IOP Conference Series: Materials Science and Engineering

PAPER • OPEN ACCESS

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To cite this article: Yu Li and Yacine Rezgui 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **301** 012123

Impact of Next Generation District Heating Systems on Distribution Network Heat Losses: A Case Study Approach

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Abstract. District heating (DH) is a promising energy pathway to alleviate environmental negative impacts induced by fossil fuels. Improving the performance of DH systems is one of the major challenges facing its wide adoption. This paper discusses the heat losses of the next generation DH based on the constructed Simulink model. Results show that lower distribution temperature and advanced insulation technology greatly reduce network heat losses. Also, the network heat loss can be further minimized by a reduction of heat demand in buildings.
Keywords: District heating; Heat losses; Distribution temperature; Building energy consumption.

1. Introduction

Heating is the most important factor influencing energy consumption in the UK, exceeding that for transport and electricity, resulting in approximately one third of UK's greenhouse gas (GHG) emission [1], [2] and [3]. More than 79% of the energy consumed in homes is for space heating and hot water, and approximately 81% is achieved by gas-fired boilers [4]. In response to the present environmental and energy issues, traditional heating mode should be updated. District heating (DH) provides a promising and efficient pathway to address low carbon challenge [5].

Heat losses in DH network are one of the major challenges impeding its wide acceptance worldwide. There is an urgent need to upgrade the current system towards the next generation. Paiho and Reda [6] discussed the motivations for next generation DH centered around low energy buildings (25~50% less), renewable energy adoption and increased efficiency of the heating network resulting from decrease of supply temperature. Lund et al. [7] pointed out that the next generation DH network will have to meet the challenges of delivering low-temperature DH system, low grid losses, integrating sustainable energy sources and integrating with other smart energy grids. In order to meet the target of high efficiency distribution network, the performance of the pipeline should also be enhanced by using advanced insulation materials.

Following this introduction, section 2 demonstrates the case study. In section 3, heat losses in the distribution network are discussed based on the next generation DH system. The last chapter provides concluding remarks.

2. Case Study

The study is based on a district heating network in south Wales. The distribution model was developed in Simulink. For more information, readers can refer to [1]. Blocks in the figure represent different buildings, pipes, sensors. The model has been validated through comparison simulated temperatures with measured temperatures collected from the site.

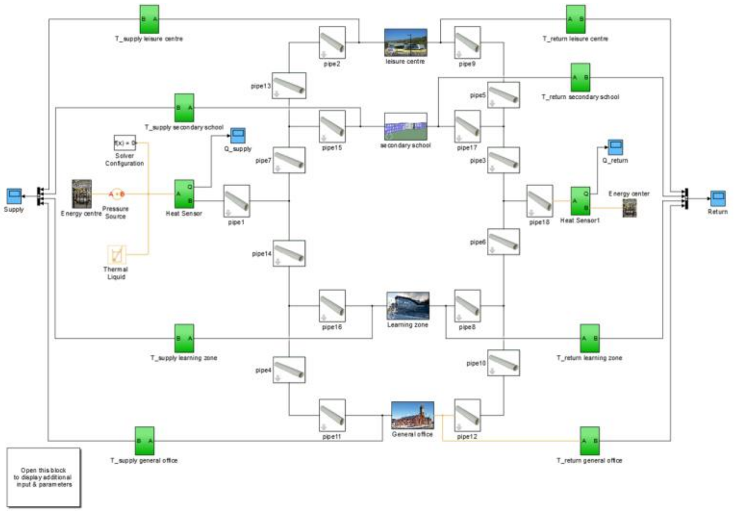

Figure1. Simulink model of the network

3. Results and Discussion

Heat losses of the distribution network will be examined in this section with a focus on the next generation DH system. As aforementioned in the introduction part, the future DH system will be built on lower energy demand network, lower supply and return temperatures and advanced insulation technologies for the piping network.

3.1. Lowering Building Energy Consumption

Future newly constructed buildings will have to meet higher regulations and policies to reduce energy demand. This can be implemented by using advanced envelop insulation technologies or by adopting heat recovery measures to improve building thermal performance in new buildings. Reduction of energy demand in existing buildings can be achieved through envelop renovation, energy systems retrofit and smart building management. Building energy demand has the potential to be reduced by 50% [8]. Decreased building energy demand not only reduces fuel consumption, it will also bring down heat loss in the piping network as shown in Fig. 2.

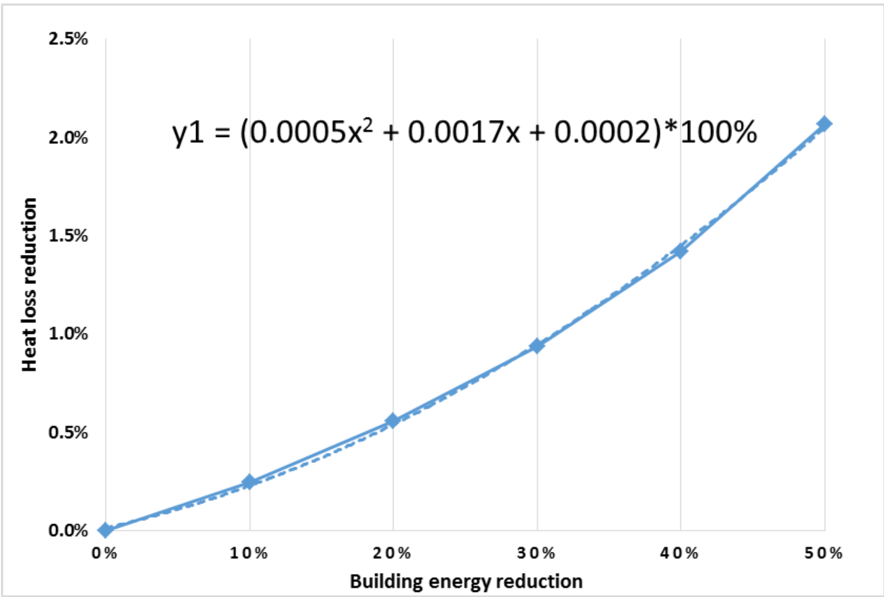

Figure 2. Heat loss reduction with building energy consumption reduction

The heat loss reduction can be expressed as:

$$y_1 = (0.0005 * x^2 + 0.0017 * x + 0.0002) * 100\% \quad (1)$$

Herein: $x = \frac{\text{Building energy reduction (\%)}}{10\%}$;

The heat loss of the network does not improve significantly for already existing heating systems when heat consumption decreases as demonstrated in Fig. 2. There is merely 2.07% heat loss reduction in the piping system when the users' heat demand reduces by 50%. However, the reduced heat demand will result in a smaller size for the piping network, which will bring down the initial investment cost for construction of new distribution network. Meanwhile, oversized pipe network results in higher heat loss [1]. For a newly constructed network that the pipe sizes are in accordance with heat demand, heat loss reduction should be more significant than displayed above. Namely, heat loss reduction should be more than 2.07% if the network is designed and constructed based on 50% energy demand.

3.2. Reducing Distribution Medium Temperature

The lower distribution temperature will promote the utilization of local available sustainable energy such as solar, geothermal and waste thermal energy that would otherwise be wasted. The possibility of heat loss reduction in a low temperature distribution network is illustrated in Fig. 3.

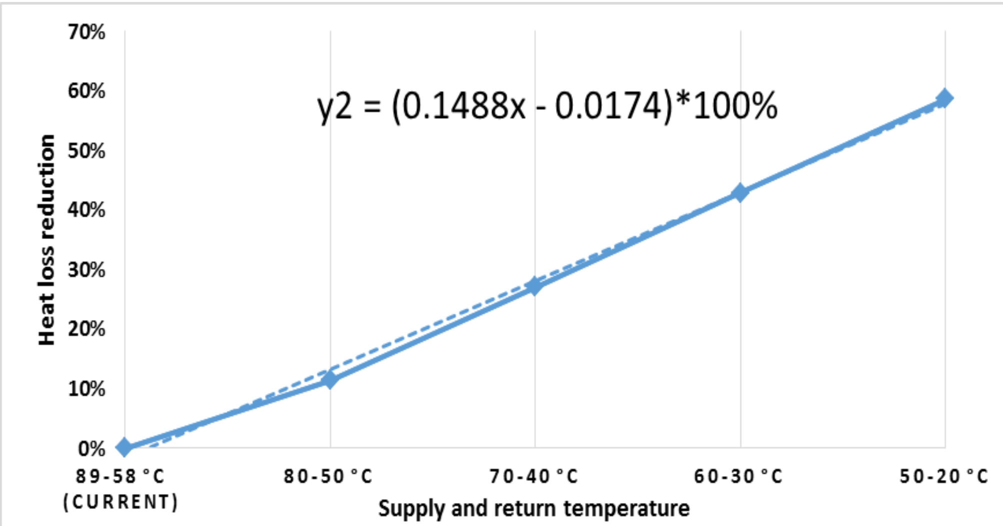

Figure 3. Heat loss reduction with distribution temperature

Heat loss reduction in the piping network can be expressed as:

$$y_2 = (0.1488 * x - 0.0174) * 100\% \quad (2)$$

Herein: $x = \frac{90 - \text{Supply temperature}}{10}$; and the temperature different for supply and return temperature is 30°C.

The heat losses in the network reduce significantly with the decrease of the distribution temperature. The heat loss reduces by almost 60% when the temperature of water reduces from current situation to 50/20 °C. Reducing the distribution temperature to a certain low level may take time in practice. However, related research have been conducted to accelerate the advancement of this technique [9]and [10]. Another problem may occur with decreased distribution temperature. The temperature in the pipes at night or on the weekend may decrease to minus 0 °C leading to frosting during winter. By-pass system offers an optimal solution for this issue which allows a small portion of hot water running through when the temperature decreases to a set point temperature so as to guarantee the temperature would not be less than the freezing point [11] and [12].

3.3. Adopting Advanced Insulation Technology
Insulation thermal performance can be enhanced by using hybrid insulation technology or using advanced insulation materials with lower thermal conductivity. The heat loss reduction with enhanced insulation thermal conductivity is shown in Fig. 4. Although there is no reported study about insulation with thermal conductivity better than 10e-3 W/(m·K) being applied in DH pipe network, there are studies about insulation with thermal conductivity in the order of less than this value [13] and [14] It is a promising technology that might be adopted in the next generation DH network.

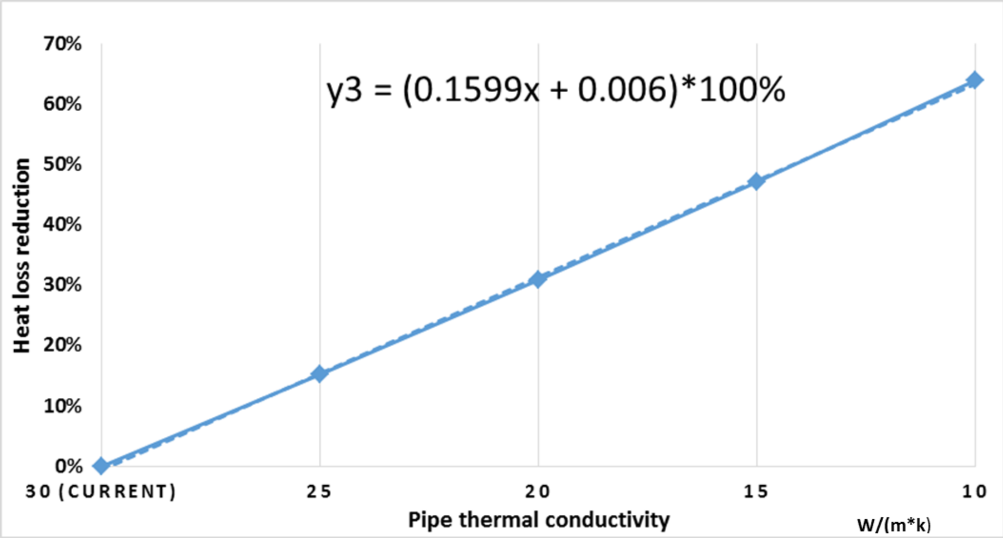

Figure 4 heat loss reduction with insulation thermal conductivity reduction

Heat loss reduction in the piping network can be expressed as:

$$y_3 = (0.1599 * x + 0.006) * 100\% \tag{3}$$

Herein: $x = \frac{30 - insulation\ thermal\ conductivity}{5}$;

Improving thermal performance of the insulation materials greatly reduces the heat loss in the network. When the thermal conductivity decreases from current state (around 30e-3) to 10e-3 W/(m·K), the heat loss decreases by approximately 64%. However, this might result in a higher investment cost for the distribution network.

3.4. The Combined Effect of the Three Factors Above
As the influences of building energy consumption, distribution temperature and insulation thermal conductivity on piping heat loss are independent factors. The effect of the combined three factors on the total heat loss reduction can be expressed as:

$$y = 1 - (1 - y_1)(1 - y_2)(1 - y_3) \tag{4}$$

Equation (4) can be applied to provide guidance for constructing new DH networks or retrofitting existing DH networks aimed at distribution network heat losses reduction. However, the refurbishment of existing building to reduce building energy consumption, replacement of heat exchanger in the substation and using better insulation materials will result in a higher investment cost. Life cycle assessment study should be carried out at the decision making stage to examine the effectiveness of the improvement and the payback periods so that the investors and users can benefit the most from the DH network.

4. Summary
The impact of next generation district heating on heat loss is examined in this study, which can provide some guidance for new network construction or replacing the existing ones. Key insights as to heat losses in next generation DH are summarized below:

(1) When the building heat consumption decreases, the network will mainly benefit from the reduction of fuel consumption with a slight drop in heat loss from the distribution network. If the network is designed appropriately, the system should benefit more from heat loss reduction.

(2) Heat loss will decrease by almost 60% when the distribution temperature reduces from current state to 50/20 °C. However, the reduction of temperature is based on a more advanced heat exchanger that can extract the same amount of heat from a lower temperature heat source.

(3) Heat loss will reduce significantly by 63.97% when the insulation thermal conductivity decreases from 30e-3 W/(m·K) to 10e-3 W/(m·K). Such a high level insulation might lead to much higher initial investment cost for the pipe network at the construction stage.

(4) A formula to express the influence of building energy consumption, distribution temperature and insulation thermal conductivity on distribution heat losses is formed, which can provide some guidance if readers want to construct or retrofit their DH network for the purpose of reducing distribution heat losses.

5. Acknowledgment
The research presented in this paper is financially supported by the EU FP7 RESILIENT project and the Building Research Establishment (BRE).

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