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Method for reducing excess heat supply experienced in typical Chinese district heating systems by achieving hydraulic balance and improving indoor air temperature control at the building level

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ABSTRACT

A common problem with Chinese district heating systems is that they supply more heat than the actual heat demand. The reason for this excess heat supply is the general failure to use control devices to adjust the indoor temperature and flow in the building heating systems in accordance with the actual heat demand. This results in 15–30% of the total supplied heat being lost. This paper proposes an integrated approach that aims to reduce the excess heat loss by introducing pre-set thermostatic radiator valves combined with automatic balancing valves. Those devices establish hydraulic balance, and stabilize indoor temperatures. The feasibility and the energy consumption reduction of this approach were verified by means of simulation and a field test. By moving the system from centrally planned heat delivery to demand-driven heat delivery, excess heat loss can be significantly reduced. Results show that once the hydraulic balance is achieved and indoor temperatures are controlled with this integrated approach, 17% heat savings and 42.8% pump electricity savings can be achieved. The energy savings will also have a positive environmental effect with seasonal reductions of 11 kg CO_2, 0.1 kg SO_2, and 0.03 kg NO_x per heating square meter for a typical case in Harbin.

1. Introduction

Research has shown that DH (district heating) is playing an important role in the societal goal of realizing an effective and sustainable energy system [1–5]. Along with the rapid growth of urbanization and industrialization, China has become one of the largest DH markets in the world in the last two decades. Statistics indicate that the total DH production in 2013 amounted to 3,197,032 TJ [6]. This number is still increasing steadily due to the process of rapid urbanization, expansion of the building area, enhancement of building services, and increases in comfort level. On the other hand, according to a World Bank report in 2012, the consumption of heating energy in China per square metre of floor area is almost twice that in developed countries at the same latitude. Nevertheless, the resulting room thermal comfort in China is still unsatisfactory [7]. Furthermore, the 2011 Annual Report on China Building Energy Efficiency [8] reports that 15%–30% of the total heat is being lost due to excess heat supply in northern China's DH systems. These high losses are primarily due to a failure to use control devices to control the heating supply in accordance with the actual heating demand. There is an urgent need to apply appropriate technical approaches to improve the Chinese DH efficiency to create the maximum synergy between energy supply security and air pollution abatement, which are the two most important challenges for China today [9].

Chinese DH systems are very different from European DH systems. Structurally, a typical Chinese DH system is like this: pressurized hot water as the heat medium is produced in the central heat source and distributed to a few area substations (the primary side of the DH system). Each area substation then serves a number of multi-storey or high-rise buildings (the secondary side of the DH system). The heat entrance is the interface connecting the large-

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area substation to the building heating system (see Fig. 1). It is usually equipped with shut-off valves, and measurement devices like thermometers, pressure gauges and heat meters, etc. [10].

In terms of temperatures, China's national design code [11] states that the DH primary side network should be designed with supply temperatures of 115 °C~130 °C and return temperatures of 50–80 °C. The design code does not state any minimum design temperature difference. For the radiator SH (space heating) systems, the design supply/return temperatures are recommended as 75/50 °C or 80/60 °C [12]. In practice, DH systems generally operate with different temperatures based on various conditions for the particular DH systems.

In terms of heat sources, the main heating production facilities are the coal-fired boilers and CHP (combined heat and power) plants. For instance, in 2013, 48% of DH came from coal-fired boilers, 42% CHP plants, 8% gas-fired boilers, and the remaining 2% came from scattered and individual heating facilities. Furthermore, coal is the dominant DH fuel in China [13]. Statistics show that 91% of the total energy supply to DH systems came from coal in 2008 [14].

Moreover, unlike European DH systems where DH supply covers both SH and DHW (domestic hot water), approx. 90% of Chinese DH systems supply SH without DHW [15].

These important characteristics make it possible to understand why excess heat supply occurs in typical Chinese DH systems.

From the perspective of temperature control, room temperature regulation and control functions are not available in approx. 84% of the total heating area in China [16]. According to the national code [12], 18 °C is the standard room temperature for heat consumers in northern China to evaluate whether the heating effect is up to the required standard. The DH utility usually increases the secondary circulation flow rate until at least critical consumers attain this standard, which often results in the systems operating with large volume flow and small temperature differences between the supply and return streams. Moreover, once the heat demands of the critical consumers are fulfilled, the secondary flow rate often remains constant, with the varying SH demand being met by adjusting the secondary side supply temperature. Furthermore, there is a lack of automatic weather compensation control in some cases at substation level. Manual adjustment may be applied. e.g., tentatively adjusting the opening of the control valve installed on the primary side of the DH system, which is eventually reflected in changes in secondary supply temperatures. Such manual operation is based on the experience of past years and the level of complaints from critical users of the system, and the purpose of adjusting the supply temperature is to correlate the heat supply with the outdoor air temperature. Consequently, when the supply temperature to the SH system is higher than required, consumers will open windows to get comfortable indoor temperatures. In some cases, TRVs (thermostatic radiator valves) are installed in the DH systems. However, they are typically left fully open. Due to the fixed heating charges based on heating area, not actual heat consumption, there is no incentive for consumers to consciously reduce the TRV settings in an oversupply situation. They would generally regulate the indoor temperature by opening the windows. All these factors mean that consumers are either unable to control their room heating supply or lack motivation for energy conservation, which means excess heat supplied is wasted.

From the perspective of flow control in the secondary DH network and at building level, there are no automatic flow control devices, which results in an uneven flow distribution in the secondary-side DH network. Buildings close to the substation receive more flow than needed and become overheated, whereas buildings located in distal parts of the network receive less flow than required and are unable to fulfil their heating requirements. There is a lack of hydraulic balance inside the buildings. Specifically, the secondary side of Chinese DH systems generally operates on a constant flow and pressure basis. The pressure head at the pump is controlled to maintain constant differential pressure at area-substations. In addition, the constant flow operation principle makes the pumps run at constant speed. Although there are some variable-speed pumps, they are mainly used to correct the deviation between the design and operation conditions in terms of the pressure head and flow rate. Large volume flow leads therefore to higher than necessary electricity consumption in circulation pumps, small temperature differences, high return temperatures, and network heat losses.

In summary, it can be said that the general failure to use temperature and flow control devices in Chinese DH systems is the direct cause of excess heat loss, which subsequently compromises the efficiency of Chinese DH systems.

Studies have investigated how to improve the efficiency of Chinese DH systems by focusing on various DH elements [17–28]. With the heat reform in 2006 in China, 16% of the total heating area in China was given a heat metering retrofit [16] to install TRVs (thermostatic radiator valves) by the year 2012. A lot of research has been carried out on TRV application in Chinese heating systems [29–35]. For instance, Xu et al. [33] investigated how hydraulic performance and energy consumption in individual apartments and the whole system were influenced when TRVs were regulated and when windows were opened. Xu et al. [34] developed a dynamic model and simulated the thermal and hydraulic behaviour of

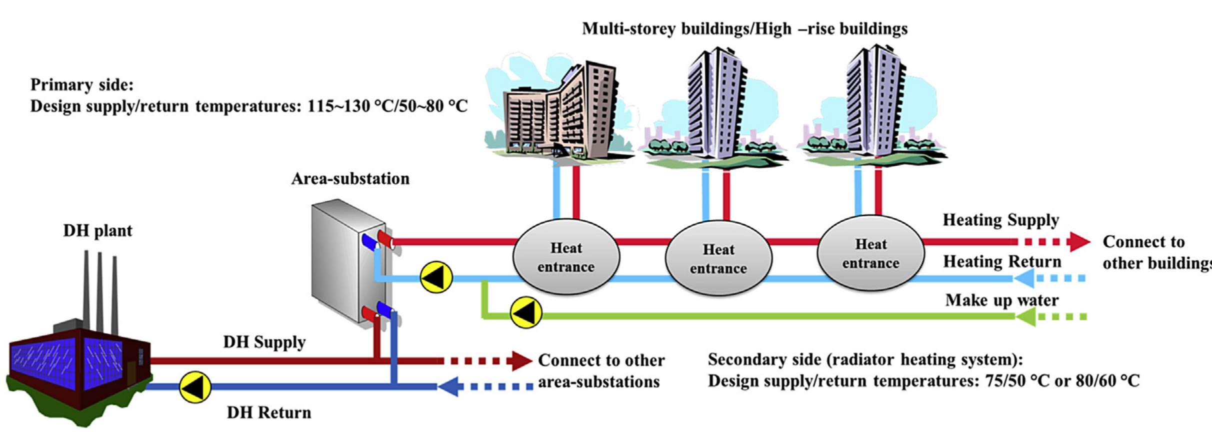

Fig. 1. Typical district heating system used in China.