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Adaptive control of radiator systems for a lowest possible district heating return temperature

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ABSTRACT

The present paper describes how the control of a radiator system connected to a district heating (DH) network via a heat exchanger can be optimized to provide the lowest possible DH return temperature. This can be achieved for each operating point by employing an optimal combination of radiator circuit supply temperature and circulation flow rate. The control algorithm gradually modifies the control curve for the radiator circuit, enabling it consistently to provide an optimal cooling of the DH water. Since the heat exchanger is dimensioned for very low outdoor temperatures, it is oversized for smaller heat loads. In addition, radiator systems are often oversized due to safety margins. Such facts render it possible to reduce the DH return temperature. The objective of the present study was to develop a control algorithm and to test it in practice. A description is here given of the algorithm, and, additionally, of field tests that were undertaken to practically verify it. The adaptive control method could be implemented in any modern radiator circuit control logics, and the achieved improvement was an added 2 °C district heating water cooling, resulting in a 3.5 per cent reduction in average district heating flow.

1. Introduction

The present paper demonstrates how the operation control of a radiator system connected to a district heating (DH) network via a heat exchanger (HEX) can be optimized to provide the lowest possible DH return temperature. This is undertaken by always selecting the optimal radiator supply temperature and flow rate.

1.1. Relevance of the topic

The benefits of low return temperatures are prominent in the DH technology [1]. In the existing DH systems, a lowering of the return temperature in the network decreases heat losses and either reduces the pumping power or allows connection of new customers to the network. There is also a positive influence on the performance of heat/power plants supplying heat to the system. However, the DH return temperature from a particular DH substation can never be lower than the return temperature generated by the internal hydronic heat distribution system of the building. Therefore, efforts have been made to optimally reduce that temperature on the design stage or by redesigning the temperature control method of the space heating system—see Section 2.2. A specific advantage of the control method demonstrated in this paper, as opposed to, for example, conventional low-flow balancing, is its robustness, enabling the lowest possible return temperatures to be consistently obtained. This is the case independently of the current outdoor temperature and heat load; even if the DH supply temperature changes, the HEX becomes fouled, or the house heating requirements change. The idea is also to utilize the fact that, since a HEX is dimensioned for an extremely low outdoor temperature, it is in fact oversized for all other (smaller) heat loads. In addition, radiator systems are generally also oversized for safety reasons, thus providing further potential to reduce the return temperature.

1.2. Objective

The objective of the study is to develop a control algorithm for determining the optimal choice of supply temperature and flow in an arbitrary, pre-existing radiator system in order to minimize the primary return temperature in the DH substation. The study is an implementation of the authors' previous theoretical work [2].

1.3. Method

The study was conducted through a combination of field experiments and computer simulations. We were able to monitor and control the substations remotely in real-time.

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1.4. Limitation

The present investigation focuses on DH substations that were indirectly connected to the DH network, i.e. hydraulically separated by HEXs, and have been in operation for at least some years. The heat transfer in the HEX is optimized in relation to demand from the DH system.

2. Heating system temperatures

2.1. Conventional temperature curves

Various ways exist to control the heat output in a heating system. Such methods can be based on a constant supply temperature combined with local flow control, or a constant flow rate in combination with a supply temperature curve, or both. The control of the heat output can be based on a feedback (e.g. indoor temperature) and/or the feedforward (e.g. outdoor temperature) control signal. Here, we have addressed the prevailing control method used in Sweden: an outdoor temperature-compensated, fixed supply temperature, ensuring that an adequate amount of heat is supplied to the building at each outdoor temperature. The feedforward signal (outdoor temperature) is usually dampened depending on the thermal inertia of the building. and, in certain cases, supplemented by, for instance, the wind speed. The radiators are normally equipped with thermostatic radiator valves (TRVs), of which the main task is to prevent heat gains (solar radiation, electrical equipment or bodily warmth) from overheating the room.

In order to select the design temperatures of the radiator system, various recommendations have prevailed during different periods and in different countries [3]. Presently, lower temperatures are generally in use (e.g. 60/45 °C, 60/40 °C or 55/45 °C as design supply/return temperatures), while higher temperatures have traditionally been employed (90/70 °C and 80/60 °C). There is a substantial oversizing of the radiator system in general, and of the radiator surfaces in particular, as presented in both Swedish [4,5] and international studies [3,6,7]. This is due to an overestimation of a building's heat losses, which often decrease over time by energy-saving measures. Moreover, another reason is that, during the design stage, the components are generally selected in sizes larger than required to ensure safety margins.

2.2. Optimized temperature programmes

The benefits with regard to the primary return temperature from adjusting the flow according to the heat load are recognized. The concept of using an optimal combination of flow and supply temperature was conceived in 1987 by Frederiksen and Wollerstrand [8], and this theory has been further studied [9,10]. The guidelines from Euroheat and Power [11] state that the lowest return temperature is obtained by varying the flow according to the consumption. If such a variable flow is used, it is controlled by TRVs either in combination with a constant supply temperature or with an outdoor temperature-compensated supply temperature. Langendries [12] suggests a central control of the flow rate through the pump's rotating speed, although claims that it appears to be a rather difficult and expensive system. Furthermore, Petitjean [13] proposes a lowering of the pump speed at low heat loads, when the TRVs are almost fully open, but finds it problematic to determine which parameter to use for controlling the pump speed.

This complies with general studies on heat exchanger optimization. In DH substations, the counter-flow plate HEX is state-of-the-art today. Considering that there is the same medium, water, on both primary and secondary sides of such a heat exchanger, the most effective solution (the highest overall heat transfer coefficient and the lowest entransy dissipation) would be if the flow on both sides of the HEX were equally large [14]. However, in a typical DH substation, the majority of the time, the HEX operates in the part load regime and the primary flow varies substantially. On average, the primary flow is significantly lower than the flow on the secondary side. Hence, this requires a dedicated control system that would maintain a secondary flow rate as close as possible to that on the primary side at all loads, without disturbing the overall function of the secondary circuit.

The control method described in this paper suggests how the secondary flow can be determined for each heat load. The flow is regulated by adjusting the pump's rotating speed. Currently, speed-controlled pumps are commonly used and provide a superior controllability [3,11].

Furthermore, with optimized control, there exists preparedness for future changes in system temperatures in the DH network. In event of the DH supply temperature being changed, an adaptive control could ensure that the lowest possible return temperature is always achieved.

In order to realize such an algorithm, control of the radiator supply temperature must be combined with control of the radiator flow as a function of the heat load and the DH supply temperature. Fig. 1 shows a simplified view of a DH-connected radiator system. The essential components for this work are displayed, such as heat exchanger, control equipment and pump. $T_{p,s}$ and $T_{p,r}$ denote primary (DH) supply and return temperatures, respectively, and $T_{s,s}$ and $T_{s,r}$ denote secondary (radiator) supply and return temperatures, respectively. The diagram to the right exemplifies temperature levels depending on current outdoor temperature in an innovative, variable flow radiator system as proposed in [2]. The improvement in primary return temperature and the primary flow to radiator flow ratio in the HEX compared to a standard 55/45 °C radiator system is also shown.

3. The test objects

The tests have been undertaken in four multi-residential buildings in the residential area of Fridhem in the town of Karlshamn, Sweden. The houses were built between 1967 and 1968 and the number of flats varies from 20 to 30 per house.

The radiators in all houses are fitted with TRVs, however, these are at least ten years old. It is thus uncertain whether they functioned properly. The circulation flow was determined as not significantly variable in any of the radiator circuits, which may have been an indication that many of the TRVs are faulty. However, it should be noted that the presented control algorithm is independent of the use of TRVs in a system. Whatever combination of optimal supply temperature and flow is identified for a given outdoor temperature, the heat supply will be identical.

The substations are equipped with control logics of the brand IQ Heat (Alfa Laval AB). The equipment for the building automation was manufactured by Siemens and furnished with a separate communications module that could also be used for executing minor computer programmes. Additionally, there is an internet connection, rendering it possible to communicate in several ways, such as via the software Saphir ScopeMeter© (Siemens), or FTP. After a reconfiguration, the pump speed could be controlled, since all pumps were equipped with communication modules.

3.1. Characteristics of the test objects

From logged data, it could be determined that all HEXs give approximately the same grädigkeit, i.e. difference between primary and secondary return temperatures. The flow rates were, in general, half of the design values, and the temperature drop at DOT was on