Optimal dimensioning of low-energy district heating networks with operational planning - Case study for existing buildings

Svendsen, Svend; Tol, Hakan İbrahim

in

Kušić, Hrvoje; Božić, Ana Lončarić; Koprivanac, Natalija (eds.)

Third International Symposium on Environmental Management - Towards Sustainable Technologies (SEM)

Faculty of Chemical Engineering and Technology | University of Zagreb, Croatia. Zagreb, Croatia. 26-28 October, 2011

photo by
Dom Fou

:: Paper No: SET-2012-51 ::

OPTIMAL DIMENSIONING OF LOW-ENERGY DISTRICT HEATING NETWORKS WITH OPERATIONAL PLANNING - CASE STUDY FOR EXISTING BUILDINGS

Hakan İbrahim Tol and Svend Svendsen
Technical University of Denmark, DK-2800, Denmark

ABSTRACT

Low-temperature operation in low-energy District Heating (DH) systems is rewarding for increased exploitation of low-temperature renewable energy sources, heightened efficiency at heat extraction, and intensified energy efficiency at heat distribution. Success of heat delivery in low-temperature operation such as 55 °C in terms of supply and 25 °C in terms of return was achieved through real cases located at Lystrup in Denmark, and “Greenwatt Way” project located at Scotland in UK as demonstration of low-energy DH systems being considered to supply heat to new houses with low-energy class. In our former study the performance of in-house heating systems was investigated for changing levels of supply temperature with consideration given both to current high-heat demand and future low-heat demand value of an existing settlement. The over-dimensions obtained at in-house heating systems originally in design stage resulted in satisfaction of heat demand of the house in low temperature operation. In this paper the operational planning of the low-energy DH systems was investigated to reduce the dimensions of the distribution network with consideration given both to current high-heat and future low-heat demand situations. The operational planning was based on boosting (increasing) the supply temperature at peak-demand situations which occur rarely over a year period. Hence optimal pipe dimensions of low-energy DH systems were investigated based on the dynamic response of in-house heating systems with changing supply temperatures ranging between 55 – 95 °C. The boosting level of supply temperature was considered to be determined separately for current high and future low heat demand scenarios. As a conclusion it was found that 40% reduction in the pipe investment cost could be reached by use of operational planning in comparison to DH network dimensioned according to high heat demand situation.

INTRODUCTION

District Heating (DH) systems are essential in the future heating infrastructure planning due to their being energy efficient, having high supply reliability, enabling use of any type heat source, and, as a consequence of all, being environmental friendly (Christiansen et al., 2009; Kristjansson, 2009; Lund, Möller, Mathiesen, & Dyrelund, 2010; Lund, 2010; Oktay & Dincer 2009; Oktay, Coskun, & Dincer, 2008.). Control philosophies such as increasing the flow rate and/or increasing temperature applied during operation of DH systems allows increase in the efficiency of the system (Gustafsson, Delsing, & van Deventer, 2010; Serhan, 2007; Steer, Wirth, & Halgamuge, 2011). In our previous study (Tol & Svendsen, 2012) it was found that the mass flow required satisfying the heat requirements of a district could be reduced by means of increasing the supply temperature in the peak coldest periods (Madsen, Sejling, Søgaard, & Palsson, 1994). The required overall mass flow for the peak winter condition was found to be reduced by means of boosting the supply temperatures due to existing in-house radiators’ being over-dimensioned assigned in their design stage. Pressure drop is a function of mass flow which is the main parameter while defining the diameter of the pipe i.e. in case a certain amount of pressure drop value set as maximum the reduction achieved in the required mass flow allows further reduction on the pipe diameters at the DH network. Hence an operational planning with the control philosophy of boosting the supply temperature in the peak coldest periods could be used to lower the mass flow requirement. The lowered mass flow values later can be used as input within the optimization algorithm developed in this study, having the basis of the optimization method given in detail at (Tol & Svendsen, 2011a; Tol & Svendsen, 2011b; Tol & Svendsen, 2011c).

METHODS

The aim of this study was formulated to find an optimal network dimensioning for DH networks supplying heat to areas with existing buildings, with consideration given to current and future heating demand of them. The idea was defined as using the operational planning by boosting the supply temperature in the cold winter periods in case of future situation and as well in the current high-heat demands in order to avoid over-dimensions respect to future low-heat demands of the same existing district since the existing houses located in the case area are planned to be renovated to low-energy class in the future.

Description of The Site

A case study was carried out involved in an existing district in the municipality of Gladsaxe, in which an existing natural gas grid currently supplying heat to 783 detached single family houses there, each was assumed with the same reference house model, and with the same substation layout (Detailed information about the house model and substation layout could be found, respectively, in (Tol & Svendsen, 2012), and in (Christiansen et al., 2009; Christiansen et al., 2011)). Unique values of space heating demand of the reference house, considered for each house in the case area, were derived as 9 kW, 5.1 kW, and 2.9 kW regarding, respectively, to original design, to current, and to future situations. Since the substation planned to be used in the future heating infrastructure was defined to be used also in the current situation, the heat demand for domestic hot water production was kept same as 3 kW in both of the current and the future heat demand scenarios.

Heat Load on the DH network

The heat load determination was based on consumer site, and on network site. The consumer site was focused on exploiting the over-dimensions in the existing radiator systems, which was investigated as dynamic response of the radiator system with changing supply temperatures while in the network site the consideration was directed to the duration of the heat load levels of the DH network in one year period and simultaneity of heat consumption determined per each pipe segment in the DH network. The mass flow values were mainly used as input data while dimensioning the DH network, which were derived from the heat load values in accordance with the temperature configuration of supply and return.

Dynamic Response of the In-Door Heating Systems

The model given in the study (Phetteplace, 1995) was used to analyze the performance of the existing radiator system, of the original heat demand, and of the heat demand of the inquired condition. In this study the implicit model based on the log mean temperature difference (LMTD) was used to find the return temperature as a function of supply temperature, of which the numerical solution used was given in the Eq. (1). The initial estimate for the iterative method for calculating the Eq. (1) was obtained by use of the explicit model based on the geometric mean temperature difference (GMTD), given in the Eq. (2) (Phetteplace, 1995).

$$T_{R\_2} = T_i + \frac{T_{S\_2} - T_i}{exp\left[(q_2/q_O)^{(-1/n)}\left(T_{S\_2} - T_{R\_2}\right)/T_{ML\_O}\right]} \tag{1}$$

$$T_{R\_2}{}^{*} = T_i + \left(T_{S\_2} - T_i\right)^{-1}\left(T_{MG\_O}\right)^{2}(q_2/q_O)^{(2/n)} \tag{2}$$

The flow rate required to satisfy the heating demand of the consumer in terms of space heating requirement was calculated by means of heat balance equation assuming the mass of the heat carrier medium in the radiator system as control volume (Coskun, Oktay & Dincer, 2011). The equation for calculating the mass flow rate was given at Eq. (3), which can be applied in any heat demand, supply temperature, and return temperature configuration.

$$\dot{m} = \frac{\dot{Q}}{\left(h_{f-S} - h_{f-R}\right)} \tag{3}$$

The unique mass flow requirement of each consumer was calculated with Eq. (3) based on the substation layout with indirect connection of DH network to domestic hot water production unit by means of a sensible storage tank of 120 liter and a heat exchanger unit. This substation layout leads the heat carrier medium of the DH network being stored in the storage tank of the substation therefore; the temperature of supply from the DH network was set as the highest temperature level of the heat carrier medium stored in the storage tank. During the discharge of the storage tank (to produce the domestic hot water consumed by the consumer) the lowest temperature level of the heat carrier medium stored in the storage tank was obtained by means of heat exchanger unit with domestic hot water production capacity of 32 kW in temperature configuration of 10 °C and 45 °C in terms of, respectively, water temperature provided by the city water supply system and the required domestic hot water temperature. The return temperature from the storage tank was calculated for different levels of supply temperature by use of the commercial software SSP G7 with input data of temperature configuration in the consumer domestic hot water production side as given 10/45 °C. The maximum charging flow rate of the storage tank was fixed at 75 l/h in the primary side of the substation, defined by the control philosophy of the substation (details provided in the studies (Christiansen et al., 2009; Olsen et al., 2008; Paulsen, Fan, Furbo, & Thorsen, 2008; Christiansen et al., 2011)).

Heat Load Factor

Annual heat consumption profile of the case area was shown by annual load duration curve based on the heat consumption data regarding the Lystrup low-temperature DH system (Christiansen et al., 2011). Annual load duration data was derived for this case study, given in 8 discrete periods, each comprising of different levels of heat load factor (respect to the coldest peak period occurring in the future scenario), and of the duration of occurrence of each heat load factor over a year, in a descending order (regardless of the chronological observations of the heat load factors), as can be seen in Table 1.

Table 1. Heat load factor and duration of occurrence of the heat load factor over a year (Worm et al., 2011).

		1	2	3	4	5	6	7	8
Heat Load Factor [-]	Current Scenario	1.44	1.28	1.07	0.77	0.57	0.43	0.25	0.10
	Future Scenario	1.00	0.89	0.74	0.53	0.40	0.30	0.17	0.07
Duration [h]		8	19	111	653	1724	1399	1565	3281

Simultaneity Factor

Consumers in a district neither consume heat at the same time nor at the same level (Tol & Svendsen, 2011b; Winter, Haslauer, & Obernberger, 2001). The simultaneity of consumption, therefore, was included while determining the heat load on each pipe segment as a function of the cumulative number of consumers. The simultaneity factor equations for space heating and domestic hot water for substations with storage tank of 120 liter were given in the studies (Thorsen, Christiansen, Brand, Olesen, & Larsen, 2011; Tol & Svendsen, 2011a; Tol & Svendsen, 2011b; Vestergaard, 2010), being used in this case study as well.

Heat Load on Each Pipe Segment

A general expression was generated to calculate the mass flow required on each pipe segment to satisfy the heat demand of the cumulative number of consumers, consisting of the simultaneity factor, and of the heat load factor, as can be seen in Eq. (4).

$$\dot{m}_{HL} = CC \times \varphi_{HL} \times [SF_{SH}(CC \times \varphi_{HL}) \times \dot{m}_{SHD} + SF_{DHW}(CC \times \varphi_{HL}) \times \dot{m}_{DHWD}] \qquad (4)$$

Optimization

The same basis used in the optimization method given in our previous studies (Tol & Svendsen, 2011a; Tol & Svendsen, 2011b; Tol & Svendsen, 2011c) was also used in this study with main changes applied in the control philosophy directed to use of boosted (increased) supply temperature in peak winter periods, avoiding over-dimensioned DH network in respect to the rest periods out of the peak periods, and in the application of optimization, this time annual heat loss considered in the objective function of the optimization. In this study the DH network was modeled to have different supply temperature levels, separately considered for each of the eight periods, shown in Table 1, applied both to current high-heat demand and to future low-heat demand scenarios. The optimization method was formed in two steps, consisting of 1) defining different maximum overall mass flow requirements by adjusting the supply temperature configurations in each period over a year and of 2) applying the optimization with the aim directed to minimize overall annual heat loss in accordance with the overall mass flow requirements generated.

The peak period (the first period of the load duration curve) is the most critique period while determining the lowest possible overall mass flow required for the whole DH network. Once the lowest mass flow is determined so as to satisfy the overall heat load in the most peak period by means of increasing the supply temperature, the reminder periods (with lower heat demands though) can be operated with the same or even lower mass flow supplies. Hence five different mass flow levels were generated as a function of supply temperature levels selected in the range in between 55 °C and 99 °C, which were the temperature limitations adopted due to the reasons, respectively, of being the minimum operating temperature for the substations and of being the maximum operating temperature for the twin pipes used in the DH network.

The calculation method to find the unique heat loss was defined by means of the statistical method, the multivariable regression, to be used in the optimization method. Several samples were observed by use of the commercial software Online Logstor Calculator (Logstor, 2011) with data consisting of dependent variable of heat loss coefficient observed as outcome of several temperature configurations of the independent variables of supply temperature, of return temperature, and of ground temperature with each temperature configuration applied to the set of pipe diameters from Logstor catalogue. The outcome of this analysis was found as an equation for calculating the heat loss factor as a function of the independent variables of supply temperature, return temperature, ground temperature and pipe inner diameter. The multivariable regression analysis was carried out by use of regression analysis tool provided by the commercial software MS Excel (Microsoft Support, 2012; Coskun, Oktay, & Dincer, 2009).

Several samples of independent variables were generated, each sample then applied to set of inner pipe diameters of the commercially available pipes of Logstor, in which independent variables consist of the supply temperatures, in the range defined in the section **Error! Reference source not found.**, of the return temperatures as dynamic responses to the supply temperatures, found by use of the method given in section 0, and of different distinct ground temperatures. Samples were generated in a total number of 408 observed as an outcome of temperature configurations with supply temperatures in the range of 55 °C and 95 °C, with their equivalent return temperatures, observed in the range of 20 °C and 80 °C, and with ground temperatures in 2 °C, 5 °C, and 13 °C. With these limitations used (though which the DH network obeyed to), application space for regression for unique heat loss calculation were generated in proper to the predictions expected. Using the samples then in the multivariable regression analysis resulted in the expression, given in the Eq. (5).

$$u_{loss} = -4.05459 + 0.10786 \times T_S + 0.10320 \times T_R - 0.21097 \times T_G + 0.05302 * d \quad (5)$$

Expression to calculate the pressure drop is directly proportional to the mass flow of the heat carrier medium while being indirectly proportional to the diameter of the pipe. Any reduction being achieved in the mass flow of the heat carrier medium (in this study by means of increasing the supply temperature) allows a gap to decrease the pipe dimension in case the pressure drop through the pipe in question is kept same.

As already stated in our previous studies (Tol & Svendsen, 2011a; Tol & Svendsen, 2011b), once the pump is established in accordance with the pressure drop observed in the critical route, then it can also handle the pressure losses occurring in the other routes of the DH network, which was considered also in this study. Moreover the pressure drop calculations were analyzed for the peak winter period (the 1st heat load factor period, first column of the Table 1) since pressure losses occurring through the routes of the DH network were observed as bigger than the pressure losses occurring through the routes of the DH network in the other heat load factor periods.

An optimization algorithm was defined with the aim of minimizing the annual heat loss from the DH network, occurring in the current high heat demand and future low heat demand situations, by means of reducing pipe dimension of each pipe segment until the head lift of the main pumping station was utilized as much as possible in connection with each route of the DH network, occurring only in the peak winter period though (details given in (Benonysson, Bøhm, & Ravn, 1995; Sanks, 1998; Tol & Svendsen, 2011a; Tol & Svendsen, 2011b; Tol & Svendsen, 2012). This optimization algorithm was then applied to different mass flow values which were generated with different supply temperature configurations changing over the year period, to analyze the heat loss values of different supply temperature configurations and their consequent mass flow values.

RESULTS

In the present paper the effects of using control philosophy –increasing the supply temperature in the peak periods– on the pipe dimensioning of the DH network and on the heat loss from the DH network were investigated.

Mass Flow Levels

Five different mass flow levels were generated in the range of the available supply temperature values of 55 °C – 99 °C, yielded in overall mass flow values required to satisfy the heating load of the district as given in Table 2 with consideration given to current and future heat demand levels of the same district, by use of the Eq. 5.

Table 2. The overall mass flow values generated in the range of the available supply temperatures

Mass Flow Scenario	m1	m2	m3	m4	m5
Maximum Limit of Mass Flow [kg/s]	107.7	80.0	50.0	20.0	15.3

The supply temperatures rates, obtained in order not to exceed the mass flow limits (given in Table 2) and the return temperatures as a dynamic response from the consumers in the DH network can be seen in Fig.1 and Fig.2, respectively, for the current and the future heat demand situations.

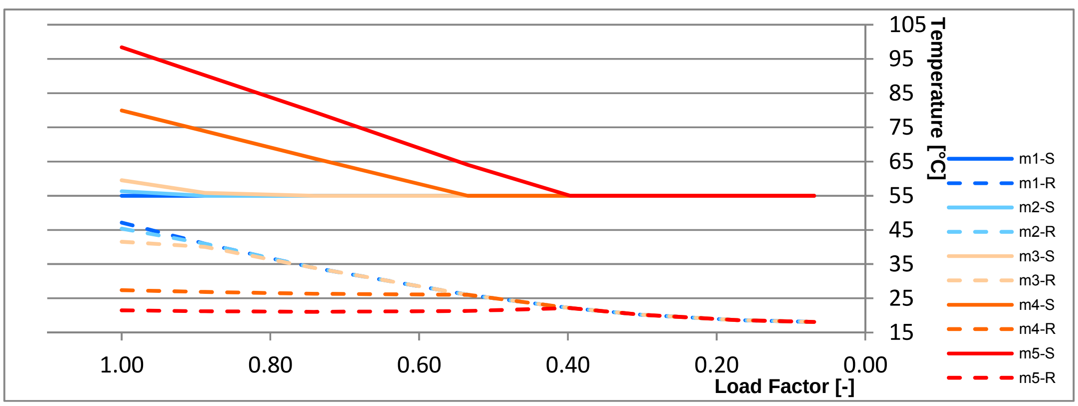

Fig.1. The supply and return temperature profiles obtained in each mass flow limit, for the current heat demand situation

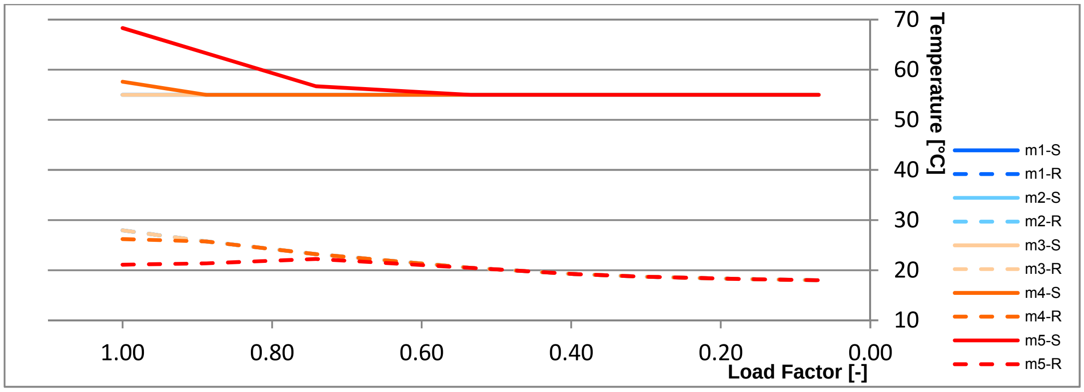

Fig.2. The supply and return temperature profiles obtained in each mass flow limit, for the future heat demand situation

Heat Loss Factor Regression

The sample data used for the regression analysis was derived for temperature configurations of supply temperature in the range of 55 °C – 95 °C, return temperature in the range of 20 °C – 80 °C, and ground temperatures of 2 °C, 5 °C, and 13 °C; each temperature configuration applied to the pipe diameter set including AluFlex twin pipes, steel twin pipes, and a pair of single pipes with inner diameter in between 10 mm – 210 mm. The obtained expression, Eq. (5), used to calculate the heat loss factor was interpreted with the statistical data of the regression result. The high value of 'adjusted regression square', observed as 0.9108 and low value of 'significance F', observed as 6.998e-211, and P-values of the independent variables nearly observed as zero were found to be the indicators of the significance of the regression within the boundaries of the application space for the regression equation.

Optimization

After the mass flow values were determined (given in Table 2) by defining the supply temperature profiles for the current heat demand situation, as shown in Fig.1, and for the future heat demand situation, as shown in Fig.2, the optimization method was applied to determine the pipe dimensions of the DH network for each mass flow level, in order to analyze the heat loss from the DH network in different supply temperature profiles.

Although the same optimization method applied on each, the overall length of each pipe type varied differently in each mass flow level, as shown in Fig.3. However, the annual heat loss values obtained in current and future heat demand scenarios decreased significantly although the supply temperatures were increased in some certain time periods, in which peak demand conditions occurred, as can be seen in

Table 3.

Table 3. The heat loss from the DH network, obtained for current and future heat demand situations [MWh]

	m1	m2	m3	m4	m5
Current Situation	44.7	30.8	17.1	5.5	4.0
Future Situation	43.8	30.1	16.6	5.3	3.8

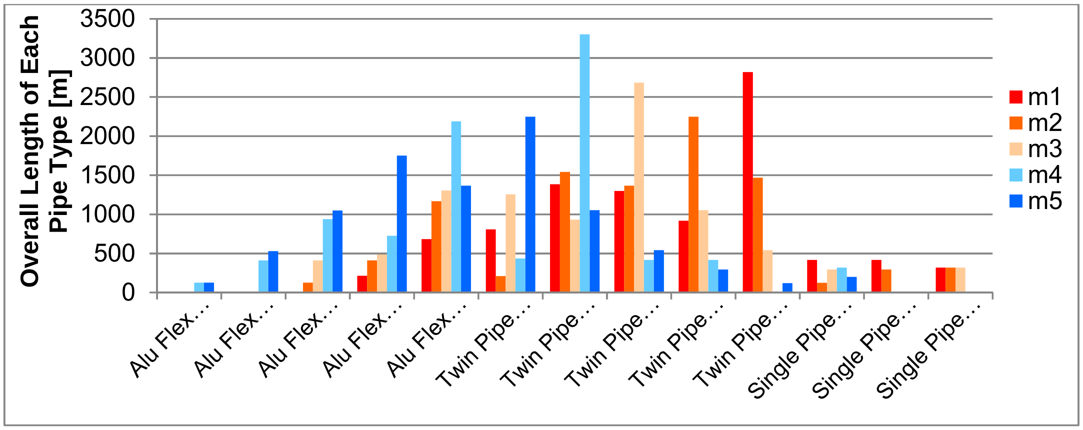

Fig.3. The overall length of pipe diameters obtained as a result of optimization for each mass flow level

DISCUSSION

Mass flow values were found to be reduced together with the boosting applied on the supply temperatures in the periods of high heat load factors, as can be seen in Table 2. The more the supply temperature boosted the lower mass flow levels were obtained more specifically in high load periods. High mass flow values were observed in case the supply temperature kept same as 55 °C for the whole year, yielded in overall mass flow of 107.7 kg/s for the coldest peak period of the current heat demand situation, which appears in short duration of 8 hours. Even an increase of 1.3 °C for the same coldest peak period of the current heat demand situation yielded in 27% reduction of the overall mass flow required and an increase of 43.4 °C in the same period in question yielded in 86% reduction in the required overall mass flow. Understanding the effects of the supply temperature and of the reduction in pipe dimension on overall heat loss from the DH network was the major research challenge given in this study. It has to be noticed that the DH network was optimized with each of the mass flow rates determined within the same constraint having the same maximum allowable pressure loss limit. Therefore, an increase in pumping energy was not considered due to stationary maximum allowable pressure loss applied in each mass flow rate, and due to the fact that required overall mass flow rate decreases with increasing supply temperature.

The lowered mass flow allowed dimension reduction achieved in the pipe segments of the DH network, as can be seen in Fig.3. However the pipe reduction, achieved by increase of supply temperature, lowered the heat loss from the DH network more than the inverse effect of increment of heat loss caused by the high temperature of the heat carrier medium. The heat loss obtained in case the supply temperature kept same 55 °C during the whole year was found to be reduced by 91% compared to the case where the supply temperature was defined as 98 °C in the coldest peak period for a duration of 8 hours, 90 °C in the following (second) cold period for a duration of 19 hours, 80 °C in the third period for a duration of 111 hours, 64 °C in the fourth period for a duration of 653 hours, and 55 °C in the rest periods of the current heat demand situation. However when the future heat load situation is considered, the supply temperatures were found not necessarily to be high as needed in current situation for example, following the previous current heat load example, the supply temperatures, in this case, were found as 68 °C in the first period, 63 °C in the second period, 57 °C in the third period and 55 °C in the rest periods, required to satisfy the heat load needed in the future situation.

CONCLUSION

The paper has presented operational planning of low-energy DH networks considered with increment applied in supply temperatures during high heat load periods, in areas with existing buildings located there. The over-dimensions in the existing radiator heating systems in the existing buildings allowed satisfaction of the heat demand of the building even at low temperature supply such as 55 °C. However the comparatively high mass flow requirements could be reduced by means of increasing the supply temperatures, yielding low heat loss from the DH network, and, driving from a logical perspective, yielding low investment cost of the network since the piping costs are directly proportional to the dimension of the pipe. One should note that significant savings can be achieved on pipe dimensions, on heat loss from the DH network, and on pipe investment const by increasing the supply temperature during some certain amount of period (cold periods though) throughout a year.

The aim in the paper has not been to adjudge what the best possible solution is to any of the problems taken up, but rather to develop a method for dimensioning the DH network for existing settlements. Therefore a district heating network should always be designed in accordance with the thermal characteristic of the existing buildings, with the capacity of the existing radiator heating systems used in the buildings located at the district, and with the simultaneity factor best fits with the social structure of the district. It should be noticed that the proposed method can be applied in districts where high temperature supply is available from the heat source.

ACKNOWLEDGEMENT

This research study is a part of a PhD project of Hakan İbrahim Tol, which is partly sponsored by Roskilde and Gladsaxe Fjernvarmeforsyning A/S. We are thankful for their willingness which has provided the opportunity of studying in real urban examples for the case studies. We are also grateful for the financial support awarded for the external study at UOIT, Oshawa, ON, Canada and for the conference participations, granted partially by the COWIfonden, by the Oticon Fonden, and by the Marie & M. B. Richter's Fond.

NOMENCLATURE

T	temperature, °C
q	heat rate in power, kW
n	empirical parameter for radiators, 1.3 [-]
$\dot{m}$	mass flow, kg/s
h_f	specific enthalpy, kJ/kg
SF	simultaneity factor, [-]
CC	cumulative number of consumers, [-]
u	unique heat loss, W/m
d	inner pipe diameter, mm

Greek Letters

φ	factor, [-]

Subscripts

S	supply
R	return
i	indoor
ML	logaritmic mean temperature
MG	geometric mean temperature
HL	heat load
Loss	heat loss
O	Initial condition
1	current condition

2 future condition

Superscripts

* initial estimate

REFERENCES

Benonysson, A., Bøhm, B., and Ravn, H. F. 1995. Operational optimization in a district heating system. *Energy Conversion and Management*, 36(5):297-314.

Christiansen, C. H., Paulsen, O., Bøhm, B., Thorsen, J. E., Ting Larsen, C., Jepsen, B. K., et al. 2009. *Development and demonstration of low-energy district heating for low-energy buildings. Main report and appendices* [in Danish]. Teknologisk Institut Report.

Coskun, C., Oktay, Z. and Dincer, I. 2009. New energy and exergy parameters for geothermal district heating systems. *Applied Thermal Engineering*. 29(11-12):2235-2242.

Coskun, C., Oktay, Z. and Dincer, I. 2011. Investigation of some renewable energy and exergy parameters for two Geothermal District Heating Systems. *International Journal of Exergy*. 8(1):1-15.

Gustafsson, J., Delsing, J., and van Deventer, J. 2010. Improved district heating substation efficiency with a new control strategy. *Applied Energy*. 87(6):1996-2004.

Kristjansson, H. 2009. District heating is tomorrow's heat market. *EuroHeat&Power*. 6:38-42.

Logstor calculator 2.1. http://calc.logstor.com. Accessed on March 2012.

Lund, H., Möller, B., Mathiesen, B. V., and Dyrelund, A. (2010). The role of district heating in future renewable energy systems. *Energy*. 35(3):1381-1390.

Lund, H. 2010. *Renewable energy systems: The choice and modeling of 100% renewable solutions*. USA Academic Press, Elsevier.

Madsen, H., Sejling, K., Søgaard, H. T., and Palsson, O. P. (1994). On flow and supply temperature control in district heating systems. *Heat Recovery Systems and CHP*. 14(6):613-620.

Microsoft Support. *About statistical analyses tools*. http://office.microsoft.com/en-us/excel-help/about-statistical-analysis-tools-HP005203873.aspx. Accessed on April 2012.

Oktay, Z., Coskun, C., and Dincer, I. 2008. Energetic and exergetic performance investigation of the Bigadic Geothermal District Heating System in Turkey, *Energy and Buildings*. 40(5):702-709.

Oktay, Z. and Dincer, I. 2009. Exergoeconomic analysis of the Gonen geothermal district heating system for buildings. *Energy and Buildings*. 41(2):154-163.

Olsen, P. K., Lambertsen, H., Hummelshøj, R., Bøhm, B., Christiansen, C. H., Svendsen, S., et al. 2008. A new low-temperature district heating system for low-energy buildings. In *The 11th International Symposium on district heating and cooling*. Aug 31-Sep 2, Reykjavik, Iceland.

Paulsen, O., Fan, J., Furbo, S., and Thorsen, J. E. 2008. Consumer unit for low energy district heating net. In *The 11th International Symposium on district heating and cooling*. Aug 31-Sep 2, Reykjavik, Iceland.

Phetteplace, G. 1995. *Optimal design of piping systems for district heating*. CRREL Report.

Sanks, R. L. 1998. *Pumping station design*. United States of America: Elsevier Gulf.

Serhan, K. 2007. The thermal effects of some control logics used in GDHS. *Applied Thermal Engineering*. 27(8-9):1495-1500.

Steer, K. C. B., Wirth, A., and Halgamuge, S. K. 2011. Control period selection for improved operating performance in district heating networks. *Energy and Buildings*. 43(2-3):605-613.

Thorsen, J. E., Christiansen, C. H. 2011. Experiences on low-temperature district heating in Lystrup - Denmark. In *International conference on district energy*. March 20-22. Portorož, Slovenia.

Tol, H. İ., and Svendsen, S. 2011a. Design of low-energy district heating system for a settlement with low-energy buildings. In *3rd international symposium on environmental management*. Oct. 26-28. Zagreb, Croatia.

Tol, H. İ., and Svendsen, S. 2011b. Improving the dimensioning of piping networks and network layouts in low-energy district heating systems connected to low-energy buildings: A case study in Roskilde, Denmark. *Energy*, 38(1):276-290.

Tol, H. İ., and Svendsen, S. 2011c. D Determination of Optimum Network Layout for Low-Energy District Heating Systems with Different Substation Types. In *the third international renewable energy congress*. Dec. 20-22. Hammamet, Tunisia.

Tol, H. İ., and Svendsen, S. 2012. Operational planning of low-energy district heating systems connected to in-house heating systems equipped at existing buildings. In *International conference on renewable energy: generation and applications*. March 4-7. Al-Ain, United Arab Emirates.

Vestergaard, J. B. 2010. The distribution network (August). *Lecture note presented at summer school district energy*, Århus, Denmark.

Winter, W., Haslauer, T., and Obernberger, I. 2001. Simultaneity surveys in district heating networks: Results and project experience [Untersuchungen zur gleich-zeitigkeit in nahwärmenetzen: Ergebnisse und projekterfahrungen] [in German]. *Euroheat&Power*, 30:42-47.

Christiansen CH, Worm J, Jørgensen H, Thorsen JE, Bennetsen J, Larsen CT, et al. 2011. *Demonstration of low energy district heating system for low energy building in Ringgårdens Afd. 34 in Lystrup* [in Danish]. Teknologisk Institut Report.