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Effect of Design Static Pressure Level on Energy Efficiency at Low Energy District Heating Systems

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ABSTRACT

Low-Energy District Heating (DH) systems with low-temperature operations, such as 55 °C in terms of supply and 25 °C in terms of return, were considered to be the 4th generation of the DH systems for the low-energy future with energy efficiencies focused to be achieved at newly built and existing buildings by the Danish building regulations. Therefore focus has been given to reduce the heat demand of the consumer site with integration of low-energy buildings, to be considered for new settlements and with renovation of existing buildings to low-energy class. The reduction of heat demand increases the ratio of heat loss from the DH network in comparison to the heat supplied to the district. In our former studies, the low-energy DH system was optimized with the aim of reducing the heat loss from the low-energy DH network in a certain limit of static pressure level of 10 bara. Thus, in this present study different levels of static pressure were investigated in design stage to discover the effects of different pressure levels on optimal pipe dimensions observed by use of the dimensioning method defined for low-energy DH networks.

Keywords: Low-Energy, District Heating, Static Pressure, Optimization

1 INTRODUCTION

Significant savings expected in energy use of Danish buildings by means of regulations promoting use of low-energy buildings in new settlements, and of renovation of existing buildings [1,2][3,4]. The low-energy buildings allowed use of low-energy District Heating (DH) systems operating in low temperatures of 55 °C for supply and 25 °C for return, with great efficiency improvement achieved in heat production with increased heat generation efficiency, and in heat distribution with reduced heat loss from the DH network and in the substations [5-12].

History repeats itself for lowering the operating temperatures in the DH system. In earlier ages of the DH system, the heat carrier medium (in the pipes) was defined as steam and as hot water. However experimental trials of reducing the temperatures of the heat carrier medium (from 85 °C to 70 °C) in an

in-operation DH system proofed that the DH network could still satisfy the heating load involving demands of space heating and of domestic hot water [13]. Recent developments were directed to reduce the supply and return temperatures of the heat carrier medium more than earlier temperature reduction experience. Therefore there have been many studies that pointed out the benefits of using low-temperature operation in low-energy DH systems and this time in low temperatures such as 55 °C and 25 °C, respectively, in terms of supply and of return. Olsen and Paulsen et al. found that low-energy DH systems are competitive to alternative heating systems in the socio-economic point of view [11,12].

Successful examples of employing extremely low supply temperatures in low-energy DH systems have been demonstrated in case projects, having been in operation in Lystrup, Denmark [9,10,14] and in the SSE Greenwatt Way development in Slough, UK [3]. Both projects showed that using low temperature operation reduces the heat loss from the DH network significantly by use of preinsulated twin pipes, avoids over-dimensioned distribution network by use of storage tanks employed in the substations, and increases flexibility in choice of heat source, with high efficiency of heat extraction from high temperature heat sources, and with availability of utilizing low temperature heat sources [3,14,15].

In our previous studies [16,17], we have developed an optimization method with the aim directed to minimize the heat loss from the DH network by means of reducing the pipe dimensions of the network until the head lift provided from the main pump station counterbalances each pressure losses occurring in each route of the DH network. The main concern of the readers has always been directed to the pressure loss value considered in the optimization method given in the previous study. Therefore in this study the effects of different magnitudes of Maximum Static Pressure (MSP) values were studied on parameters such as pipe dimensions and such as heat loss from the DH network.

2 METHODS

Satisfying the heating demand of each consumer in such complex structures like DH systems needs several simultaneous considerations of several parameters i.e. requirements needed in adequate cooling of the heat carrier medium in the substations, sustainability of the supply temperature with constantly keeping the temperature of the heat carrier medium above a certain level, establishing a hydraulic balance in the DH network etc. [18-21].

2.1 Description of the Site

The case study was formulated for a suburban area of Trekroner in the municipality of Roskilde in Denmark, where a branched DH network, with overall pipe length of about 1.2 km, was planned to supply heat to 165 low-energy houses. The heat demand of the reference house was derived from studies ([9-12]), as 2.9 kW in connection with space heating, and as 3 kW in connection with domestic hot water for the substation layout equipped with storage tank having 120 liters (For details: [16,22,23]).

2.2 Optimization Method

The optimization method given in [16] was used in this study to minimize the heat loss from the DH network. The mass flow values were defined in accordance with the heating load of the district (including the degree of simultaneity of the heat consumers involved) based on the supply and return temperature. After the mass flow values were found (the method described in detail in the study [16]),

the DH network was optimized severally with five different maximum available static pressure values given in Table 1. The pressure loss through the house connection branch and the substation was defined as 0.5 bar at maximum by Logstor. Cavitation in a closed piping loop can be avoided by keeping the static pressure occurring in a network always above the atmospheric pressure with a holding pressure provided from an expansion vessel located close to the heat production plant [18]. In this study, we defined the holding pressure provided from the expansion vessel as 1.5 bara. Maximum Allowable Pressure Drop (MAPD) value was therefore defined by use of the equation (1) for each MSP values defined.

Table 1 MSP Values Used as Input to Pipe Dimensioning Method [bara]

P1	P2	P3	P4	P5	P6
4	6	8	10	15	25

$$\Delta P_{Max} = P_{Max} - P_h - P_s \quad (1)$$

The optimization method was modeled with the aim of decreasing the network pipe dimensions as low as possible under the constraint of not exceeding the MAPD [16], since pressure loss is inversely proportional to the pipe dimension i.e. low dimension yields in high pressure loss value under fixed mass flow condition [24]. Besides that, increasing the design value of MAPD has some limitations for the dimensioning method i.e. AluFlex Twin pipes can not be used above MSP value of 10 bara. The limits on the pipe dimensions and on the pipe type due to the MSP values were given in Table 2.

Table 2 Limits of Pipe Type and Of Inner Diameter

	≤10 bara		>10 bara	
	Min	Max	Min	Max
AluFlex Twin	10	26	-	-
Steel Twin	37.2	82.5	21.9	82.5

There has been a minor change applied on the optimization method, given in [16], regarding to the heat loss calculation method used. In this study the heat loss expression in the optimization was defined by use of multi-variable regression of dependent variables of supply temperature, of return temperature, of ground temperature, and of inner diameter, as given in Eq. (2), details explained in [25].

$$u_{loss} = -4.1 + 0.11 \times T_s + 0.10 \times T_R - 0.21 \times T_G + 0.05 * d \quad (2)$$

The changes on the observed values of the heat loss from the DH network and of the pump electricity consumption (due to changing MSP values) were compared in terms of exergy in according to the exergy factors given in Table 3, the values taken from [26].

Table 3. Exergy Conversion Factors of The Energy Forms [MJ_{ex}/MJ_{en}]

DH	Electricity
0.17	1

3 RESULTS

The overall length of each dimension of the pipes varied through the range of MSP used in the optimization method, as shown in Figure 1.

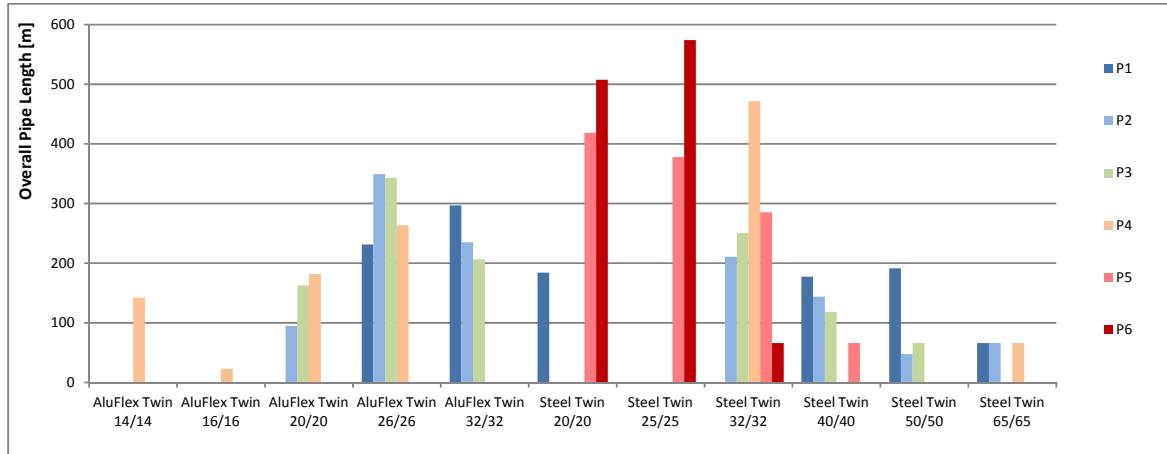


Figure 1: The Overall Length of Each Pipe Dimension in Different MSP

For each MSP values, heat loss from the DH network and pump energy required varied as well as pipe dimensions differed, although the mass flow values were kept same in each MSP value.

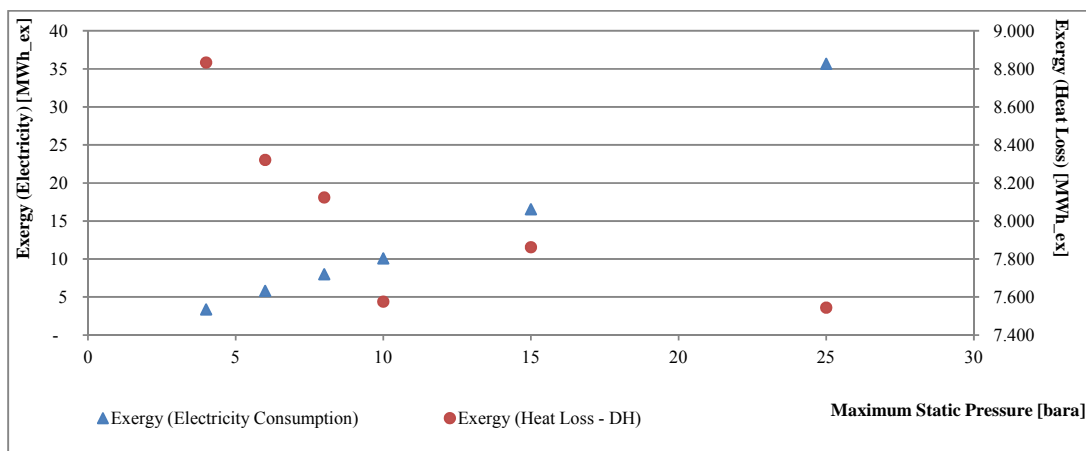


Figure 2: Comparison of Heat Loss from the DH Network and Pump Electricity Consumption in Terms of Exergy

4 DISCUSSION

The study provides the effect of different pressure levels on the pipe dimensioning of a low-energy DH network, concerned with Trekroner, a suburban area located in the Municipality of Roskilde in Denmark.

Although the same heat demand value was taken as input data in all cases of pipe dimensioning, each carried out the same optimization method but with different input values of MSP, the pipe dimensions obtained were found to differ considerably. It was observed that the level of maximum limit

of static pressure determined in the design stage significantly affect the resultant pipe dimensions due to different reasons. One reason was found firstly in the design stage since the pressure levels above 10 bara do not allow use of AluFlex twin pipes, which contains smaller (commercially available) dimensions and has better insulation properties than steel twin pipes. Another reason can be pointed to the maximum allowable pressure drop, since the higher its value determined during the design stage, the lower the pipe dimensions observed under the same range of commercially available pipe dimensions used in the optimization method, as can be observed in Figure 1 and Figure 2. The basic idea behind this occurrence is due to the existence of inverse proportion between pipe dimension and pressure loss, since in this study mass flow was defined as constant and optimization method was modelled to decrease the pipe dimension until the pressure loss reached to the level of MAPD value defined.

There are some more points that should be noted that having a DH network with high MSP has some additional effects on the durability of the DH network such as having excessive need of maintenance of the pipeline, and of the piping equipments like valves, controllers etc [18].

Exergetic comparison of heat loss from the DH network and pump electricity consumption showed that increase of MSP defined in the design stage (and as a conclusion of allowable pressure drop values) resulted in increment observed in pump energy while the heat loss from the DH network was inclined to lessen due to the reduction achieved in the pipe dimensions with increasing pressure level. Not being able to use of AluFlex twin pipe above MSP value of 10 bara caused a rapid increase in the heat loss. However, although only steel twin pipes were considered, the dimensions obtained when the MSP was defined as 25 bara resulted in heat loss value as low as heat loss obtained when the MSP was defined as 10 bara, since MAPD defined (23 bar) provided a huge gap allowing excessively reduce pipe diameters in each of the pipe segment. For example while the largest diameter was found to be Steel Twin pipe with nominal diameter of 65 mm in the other MSP values below 10 bara and Steel Twin pipe with nominal diameter of 40 above 10 bara, the dimensioning the DH network with input value of MSP value of 25 bara resulted in the same pipe segment as Steel Twin pipe with nominal diameter of 32 mm. It was observed that the total exergy consumption consisting of pump energy consumption and of heat loss from the DH network resulted in equal value while comparing the MSP values of 10 bara and 25 bara due to slight reduction in heat loss achieved in the network dimensioned with 25 bara being balanced with significant increase observed in pumping energy consumption.

5 CONCLUSION

The aim of this study here has not been to adjudge what the best possible solution is to any of the problems taken up, but rather to explore the effects of each of the parameters of interest that are considered here can have on a variety of different matters of interest here. One should note that DH systems should always be designed in accordance with what works best within the district itself [16,27]. It is rewarding to point some general conclusions regarding the study carried out and its results. One conclusion is that it is highly important to determine the level of the max static pressure and hence the MAPD while dimensioning the DH network with consideration given to the elevation change situated in the district, which has not been involved in this study, and to the commercial pipe catalogue available to the district. However use of Alu Flex twin pipe allowed great savings in the heat loss, even in the highest level of MSP defined (10 bara), with slight increase observed in pumping energy consumption compared to the maximum pressure values below 10 bara. It should be noted that high values of MSP determined can decrease the durability of the system including the piping network

and the equipments formed in the DH network, although savings in heat loss can be achieved by use of such high pressure levels.

6 NOMENCLATURE

Roman Letters

d	: Inner diameter	[mm]
P	: Pressure	[bar]
T	: Temperature	[°C]
u	: Heat Loss Coefficient	[W/m]

Greek Letters

Δ	: Difference	[-]
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Subscripts

h	: Holding pressure
G	: Ground
Max	: Maximum
R	: Return
s	: Pressure loss in the substation (primary side)
S	: Supply

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