how much CO_2 emission will be saved, how the reduced heating demand will affect the DH companies from the perspective of heating sold and the reduction in peak heat output of boilers, and suggesting new price tariffs [12]. But we found no papers focussing on the possible reduction of DH supply temperature to existing buildings, and considering their DHW and SH systems from the perspective of integration of renewable heat sources into the DH network.

The maximum supply temperature needed can be reduced by improving the building envelope or by changing the original SH system to low-temperature system. From the long-term perspective, the preferred solution is to reduce the energy demand by improving the building envelope, but due to the cost not every house owner is willing to do this. Changing the SH system is a cheaper and faster solution, but it does not bring any energy savings; it just allows existing buildings to be supplied by DH with reduced supply temperatures. The refurbishment measures carried out on existing houses, e.g. those built in the 70s, vary from no measures (original state) to extensive renovation, including replacing the windows and wall and roof insulation. Replacing the windows is the most typical refurbishment carried out on these houses, because the window lifetime of 30 years has passed and a relatively small investment brings considerable heat savings.

1.1. Proper design and operation of space heating system

To evaluate the possible reduction of supply temperature to existing buildings, we should start with the proper design of an SH system and with realistic operation conditions. According to Danish Standard DS418 [13], SH systems should be designed for an operative temperature of 20 °C as an indoor temperature, a steady-state outdoor temperature of −12 °C, and no internal and solar heat gains. The operative temperature involves both air and mean radiant temperature, and thus defines how the occupants perceive the environment. Nevertheless, it is very probable that SH systems in the 70s were in fact designed with the air temperature alone, because the hand calculation of operative temperature is simply very complicated. In low-energy buildings, the difference between operative and air temperature is very small, so error caused by using air temperature is negligible, but in older buildings, constructed without good insulation properties, the difference can be rather high due to cold surfaces. This means that, even when the air temperature is at a comfort level of 20 °C, the occupants can feel cold because the operative temperature is lower (e.g. 18 °C). Moreover occupants tend to set the operative temperature to 22 °C instead of 20 °C [10]. This raises the question of how an SH system designed on the basis of air temperature will perform when the occupant increases the set-point temperature and how this will affect the DH network. Both will result in the need for higher heat output from the SH system and thus increased water flow and higher return temperatures from the SH and also DH system and, if one of the systems does not have enough hydronic capacity, this can cause thermal discomfort for customers. This clarification is therefore important in any investigation into the possible reduction of the DH supply temperature.

1.2. DHW system

Considering the possibilities of reducing the DH supply temperature to 50 °C, it should be kept in mind that DH is used also for DHW heating. For DH supply temperature reduced below 60 °C, the recently used DHW substations need to be replaced with specially designed low-temperature DHW substations. Such substations with compact and very effective heat exchangers are already in use in Lystrup [5] and provide a high level of comfort for occupants as well as good cooling of DH water. For the design conditions, i.e. 13.2 L/min of DHW heated from 10 to 45 °C, the substation provides cooling on the primary side from 50 to 20 °C [14]. The only change the customers experience is the maximum DHW temperature reduced to about 47 °C which is still enough. However since the DHW temperatures is below 55 °C a special attention should be paid to the risk of Legionella, increased mainly in the temperature range 30–50 °C. Most of the national DHW standards therefore require minimal temperature of DHW to 55 °C, simply not reachable by low-temperature DH. Nevertheless due to the German standard DVGW 551 [15] there is no requirement for the minimal DHW temperature for "small DHW systems with volume below 3 L" (excluding volume of the heat exchanger and DHW circulation loop) giving the possibility to use low-temperature DH anyway. In fact most single-family houses with a modern DHW system will fulfil this requirement, because 3 L for ½″ pipe (DN 15) means 15 m of pipes, which should be enough. If the volume of water in the DHW pipes is above 3 L, the piping can be changed from 1/2″ to 3/8″, which will increase the maximal length of the pipes to 25 m.

Where buildings currently use an in-house substation with DHW storage, a 3 L requirement can be fulfilled by replacement of the original substation with a 120 L storage tank for DH water [16]. The principle is shown in Fig. 4. The storage tank acts as a buffer tank for DH water, and DHW is heated instantaneously in the heat exchanger only when needed. In such a solution, there is no storage of DHW, which otherwise should follow the rules about a minimum temperature of 55 °C. DHW circulation is not prohibited for either type of DH substation, but it is not recommended because of large heat losses.

For multi-storey buildings with a traditionally designed DHW system with vertical risers, low-temperature DH can only be used if some kind of DHW disinfection is provided, because the volume of the DHW system is above 3 L. Thermal disinfection is a well-known concept, but the connection of low-temperature DH means there is a need for an additional source of heat, because efficient thermal disinfection needs at least 60 °C while the supply temperature of low-temperature DH is only 50 °C. The higher the disinfecting temperature is, the shorter time water