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Evaluation factor for district heating network heat loss with respect to network geometry

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Abstract

The district heating (DH) networks are widely in use in northern countries. It is often necessary to compare the efficiency of different DH networks from their size and layout and for this purpose mostly the "relative heat loss" is used. Generally, this parameter gives a first impression of the network. However, relative heat loss does not reflect the actual efficiency of pipe insulation or overall efficiency of the network; moreover, at least heat consumption density should be considered. E.g., the average relative heat loss in Denmark is about 20 % and in Sweden only 9 %. Does this mean that the Swedish network insulation is 2 times better? The data from different networks is taken in order to make an analysis and figure out a proper comparison methodology. The following main parameters are taken into account: supply, return and ambient temperatures; the network average diameter and length; annual heat consumption or linear heat density.

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Keywords: district heating; relative heat loss; linear heat density; insulation efficiency

1. Introduction

It is common that for the evaluation of district heating efficiency, the relative heat loss is used. The relative number is the rate of lost heat energy to heat output from a heating plant to the district heating (DH) network. This method can give some impression about the network. However, a more detailed analysis should be performed in order to get the correct understanding of network efficiency. For example, two similar networks may have the same relative heat loss, but the average water temperature in the first network is 85/50 °C and in the second 75/45 °C. In this case, the

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first network has better insulation and higher efficiency while the second shows a higher potential for renovation. Moreover, the amount of heat consumption per network length or heat consumption density also affects the heat loss. This means that the relative heat loss figure is not always correct and can produce misleading results.

The aim of this paper is to describe and analyze the main factors affecting network heat loss. As a result, a technical evaluation factor will be found for the correct comparison of technically different DH networks. The same factor may be used as an indicator of potential network efficiency increase capacity.

Nomenclature

Q_s	annual consumed energy amount, Wh
Q_p	annual energy amount delivered to DH network, Wh
Q_{hl}	annual heat loss in DH network, Wh
q_{hl}	relative heat loss, %
t_s	annual average network supply temperature, °C
t_r	annual average network return temperature, °C
t_{amb}	annual average network ambient (soil) temperature, °C
K	network effective average heat transmission coefficient, W/m^2K
L	network route length for the pair of pipes (one pipe length), m
D_a	effective average pipe inner diameter, m
G	degree hour number, annual integration of the average distribution temperature difference, °Ch

2. Method

The way to develop a technical evaluation factor is as follows: first, the factors affecting main heat loss are found and described using the heat mass flow theory.

Second, a possibility is examined to connect the factors and describe them as one factor that can describe the technical condition of the network, give a possibility to compare DH networks and evaluate the technical improvement potential.

Finally, the real networks data analysis is performed to check the correlation of technical evaluation factor (TEF) with the real condition of networks.

2.1. *Heat loss components in DH networks*

By definition, the relative heat loss is a ratio between the lost and produced energy (energy output from a plant to the network):

$$q_{hl} = \frac{Q_{hl}}{Q_p} \cdot 100\% = \frac{Q_p - Q_s}{Q_p} \cdot 100\% \tag{1}$$

By the heat loss definition and heat mass flow theory, the heat flux through a two-piped DH network is [1]:

$$Q_{hl} = K \cdot \pi \cdot D_a \cdot 2L \cdot G, \ where\ G = \left(\frac{1}{2}(t_s + t_r) - t_{amb}\right) \cdot 8760 \tag{2}$$

Based on the equation we can see that the following parameters affect the network heat loss:

- Overall network heat transmission: presently used insulation materials produce a heat loss level of about 0,100–0,350W/mK from a pair of pipes for the pipes up to DN300 [2];
- Temperature level of network: drop of temperature level in a DH network will bring about the reduction of heat loss due to a smaller temperature gradient between the DH heat media and external environment. The reducing

temperature schedule in the network is one of the easiest possibilities to decrease the loss in case there are no hydraulic problems and consumer substations are able to work with lower parameters and deliver the needed amount of heat to the house heating system [3]. Lower network temperature also has positive effect on production site [4, 5];

- Network geometrical dimensions or network heat transmission area: heat loss in DH networks depends on the heat transmission area of the DH network, which in turn depends on the average network diameter and length. If other parameters in two DH networks are the same, the network with a smaller average diameter and shorter length will have smaller heat loss;
- Others: there are other factors affecting heat loss in DH networks, like the heat transmission factor from water to pipe, pipe wall material, heat transmission from pipe to soil, which mainly depends on the soil moisture content, distance between the pipes, wind speed for above-ground pipes [6].

By combining (1) and (2), it is possible to express the relative heat loss as follows:

$$q_{hl} = 1/(1 + \frac{Q_s}{L} \cdot (K \cdot 2\pi \cdot D_a \cdot G)^{-1}) \tag{3}$$

It shows that the relative heat loss also depends on the heat consumption per network length [6]. Some of the above-mentioned parameters have smaller effect on heat loss and may be neglected; some are almost the same for all networks, but most of them should be taken into account for the network efficiency calculation and network comparison.

2.2. *Factor for the characterization of technical conditions in DH networks*

In order to take all parameters as one factor, the overall heat transfer coefficient (effective average heat transmission coefficient) can be used as a correct parameter for describing the network heat loss. The basic equation for calculating the overall heat transfer coefficient is:

$$K = Q_{hl}/(L \cdot 2\pi \cdot D_a \cdot G) \tag{4}$$

In order to simplify the calculation and not include the pipe insulation material and thickness parameters into the equation, an effective average inner diameter is used here. Generally, all data required for the calculation is available for any DH network. An effective average nominal diameter (DN) can be used instead of the average diameter. However, an error up to 11 % depending on the pipe diameter and wall thickness should be considered.

The comparison of DH networks solely by the heat transfer coefficient will not give an adequate result: the networks with a higher average diameter have a smaller heat transfer coefficient because of the smaller ratio between the network area and delivered energy. For this reason, the average network diameter should be taken into consideration simultaneously with the K-coefficient. The reference conditions of allowed heat transmission will be calculated below.

The high-quality technical reference conditions are defined as preinsulated pipes class 2, buried in soil at 0.5 m depth using the calculation methodology according to EN13941 [8]. The low-quality technical reference conditions are defined as old channel layout pipes with 50 mm mineral wool insulation [9].

A gap between the calculated overall heat transfer coefficient for high-quality and low-quality technical reference conditions is shown in Fig. 1. For this parameter, the difference between old and new insulation is about threefold as also confirmed by other investigations [10, 11]. It can be seen that for the correct comparison of geometrically different networks, the overall heat transmission coefficient should be compared with the average network pipe diameter simultaneously.

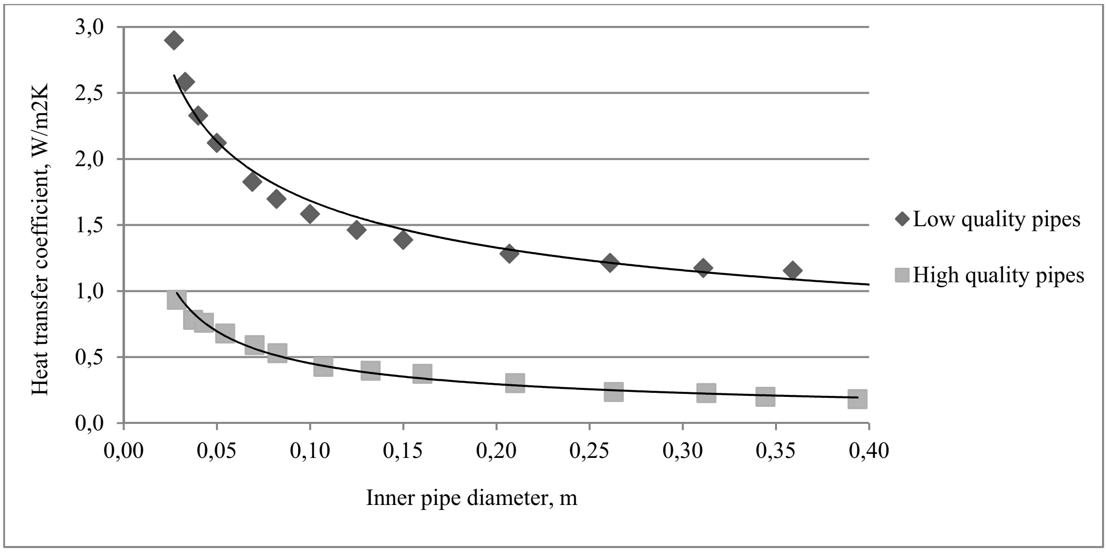

Fig. 1. Overall heat transfer coefficient for high quality (preinsulated) and low quality (old channel layout) pipes.

Both lines in Fig. 1 can be described by power functions with the sufficient accuracy (R-squared values are 0.9696 and 0.9904, respectively) where the low-quality coefficient is described by the following function:

$$K_{low}(D_a) = 0{,}7676 \cdot {D_a}^{-0{,}341} \tag{5}$$

The trend line function of high-quality coefficient is described as follows:

$$K_{high}(D_a) = 0{,}1088 \cdot {D_a}^{-0{,}619} \tag{6}$$

In order to better express the renovation potential or technical evaluation factor (TEF) of the network, the percent scale can be used. When TEF is 0 %, it means that the network has no renovation potential and the network heat transfer coefficient is the same as that for preinsulated pipes with the same inner diameter. When TEF is 100 %, it means that the network is in the same condition as a low quality network; TEF>100 % corresponds to a higher heat transfer coefficient than that in case of the low quality pipe. It may also be a sign that closing of this DH network should be considered because of too low heat consumption density.

Based on the above-mentioned assumptions, the technical evaluation factor of DH networks can be expressed as follows:

$$TEF = \frac{K_{network} - K_{high}(D_a)}{K_{low}(D_a) - K_{high}(D_a)} \cdot 100\% \tag{7}$$

2.3. *Case specific calculations*

In Estonia the data of 16 networks with different geometry (for the network length from 370 to 427000 meters) has been analyzed in order to check their TEF correlation to the real condition in networks (Table 1). The average wear of network pipes for all cases is higher than 15 years and DH networks have mostly the channel layout.

Table 1. Investigated parameters of DH networks and TEF calculation.

No	Average diameter (m)	Network degree hour (K·h)	Heat consumption density (MWh/m)	Heat transfer coefficient (W/m^{2}K)	Relative heat loss (%)	TEF (%)
1	0,224	498181	3,59	1,05	17,0	77
2	0,294	512416	4,16	1,03	19,0	85
3	0,188	470762	3,50	1,04	14,2	70
4	0,199	498137	3,79	1,17	16,1	84
5	0,306	510577	1,93	1,01	33,8	85
6	0,150	455520	2,62	1,17	16,1	73
7	0,123	451140	2,86	1,37	14,3	83
8	0,088	397536	2,17	2,07	17,4	125
9	0,073	401472	1,78	2,13	18,0	119
10	0,084	432960	1,68	2,49	25,3	155
11	0,166	472320	2,09	1,13	21,0	74
12	0,082	445300	2,36	1,96	16,0	113
13	0,089	615500	1,74	1,38	21,4	70
14	0,065	476256	3,18	0,82	4,8	17
15	0,140	520000	2,90	0,70	10,0	30
16	0,100	471139	3,32	0,96	7,8	41

All networks can be divided into three groups:

- The networks No. 8–10 and 12 have less than 10 % of preinsulated pipes and the insulation condition for the channel layout pipes is poor;
- Networks No. 1–7, 11 and 13 include about 25–35 % of preinsulated pipes, the insulation conditions for the rest is relatively good;
- Network No. 14 and 16 consists for 80–100 % of ten year old preinsulated pipes. Network no 15 is the reference as an average Swedish network [1].

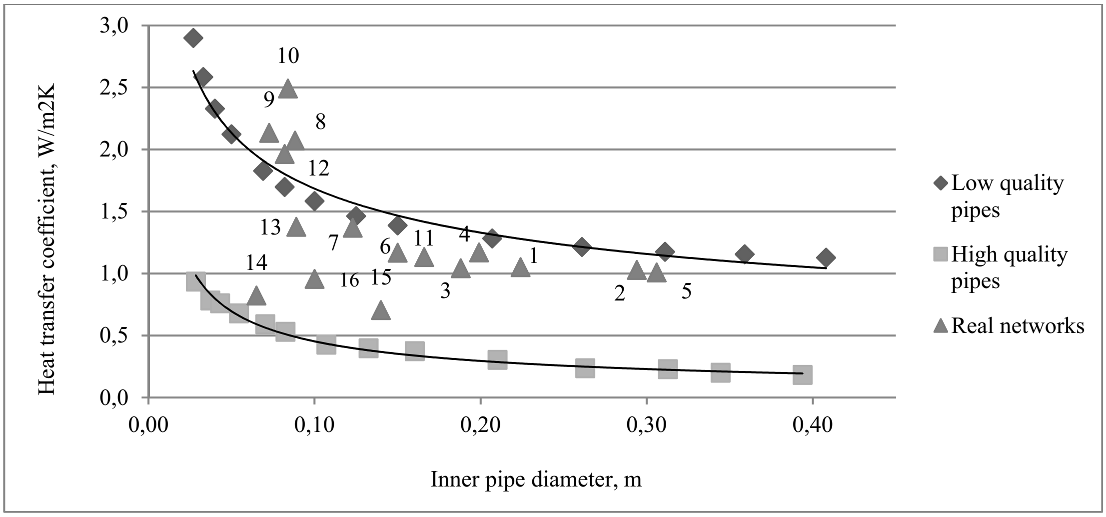

Fig. 2. Overall heat transfer coefficient for high quality (preinsulated) and low quality (old channel layout) pipes, trend lines and case specific calculation results.

3. Results and discussion

The calculation results confirm that most of the analyzed networks have a high heat transmission coefficient, which is close to the low quality reference line. Some small networks have even a higher K-factor than the low quality reference line: this can be explained by worse insulation conditions due to the smaller financial possibilities for renovation (Fig. 2). Those networks require higher attention, and insulation renovation works have to be done as soon as possible. Larger networks usually have about 30 % of preinsulated pipes, but the improvement potential is still high. The networks with higher average diameters have long transmission lines from heat plants to consumers and despite the fact that one network has relative heat loss over 30 %, it could be considered a common network.

We can conclude that the TEF as an expression of effective average heat transmission coefficient for insulation and average diameter is a valid factor to compare the DH networks insulation quality and network heat transmission performance. The described methodology requires additional calculations for the following DH network cases:

- Overground DH networks, due to the wind, precipitations and solar impact on heat transfer have not been taken into account (convection heat transfer) since the reference lines are not suitable for these cases;
- Networks where soil parameters affect heat transfer in the form of moisture: in case of wet soil, reference lines should be higher because of higher heat transfer from the pipe outside surface to soil;
- Complicated networks where more than two parallel pipes are used, or pipe diameters are different for the supply and return pipes, the length of pipes should be taken into account instead of the network length.

When considering preinsulated pipes, the difference between diverse insulation classes and single or twin pipes is too small and this cannot be taken into account in the TEF calculation. For the correct result, it is important to pay attention to the average diameter and network temperature data: a sufficient database of pipe geometry should be available and for temperature calculation, the SCADA data from different network points should be analyzed as well as the temperature of pipe surrounding medium. Especially in case of networks with many pipes located in house basements, e.g. transit lines, the network temperature level should be calculated more accurately.

4. Conclusion

An analysis of factors influencing district heat loss was made and the result described as a mathematical equation. The most important factors are: network temperature level, insulation heat transmission coefficient, network average diameter and length. As a result, an overall network heat transmission coefficient was found as most suitable factor for the network insulation quality analysis and efficiency comparison between networks. The K-factor depends on the pipe geometry and that is why it should be used simultaneously with the average diameter of reference network. Moreover, in order to exclude the pipe and insulation material properties and thickness, the average inner diameter should be used.

For a better comparison of networks, the technical evaluation factor was offered as a degree of renovation potential for the network insulation. The TEF was calculated for 14 networks with different rate of preinsulated pipes, and the correlation was confirmed.

In summary, the relative heat loss number is not a correct factor for the network evaluation, because heat loss depends on many other parameters and network insulation with high relative loss may work well and vice versa. In case of networks where a significant amount of pipes is not in the ground, for the TEF calculation additional correction factors are required for the TEF calculation.

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