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Method to investigate and plan the application of low temperature district heating to existing hydraulic radiator systems in existing buildings

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ABSTRACT

This study presents a method to adapt existing hydronic systems in buildings to take advantage of low temperature district heating (LTDH). Plate radiators connected to double string heating circuits were considered in an optimization procedure, based on supply and return temperatures, to obtain the required logarithmic mean temperature difference (LMTD) for a low temperature heating system. The results of the analysis are presented as the average reduction of LMTD over the heating season compared to the base case design conditions. Two scenarios were investigated based on the assumption of a likely cost reduction in the end users' energy bills of 1% for each 1 °C reduction of return and average supply and return temperatures. The results showed possible discounts of 14% and 16% respectively, due to more efficient operation of the radiators. These were achieved without any intervention in the thermal envelope or to the heating systems, through simply adjusting the temperatures according to demand and properly controlling the plate radiators with thermostatic radiator valves (TRVs).

1. Introduction

In the EU households, heating for space heating (SH) and domestic hot water (DHW) consumes 79% of the total final energy use (192.5 Mtoe), representing one of the largest carbon emitting sectors of the economy [1,2]. As a consequence, decarbonizing the heat sector is being considered central to the EU energy policy to foster a carbon neutral society and achieve the reduction in the greenhouse emission of 40% and 80% by 2030 and 2050 respectively to the level of 1990 [3–5]. Currently, heat supply in buildings in the EU is mainly provided by individual heat sources installed in buildings or alternatively through district heating (DH) networks. The latter are widely used in Scandinavian, Eastern European countries and Russia. District heating offers high flexibility for the integration of renewable heat sources, though still faces the technical challenge of matching different heat sources' supply temperature and demand. Driven by the need to use low carbon heat sources, the current focus is to develop low temperature district heating systems, referred to as 4th generation district heating (4GDH) [6]. One key design parameter in the development of 4GDH is the reduction of supply and return temperatures from the current standard of 80/40 °C to load dependent temperatures with a target of 50/20 °C. As DH in general covers the demand for SH and DHW, the limit for the supply temperature of 50 °C is imposed to avoid health problems due to Legionnaires' disease in sanitary water [6,7]. Recent studies show that buildings can be maintained at comfortable temperature levels with low supply temperatures for the majority of the heating season and using a 4GDH system with flexibility to adjusting the temperatures according to heat demand during extreme low outdoor temperatures. This would improve the overall efficiency of heat generation and reduce heat losses in the network [8–10]. Therefore, one of the issues in the implementation of low temperature district heating (LTDH) is the calculation of the optimal combination of supply and return temperature to operate the heating systems according to heat demand. In fact, reducing supply temperature to 50 °C poses few technical problems in regard to the capability of existing heating systems to guarantee the same thermal comfort. Commensurate with low-energy buildings, which use efficient heat emitters such as low-temperature radiators or underfloor heating, water supply

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List of symbols and acronyms

DH	district heating
LTDH	low-temperature district heating
LMTD	logarithmic mean temperature difference (°C)
$LMTD_0$	logarithmic mean temperature difference at design condition (°C)
ΔT	delta T between supply and return temperature
TRV	thermostatic radiator valve
SH	space heating
DHW	domestic hot water
ϕ	heating power at operating temperatures (W)
ϕ_0	nominal heating power at design conditions (W)
n	radiator exponent
$\dot{m}$	mass flow rate (kg/h)
$\dot{m}_0$	max mass flow rate (kg/h)
c_p	specific heat capacity of water (J/kg °C)
T_S	supply temperature (°C)
T_{S_0}	supply temperature at design conditions (°C)
T_R	return temperature (°C)
T_{R_0}	return temperature at design conditions (°C)

temperatures of 50 °C or even lower would technically be adequate to meet SH demand all year round [11–13]. Hence, the challenge is to adapt the existing large building stock and the already installed hydronic heating systems for the applicability of LTDH, without any major design and construction intervention, yet adjusting water temperatures to heat demand.

1.1. Aim

The aim of the work presented in this paper was to develop a method to investigate and plan the introduction of LTDH to existing hydraulic radiator systems in existing buildings. The scope of this work was to express the heat demand as a function of logarithmic mean temperature difference (LMTD) between the water of the hydraulic radiator and the heated building zone. The results of the investigation are expressed as an average reduction in LMTD over the heating season compared to the design conditions. The needed LMTD can be reached by numerous combinations of supply and return temperatures to the radiator; these have different economic benefits and therefore an optimization process to define the best combination of supply and return temperatures is needed. Hence, two different scenarios for double string plate radiators were used to test the developed method and outline the strategy to connect existing buildings to LTDH.

1.2. Modelling performance of different types of heating elements for low temperature operation

Lower return temperatures are beneficial for DH technology, by reducing the network distribution losses and mass flow rates, as well as improving the efficiency of energy generation [14–17]; this is even more important for the LTDH concept, where return temperatures have to be cooled to almost indoor temperature. In mature DH markets such as in Denmark, Sweden and Finland, LTDH has been successfully applied and tested in real projects. Good results proved the concept in case of low-energy buildings [8,18,19] and further investigations have been carried out for existing buildings at different levels of refurbishment [20,21]. However, none of these articles includes an optimization process, based on the economic value of lower supply and return temperatures for DH companies and end users, to define the optimal operating temperatures in the implementation of LTDH to existing buildings with radiator based heating systems. Hence, to correctly address the challenge of operating existing hydraulic radiators with low water supply temperatures, necessary considerations must be given both to the design of the heat emitting radiators (hardware) and the modelling analysis to optimize the performance.

1.3. Hardware part – type of heating systems

Hardware considerations include the different types of heating elements, the way they are operated and controlled in order to efficiently perform. Commonly, flat panel radiators are manufactured by combining up to three flat plates and incorporating fins to augment the heat transfer area [22,23]; they can have a high or low profile. By far the most used hydraulic configuration for radiators is the double string system, consisting of two pipes, one for supply and one for return. Typically, hot water is supplied to the top of a radiator to let the water flow diagonally downwards and cool gradually before leaving from the opposite bottom corner [24]. Although low level panel radiators are used in some cases, especially if there are space restrictions, they can lead to slightly higher return temperatures compared to taller ones, due to the reduced height; hence particular attention is necessary during the selection of the element if low return temperatures have to be attained. Another possible hydraulic configuration for radiators is the one string system, characterized by only one pipe for both supply and return; the radiators are connected in a way that a fraction of the water flow in the main string runs through the radiator and exits back to the main string. The temperature though is gradually reduced as this enters to each successive radiator. This solution fosters the system to work with higher mass flow rates and lower temperature difference (ΔT). If carefully designed by increasing the size of each successive radiator [25], as reported in this study published by the Swedish DH association [26], return temperatures can be as low as in double string systems in typical DH networks. Nonetheless, as difficult to properly control, it is common to experience higher return temperatures and smaller ΔT in the substation, hence this reduced their attractiveness in comparison to double string systems, in particular when connected to district heating [27]. Similar to the radiators with single string hydraulic configuration, heat convectors lead to higher return temperatures due to high flow rate and low ΔT. They are characterized by heat transfer to the surrounding mainly by convection and the most common layout consists of a finned long tube, which generally follows the perimeter of exposed walls and/or windows [22–24,28,29]. These heating elements – likewise water radiators with single string layout – still can be found in existing buildings, but they are not recommended for DH in general and in particular not for LTDH applications, where return temperatures close to room temperatures have to be achieved. Central to hardware discussion is also the way radiator elements are controlled, typically by thermostatic radiator valves (TRVs). TVRs are passive water flow regulating devices that maintain set-point room temperature; this guarantees the required indoor comfort in an efficient way as well as the expected cooling of return temperatures. It also allows the heat output to modulate and compensate for emitters that can be over-dimensioned during some periods of the heating season [30–32]. However, it is quite common in real applications for TRVs to operate poorly and negatively affect the overall system efficiency. The work of Ziao et al. [33] found that in hydronic radiator systems, although TRVs were installed in almost all the systems surveyed, in 65% of the cases they were performing poorly, mostly due to occupants misuse, and generating thermal discomfort and wasted energy. Therefore it is important to limit the side effect of human behavior on the effectiveness of TRVs [34], as these have a decisive role in overall system efficiency and in the