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Research Article

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Survey of District Heating System Operational Temperatures: Return Line-Based View

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Abstract The work follows tasks to reiterate return line overheating issue, provide an appropriate technique to evaluate overheating, and compare results obtained with the 'as is' pattern.

We provide a novel method for calculating an overheat taking into account an actual temperature in supply line, a temperature in supply line according to curve, and an average through the day outdoor temperature. Real operational temperatures are obtained by full automatic heat metering system installed at an inlet and outlet of the central heating plant.

We showed no direct correlation between actual temperatures in the supply and return temperatures. The new overheat profile represents more accurate case since it always relies on actual values and does not drop below zero while heat metering continuously shows design curve is not met. By means of novel calculation technique we are now able to predict whether substation is faulty.

The proper assessment ensures DH Supply Company to approve sanctions accurately. The issue of running high temperature of return water from the residential area is another time highlighted. Further troubleshooting in individual building installations is expected to lower the return temperature, thus modern substations for each building or group of buildings should be installed.

Keywords DH; pipe; network; substation; combined heat-and-power

Introduction

Temperatures of supply and return lines affect many critical parameters such as amount of energy that can be stored in the District Heating (DH) network, heat losses while energy is distributed and efficiencies for electricity production in steam turbines [1]. Web page [2] answers why low flow return temperatures are not achieved. Introduction of 4th generation district heating (4GDH) concept is an enormous challenge for district heating (DH) companies in Latvia and Russia, since most of the DH systems are now running at high temperature mode [3]. Probably following this idea Russian and not only scientists [4–6] put reliability and life time concerns first.

Lower return temperature has several benefits in a DH system such as increased electrical output from CHP-plants; it increases heat recovery from flue gas condensation as well [7]. Bolonina et al. [8] have studied the similar theme although they analysed the impact of supply temperature modification. Return line has a great impact on a supply one and vice versa since the DHN is a closed system, where supply and return lines are connected via consumers' sub-stations [9] Many studies are confirming the high efficiency of district heating compared to other heating options. Ma et al. [10] emphasis the role of data since it opens up new opportunities for a better understanding of consumer behaviour, clustering energy consumption patterns, and further optimizing energy production and distribution. As for currently trending heat pumps [11,12] the model variables are typically heat flows and the effects of the supply temperature and flow meanwhile return temperature is not directly considered [1]. Since high return temperature will lead to large amount of overall distribution energy cost, the temperature difference faults can be detected and eliminated by using fault detection approaches such as [13]. At the meantime quite a comprehensive review [14] identified no modelling tool with a potential of overheat simulation. There is also pretty much literature discussing load variation [15–18]. As expected, since the main target of these algorithms is to smooth load profiles, not to reduce operational temperature. Zarin Pass et al. [19] contributed science studying an effect of relative heating/cooling load on a DH plant flow rate and temperatures. Vanhoudt et al. [20,21] provide correlations to approximate impact of thermostatically controlled loads on a DH network for a wide range of conditions. M. Chertkov and N. Novitsky [22] investigated return temperature diversity depending on the amount of heat demanded by customers. Latosov et al. [17,23] surveyed the amount of heat consumption thoroughly. Relevant sources [3,24] concentrate on DH network temperature but with a designing and drafting point of view, not an operation and maintenance (O&M) one.

The common solution to reducing heat losses is to apply more insulation [25–27] and even to keep the supply and return lines in the single casing affecting increase of return temperatures. Our conclusions once again raised an issue of the necessity of planning strategies for district heating networks [28]. Basalaev et al. [29] focused on modeling DH network with a simulation study on temperature though only supply one. Additional information about the models can be obtained from Claessens et al. [21] but they are mainly at simulation of buildings' impact. Furthermore several studies [13,30] have been conducted where performance of DH system has been evaluated in existing buildings (substations) to investigate if the operating temperatures can be modified.

The present work follows tasks to (a) reiterate return line overheating issue occurring due to poor operation, (b) provide an appropriate technique to evaluate overheating numerically, and (c) compare results obtained with the 'as is' pattern.

Materials and Methods

As stated in [14], the mass flow rate and the temperature can be assumed to be decoupled, without losing accuracy in the case of the distribution pipe model. So that any hydraulic issues are here neglected. Supply temperature is typically modulated to meet a pre-programmed supply temperature curve commonly linked to the outdoor temperature. Traditional design conditions in Russia, particularly in Omsk city, for DH systems with conventional radiators involve supply and return temperatures of 150 and 70°C respectively. DH network design temperatures are based on the design power of the whole system. This design power corresponds to the maximum heat output based on the difference between the indoor temperature and the outdoor temperature on a very cold day. The outdoor temperature for which the design power is selected, is called the design outdoor temperature (DOT). This temperature varies depending on the climate of the location where the city is located [30]. For Omsk city, a common DOT for the design of a DH network is -37 °C. The change-point temperature is +0.3 °C above it base-loads are served.

More specifically, base-loads are part of a class of load that is temperature-independent. Loads related to maintaining comfortable space conditions are temperature-dependent. The change-point temperature is a measured point for outdoor temperatures above which the heating load becomes independent of temperature (or vice versa for cooling).

Unexpected raise of return temperature (overheat) is normally calculated as follows:

$$\Delta t = t_r^a - t_r^c \tag{1}$$

where t_r^a is an **A**ctual temperature in **R**eturn line (°C),

t_r^c is a temperature in **R**eturn line according to **C**urve (°C).

We provide a novel method for calculating an overheat:

$$\Delta t' = t_r^a - \left[t_s^a - (t_s^c - t_r^c) \cdot \frac{(t_s^a - t_o)}{(t_s^c - t_o)} \right] \tag{2}$$

where t_s^a is an **A**ctual temperature in **S**upply line (°C),

t_s^c is a temperature in **S**upply line according to **C**urve (°C),

t_o is an average through the day **O**utdoor temperature (°C).

As stated our case study is a traditional high-temperature DH system in Omsk, Russia. The system includes the CHPP#5 using fossil fuel (coal) as a source of heating and electricity only (no cooling loads) to cater energy to buildings connected to a DH network.

Hot water is pumped through the primary network to substations tend to be situated in these buildings. The heat exchangers in the substations supply secondary pipes which enter into a building that is called indirect connection. There is no exact record about the number of substations, which adversely affects the function of the DH system itself. The system is believed to include more than 3000 operational heating substations (according to the DH system maps obtained from the Company) with capacity of 1264.583 Gcal/h.

Here invoicing is not based on the actual heat consumption, and heat tariffs do not promote efficient use of heat in the buildings, therefore a problem of inefficient heat use and associated with it return overheating exist. Real operational temperatures are obtained by full automatic heat metering system installed at an inlet and outlet of the central heating plant (CHPP#5); it is now available as a data set [31]. When more data is available, more valuable results can be obtained from data analysis [10].

Results and Discussions

The relationship between the outdoor temperature and DH network temperature is also evident from Figure 1, which shows that there is a clear difference in actual and design temperature curves.

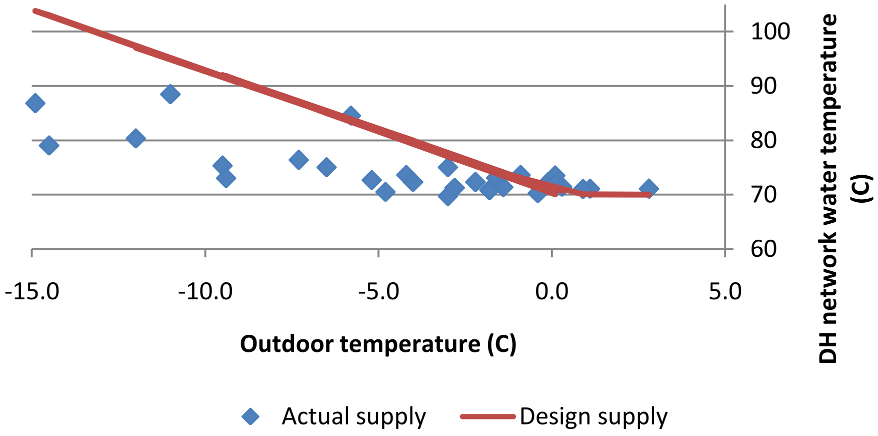

Figure 1: Actual and desired control curve of the DH network supply temperature

Figure 2 illustrates the thermal load on a DH substation with no evident daily or weekly cycles being dependent excluding on outdoor temperature.

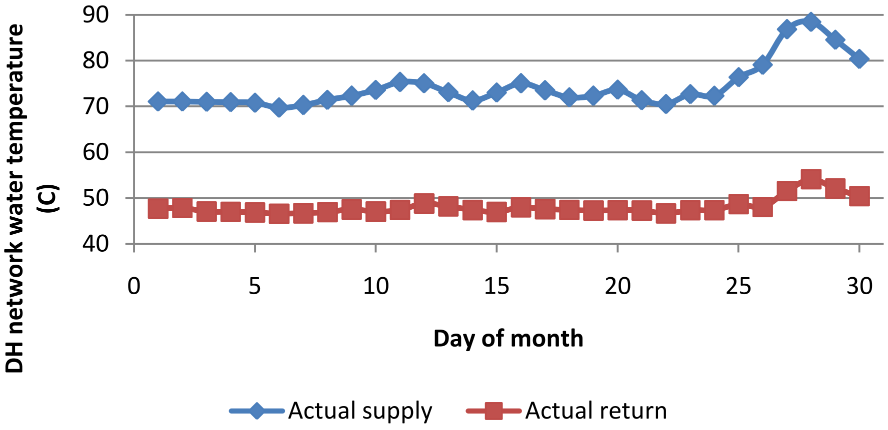

Figure 2: Actual temperatures versus month day for a DH system during November 2017 in Omsk (Russia)

The heating power is especially high since 26th till 30th November 2017, and is low during the first month decade. Figure 2 indicates no direct correlation between actual temperatures in the supply and return temperatures as exists in a DH system e. g. between diversity and exergy efficiency [19].

According to proposed pattern (eq. 2) the return temperature should have been kept at about 43 °C in average while the figure 2 indicates the fact that the return temperature of the DH system in average equaled 48.0 °C. This is higher than expected, and can be put down on some few consumer substations, where the bypass flow has been to high either due to faulty settings or defective components (valves etc.).

In addition to the weather-dependence of the return temperature, the red curve of Figure 3 illustrates an inverse relationship between supply and return temperature; when the actual supply temperature increases sharply, the overheat decreases, while innovative calculation of flow return temperature increase (blue) declines more moderate.

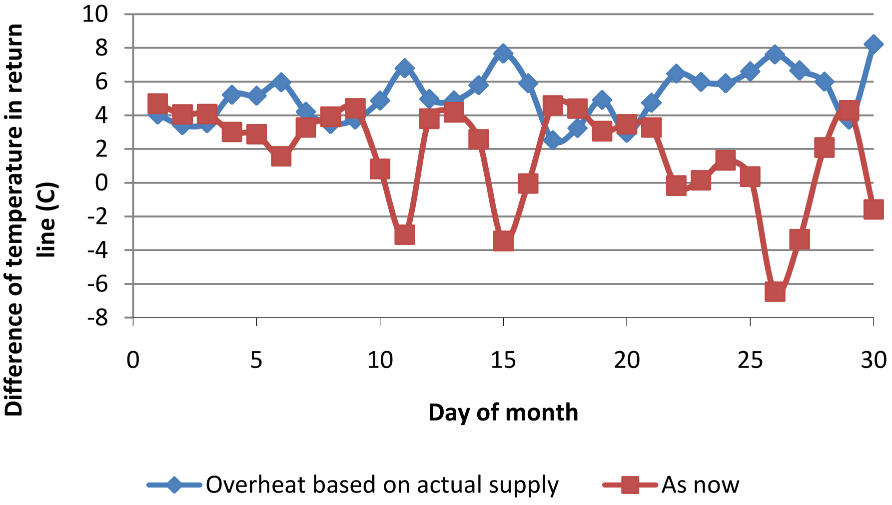

Figure 3: Calculated with eq. 2 (denoted with blue) and eq. 1 (denoted with red) overheat

The new overheat profile represents more accurate case since it always relies on actual values and does not drop below zero while heat metering continuously shows design curve is not met (fig. 1). The blue curve is also smoother which makes easier contracting and reporting tasks. The red curve representing an empirical eq. 1 only can yield a rough estimate of overheat due to the inherent complexity of variable temperature in a supply line, but the influence of such a rough estimate on the whole calculation is sufficient.

4. Conclusion

In many systems, where energy to the consumer is measured for billing purposes, temperature sensors assist in calculating the energy consumed as well as in diagnosing performance [7]. By means of novel calculation technique we are now able to predict whether substation is faulty. The proper assessment ensures DH supply company to approve sanctions accurately. We identified the basic approach to conduct a survey of DH system operational temperatures, which takes into account supply and an average through the day outdoor temperatures. The issue of running high temperature of return water from the residential area is another time highlighted. This is a huge problem for CHP unit occurring due to opened summer by-passes in a valve vault, improper operation of the substations, etc. Further troubleshooting in individual building installations is expected to lower the return temperature, thus modern substations for each building or group of buildings should be installed. This will allow a customer to regulate their heat use according to the actual heat demand, moreover the building control systems should be equipped with return temperature regulation.

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