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The new dimensioning method of the district heating network

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HIGHLIGHTS

- Probabilistic hot water consumption.
- Dimensioning the district heating (DH) network considering the probability of hot water consumption.
- The heat loss calculation of the DH network.
- Determination of pumping costs for the DH network.
- Decrease in the construction cost of the DH network, boiler power, pumping costs and DH network heat losses with the new calculation method.

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ABSTRACT

Optimal dimensioning of the district heating (DH) network is essential for successful use of DH. Two methods of DH network dimensioning have been compared for the tree figure network. The new method is based on a probabilistic determination of the flow rate for hot water heating.

In the article, network dimensioning, heat loss, and the basics of calculating the cost of electricity for pumping are presented. A specific reference calculation is made for a tree figure network with 10 consumers. It is seen that the new method of calculation decreases the power of boilers by 45%, the cost of the DH network by 12%, and the pumping cost by 35%.

1. Introduction

The heat supply of buildings in Eastern European and Scandinavia, as well as Western Europe and some other countries, is often based on district heating (DH). It should be noted that for successful use of district heating, optimal and correct dimensioning of the network is essential. DH use and dimensioning aspects have been treated by many researchers. Most attention is being paid to sustainable energy, which involves three different aspects: energy savings, efficiency, and use of renewable energy. DH researches are focused on the supply of areas with low heat demand and low-energy buildings [1–4].

It is important to distinguish between future buildings and existing buildings. Lund et al. have described and compared three different scenarios under which the Danish system will have converted to 100% renewable energy sources by the year 2060 [2]. Use of biomass or solar thermal energy is a possible strategy to convert DH to renewable energy sources. In a case study by Hassine and Eicker [4], a biomass-powered DH network in Scharnhauser Park, Germany was studied. The network description was based on a graph-theoretical method and the Newton algorithm was used for solving the system of nonlinear equations. The same method of DH network calculations and optimization has also been used by Wang et al. [3]. According to the simulation results [3,4], it can be concluded that the different geographical distributions of consumers within the network have a slight impact on the primary energy use and on the CO_2 emissions of the system.

To increase the efficiency of the DH, combined heat and power can be used [1,5]. Kuosa et al. [1] also showed that DH is widely used and is now increasingly produced with combined heat and power. In this study a new distribution concept is proposed using mass flow control. A new control system gives advantages for the small district. Two networks (Y-type and ring) were tested in this study: mass flow rates, pressure losses, pumping power, heat losses, and return temperature [1]. Combined heat and power has also been studied in an article by Holmgren [6]. The author analyses Göteborg Energi power consumption: heat from industries, waste incineration, and combined heat-and-power as well as heat pumps that use heat from sewage water [6]. Sperling and Möller show the impacts of expanding DH and implementation of end-use energy

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Nomenclature

c	specific heat of water, kJ/(kg K)
D	inside diameter of district heating (DH) pipe, m
$D_{is} = D_{tv}$	inside diameter of insulation or outside diameter of service pipe, m
D_{iv}	outside diameter of insulation, m
D_{out}	outside diameter of casing pipe, m
E	electricity consumption, MWh
Φ	heat loss of DH pipeline section, W
Φ_{sv}	required capacity of hot water heating, kW
G_{SV}	probabilistic water flow rate in DH network for heating domestic hot water, m^3/s
G_{DHW}	design flow rate of domestic hot water (DHW) consumption, l/s
G	design flow rate of DH network, m^3/s
h	installation depth from ground to pipe axis, m
h_t	equivalent depth of pipe axis, m
ΔH	pressure head, m (H_2O)
l	length of pipe section, m
l_{ti}	equivalent length of pipe section, m
L	distance between centres of flow and return pipes, m
N	power consumption of pump, W
N_1	number of showers
N_2	number of students, children, people, or visitors
N_3	number of water outlet devices
n	number of apartments or bathrooms
Δp	pressure losses, Pa
q	specific heat loss of DH pipeline, W/m
Q	heat loss from DH pipeline during the period, MWh
R	specific pressure loss, Pa/m
R_p	thermal resistance of the ground, (m K)/W
R_{ting}	thermal resistance considering the thermal resistance between flow and return pipes, (m K)/W
R_i	thermal resistance of pipe insulation, (m K)/W
R_1	thermal resistance of the ground and pipe insulation, (m K)/W
R_k	specific pressure loss of pipe section, Pa/m
S	number of degree-days, °C d
t_1	flow temperature during the period, °C
t_2	return temperature during the period, °C
$t_{\dot{o}}$	average air temperature of the period, °C
t_b	balance temperature for the heating period, °C
Δt_{DHW}	temperature difference between hot and cold water, K
Δt_{sv}	difference between the flow and return temperatures of network water, K
Δt_H	difference of DH network design flow temperature and design return temperature for heating systems, K
U_{ting}	heat transfer coefficient considering the thermal resistance between flow and return pipes
z	number of hours
α_o	coefficient of heat transfer from ground to air, W/(m^2 K)
λ_p	coefficient of thermal conductivity of the ground, W/(m K)
λ_i	coefficient of thermal conductivity of the pipe insulation, W/(m K)
λ	friction factor
η_1	pump efficiency, %
η_2	motor efficiency, %
ρ	density of water, kg/m^3

savings under evaluation in relation to an existing local energy system and also a local renewable energy system in the short term. The results show that end-use energy savings and DH expansions combined in the existing energy system improve the overall fuel efficiency of the system and also do so in renewable energy systems [7].

In the case of the design of low-energy DH it is possible to describe different pipe dimensioning methods, substation types, and network layouts [8]. When dimensioning the DH network it is of great importance to determine the flow rate for DHW heating and to consider the probability of DHW consumption [8–10]. The energy losses forming in the distribution of heat should also be considered [11]. The calculation method should aim to systematize the data processing of the transition temperature, evaluate temperature effects on pipe fatigue life, and optimize the size of DH pipes. The results can be used to set efficient operating conditions and to stabilize water temperature in future designs, operations, and energy savings [12]. The supply and return temperature regime and DH operating strategy have a substantial impact on annual energy performance and the equivalent annual cost. The design cases with minimum annual total energy consumption and equivalent annual cost had different pipe diameters and pump sizes under different operating methods and temperature regimes [13].

On the other hand it is always possible to use alternative methods in design. For example Wang et al. analyse the overall efficiencies of heating systems in China. In order to make the system more efficient, the authors propose the application of gas-fired boilers in underperforming heating substations. It is stated that the combined heating system (coal and gas-boilers) can solve the problem of excessive heat supply in a primary heating network [14].

2. The calculation method

In Eastern European DH systems, DHW heating in substations with instant water heaters is fairly common. In this study the calculation method takes into account this type of DHW production, that is, DHW production in instant water heaters.

The optimal calculation methodology of DH network dimensioning requires the use of the probability of domestic hot water consumption that is close to reality. Long-term studies conducted in Estonian conditions have shown that the probabilistic hot water consumption of apartment buildings can be determined depending on the number of apartments or bathrooms by Equation (1) [10]:

$$G_{DHW} = 0.2 \cdot n^{0.36} + 0.002 \cdot n \tag{1}$$

The probabilistic water flow rate in the DH network for heating domestic hot water can be determined by the formula

$$G_{SV} = \frac{\Phi_{SV}}{\Delta t_{SV} \cdot c \cdot \rho} \tag{2}$$

The required capacity of hot water heating is determined by (3)

$$\Phi_{SV} = G_{DHW} \cdot c \cdot \rho \cdot \Delta t_{DHW} / 1000 \tag{3}$$

As the new calculation method is based on the probabilistic hot water consumption of residential buildings the equivalent numbers