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Effects of boosting the supply temperature on pipe dimensions of low-energy district heating networks: A case study in Gladsaxe, Denmark

Hakan İbrahim Tol [*,1], Svend Svendsen

Department of Civil Engineering, Technical University of Denmark, Kongens Lyngby, Denmark

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ABSTRACT

This paper presents a method for the dimensioning of the low-energy District Heating (DH) piping networks operating with a control philosophy of supplying heat in low-temperature such as 55 °C in supply and 25 °C in return regularly while the supply temperature levels are being boosted in cold winter periods. The performance of the existing radiators that were formerly sized with over-dimensions was analyzed, its results being used as input data for the performance evaluation of the piping network of the low-energy DH system operating with the control philosophy in question. The optimization method was performed under different mass flow limitations that were formed with various temperature configurations. The results showed that reduction in the mass flow rate requirement of a district is possible by increasing the supply temperature in cold periods with significant reduction in heat loss from the DH network. Sensitivity analysis was carried out in order to evaluate the area of applicability of the proposed method. Hence varied values of the original capacity and the current capacity of the existing radiators were evaluated with the design temperature values that were defined by two former radiator sizing standards.

1. Introduction

District Heating (DH) systems, distribution of heat supplied from centralized heat production facilities to urban districts, are environmentally friendly, highly efficient in heat production, and reliable from the perspective of long-term energy security due to availability in the use of a wide range of energy sources [1–5]. A recent project of IEA-District Heating and Cooling has aimed at developing the "4th Generation District Heating" with a focus directed to increase the energy efficiency of DH systems by the use of low temperature operation, reduced down to 55–25 °C in terms of supply temperature and return temperature, respectively [6,7]. Low-energy DH systems have some additional advantages such as increased efficiency in heat production, further exploitation of low-grade energy sources, reduced heat loss from the DH network, and ease attained in receding the use of natural gas [6,8–10]. Successful examples of employing low temperature operation in low-energy DH systems connected to low-energy buildings have been demonstrated in real-case projects in Lystrup, Denmark [11,12], and in the SSE Greenwatt Way development project in Chalvey, UK [6,13]. Also, some studies pointed out that low temperature operation can satisfy the heat demand of existing buildings at low supply temperature since the existing indoor heating systems were over-dimensioned in their design stage [14–18]. One successful example of a large-scale low temperature DH system has been in operation in Kırşehir, Türkiye with temperatures of 54 °C and 49 °C for supply and for return, respectively. This low temperature DH system that is based from a geothermal source available at a temperature of 57 °C has been supplying heat to 1800 dwellings without any complaints delated from consumers since 1994 (more information can be obtained from [19–21]).

The objective of this study, therefore, has been defined to develop a dimensioning method for low-energy DH networks connected to existing buildings. The dimensioning method was developed with consideration directed to several points such as exploiting the over-capacity of the existing in-house heating systems (radiators) determined in their design stage, utilizing the control philosophy with boosting the supply temperature in peak

* Corresponding author. Tel.: +45 45 25 50 27; fax: +45 45 88 32 82.
E-mail addresses: hatol@byg.dtu.dk, hakantol@gmail.com (H.İ. Tol), ss@byg.dtu.dk (S. Svendsen).
[1] Faculty of Engineering and Applied Science, UOIT, Oshawa, ON, Canada.

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Nomenclature

Sets

$\mathbb{R}$	set of real numbers
TPD	set of inner diameters of the commercially available pipes

Roman letters

CC	cumulative number of consumers at the node [dimensionless]
D	inner diameter [mm]
h_f	specific enthalpy [kj/kg]
i	the index for the node [dimensionless]
$i-1$	the index for the predecessor node [dimensionless]
k	the index for the period [dimensionless]
l	the index for the route [dimensionless]
L	length [m]
$\dot{m}$	mass flow rate [kg/s]
N	node entry in the set of nodes [dimensionless]
n	overall amount of the entry type, indicated in the subscript [dimensionless]
n_1	empirically determined exponent in radiator equation [dimensionless]
P	pressure [bar]
p	pipe segment entry in the set of pipe segments [dimensionless]
Pr	period [dimensionless]
PS	sequences of linked pipe segments [dimensionless]
q	heat load rate [kW]
$\dot{Q}$	heat rate [kW]
R	route [dimensionless]
s	the index for the scenario [dimensionless]
Sc	label number of scenario [dimensionless]
SF	simultaneity factor [dimensionless]
T	temperature [°C]
t	time [hours]
U	heat loss coefficient [W/m]
x	the index for the situation [dimensionless]

Greek letters

Δ	difference
μ	heat load factor [dimensionless]

Subscripts

0	original design condition
a	indoor air temperature
Alu	aluFlex twin pipe
DHW	domestic hot water
DHWD	unique heat demand of domestic hot water
DHWL	heat load of domestic hot water
G	ground
GMTD	geometric mean temperature difference
HD	unique heat demand
HL	heat load
int	initial estimate value for iteration
LMTD	logarithmic mean temperature difference
Loss	loss
Max	maximum
Min	minimum
R	return
S	supply
SH	space heating
SHD	unique heat demand of space heating
SHL	heat load of space heating
STPc	steel twin pipe – continuous
STPt	steel twin pipe – traditional

Superscripts

*	continuous (non commercially available) value

winter periods, and changing the heating requirement of the existing buildings, expected to be renovated due to Danish building regulations [16,17].

2. Methods

2.1. Description of the site

This case study has been carried out on a district located in the municipality of Gladsaxe in Denmark, in which an existing natural gas distribution network currently supplies natural gas there to 783 dwellings. Each of the existing dwellings was considered with the same reference single-family house, constructed in the period of 1961–1972. In this project the existing natural gas heating system in the case area (Gladsaxe Municipality) was considered to be replaced to a low-energy DH system (its illustration is given in Fig. 1), with the layout of a reference substation with adequate control proper to low temperature operation of 55 °C in terms of supply and 25 °C in terms of return. Reasonable values of unique heat demand in proper with the existing single family houses were derived for the Current Situation (CS) and for the Future Situation (FS) by use of the studies [11,22,23], due to lack of available real data for existing Danish buildings and of studies in this field. Hereby, regarding space heating requirement, the reference single family house was assumed to have values of unique peak heat demand as 9 kW, 5.1 kW, and 2.9 kW, defined for design value, CS, and FS, respectively (the heat demand values are based on the references [12–14,22,23]). The reference substation was considered to be equipped with a direct connection from DH network to the in-house space heating system. Moreover, the heat demand requirement for the production of domestic hot water was assumed to be 3 kW both in CS and in FS since the reference substation was considered to be equipped with an indirect connection involving of a buffer tank with a capacity of 120 L and a heat exchanger unit (the heat requirement is based on the references [11,12]).

The search-space of the optimization method was defined as finding the minimum pipe diameter within the commercially

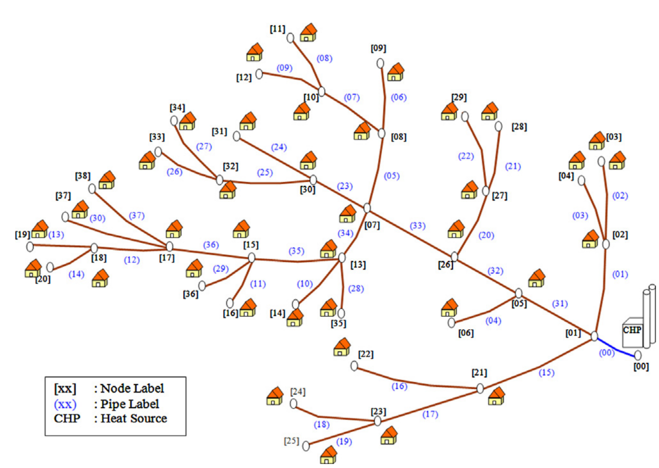

Fig. 1. Illustrative sketch of the DH network indicating both, the nodes and pipe segments.