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The feasibility analysis for the concept of low temperature district heating network with cascade utilization of heat between networks

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Abstract

Recently, low temperature district heating networks (LTDH) have received attention in district heating and cooling market due to their benefits in terms of efficiency, greenhouse gas reduction, flexibility to use renewable energy sources and economic benefits. In this work, physical and techno-economical aspects of the new concept of cascade types with high temperature district heating (HTDH) return is utilized to supply heat at low temperature networks. The HTDH return water temperature is around 45°C and supply of LTDH can be set around 60°C. The return water temperature of HTDH return line at 45 °C can be raised to 60°C with the help of heat pump. A detailed study of major components, network design, pressure drop, heat loss and power consumption was performed to formulate an annual, hourly, based energy simulation to assess the techno-economic feasibility of the systems for different types of customers (residential & commercial) The economics were also analysed in terms of internal rate of return (IRR) and the results show that IRR for residential buildings varies from 14 ~ 17%. In order for the successful realization of the proposed system in the market new sustainable systems encouragement in government level is desired to be provided in the form of renewable energy target/certificates or CO2 reduction incentives especially at the initial stage of the commercialization of the model.

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Keywords: Low temperature district heating; heat pump; cascade heat utilization

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1. Introduction

District Heating (DH) is concerned with centralized production of heat and electrical power and its distribution in such efficient way that the production and maintenance cost incurred is lower than individual production of end user [1]. District heating network has evolved over time in terms of its supply temperature and efficiency. Fig 1 presents the evolution and enhancement of efficiency of DH network with respect to the supply temperature. It is evident that the low temperature district heating networks are the best in term of efficiency and will be sustainable alternative in future of DH technology.

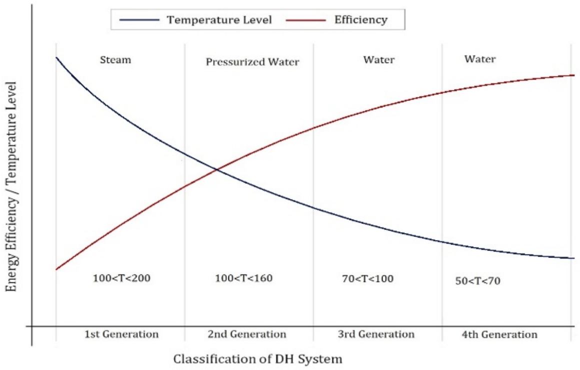


Figure 1. Classification of DH system based on temperature

The advantages of low temperature district heating include the following

- Reduced Network heat loss

  Decreasing the temperature of supply reduce the overall mean temperature difference between pipelines and ambient and thus heat loss is reduced without changing the insulation.

- Reduced Pipeline Thermal stress

  Using lower supply temperature, there will be less variation in supply temperature along the pipeline. The reduced risk of pipe leakages due to thermal stress and maintenance cost will be reduced. Furthermore, different material can be considered as candidates instead of steel or copper as in HTDH.

- Reduced Risk of boiling

  The Lower supply temperature reduces the risk of boiling as fluid temperature is far from saturation temperature.

- Renewable/Multiple heat source

  With reduced temperatures, it is not necessary to always use high exergy heat source. Renewable or multiple heat sources can also be used with ease.

- Greater utilization of thermal storage units

  Utilization of thermal storage units allow to handle the peak loads without greatly oversizing equipment and so reduce investment costs.

- Improved power to heat ratio in steam CHP system

  The efficiency of CHP unit is dependent on the condensing temperature of CHP unit. Low network supply and return temperature allow more power to be extracted from steam turbines. The reduction of the electricity output can be defined by z-factor as (1):

$$\boldsymbol{Z} = \frac{E_{electricity,loss}}{E_{electricity,produced}} \tag{1}$$

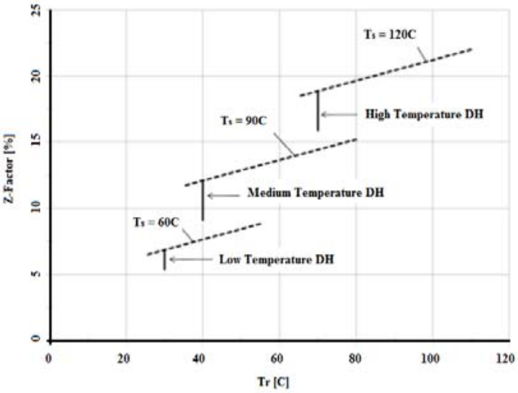


Figure 2. Z-factor in an extraction-condensing turbine for CHP as function of DH temperature [2]

Table 1. Practical application of LTDH

Name	Year	Supply Temp.	Return Temp.	Outdoor Temp.	Heat Supplied	Heat Sold	Heat Loss
		C	C	C	GJ	GJ	GJ
Kirsehir, Turkey	1995	57	38	11	39,312	33,572	5,739
Lystrup, Denmark	2009	52	34	8	986	790	196
Okotoks, Canada	2007	39	31	4	2,705	2,564	141
Halmstad, Sweden	2010	70	38	7	920	809	111
Falkenberg, Sweden	2010	78	44	7	1,374	1,252	122
Munich, Germany	2006	59	33	10	6,534	6,379	155
Slough, UK	2010	51	34	11	178	129	49
Høje Taastrup, Denmark	2013	70	40	9	1,978	1,715	263

Table 1 presents the practical demonstration of low temperature district heating networks. It can believed that LTDH systems can be implemented with reliability and will be sustainable solution of future DH systems.

2. HTDH return cascade utilization in LTDH

Fig 3. Represents the scheme where an already high temperature district heat network is operational and the return water temperature of HTDH is sent to a substation where the temperature is boosted up to 60°C by the utilization of heat pump. The heating load profiles were generated by estimating the heating load for the apartment complex type of building in Seoul. The number of houses per floor were 4 and total of 15 floors per apartment were considered. The supply and return water temperatures were kept at 60°C & 30°C, respectively. Fig 4 presents the piping layout of the considered building type.

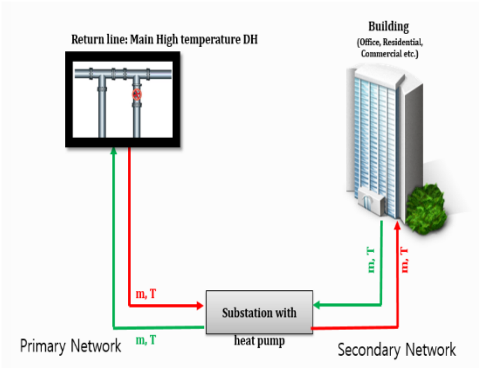


Figure 3. Utilization of HTDH return in LTDH using heat pump

Figure 4. Layout of piping in building

3. Heat Loss Model

Heat loss in piping is considered in two parts, building pipe heat loss & underground pipe heat loss.

$$Pipe\ Heat\ Loss = Q_{loss} = UA_{p,s}\left(T_f - T_a\right) = UA_{p,s}\Delta T \qquad (2)$$

$$Pipe\ Surface\ Area = A_{p,s} = 2\pi D_4 L \qquad (3)$$

$$U = \frac{1}{R}\ ;\ \ R = \frac{1}{h_i} + \frac{r_{4\ln\frac{r_2}{r_1}}}{k_p} + \frac{r_{4\ln\frac{r_2}{r_1}}}{k_p} + \frac{r_{4\ln\frac{r_3}{r_2}}}{k_i} + \frac{r_{4\ln\frac{r_4}{r_3}}}{k_c} + \frac{1}{h_o} \qquad (4)$$

$$h_i = \frac{k_p}{D_1} \times 0.023 Re^{0.8} Pr^{0.4} \qquad (5)$$

$$h_o = 13.79 + 0.03232\Delta T - 40.86 D_4 + 0.000117\Delta T^2 + 97.3{D_4}^2 - 0.01388\Delta T D_4 \qquad (6)$$

Table 2. Parameter of pipe material used in model

Pipes	**Density [kg/m3]**	**Thermal conductivity [W/mK]**	**Thermal capacity [kJ/kg.K]**
Carrier pipe	940	0.38	2.31
Insulation	60	0.0237	1.21
Outer pipe	918	0.33	2.31

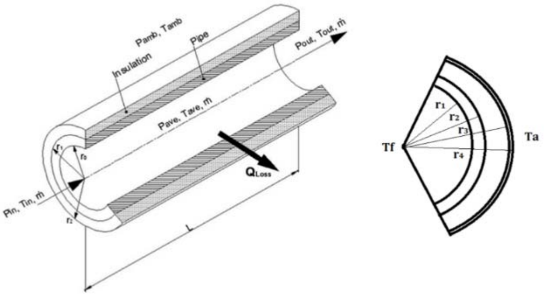


Figure 5. Layout of pipe and insulation layer

The heat loss model formulated using equations (2) ~ (6) and the material and parameters used in modelling are presented in Table 2. Fig 5 presents the layout of piping scheme. Fig. 6 presents the heat loss in terms of load if LTDH supported apartment is at 1km, 2km and 3km distance from HTDH network. The respective total heat load is also presented in Fig.6. Fig. 7 presents the heat component of heat loss with respect to total load for every month of the year.

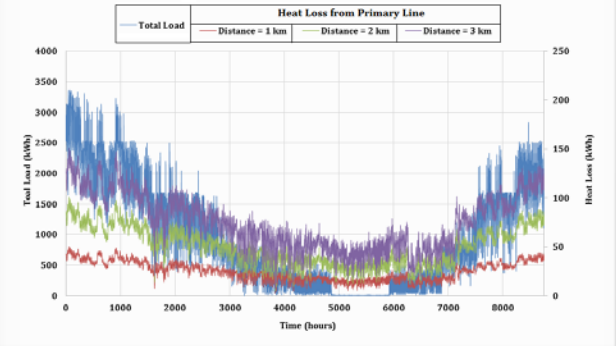


Figure 6. Annual heat loss & total load profile of LTDH with respect to distance from HTDH network

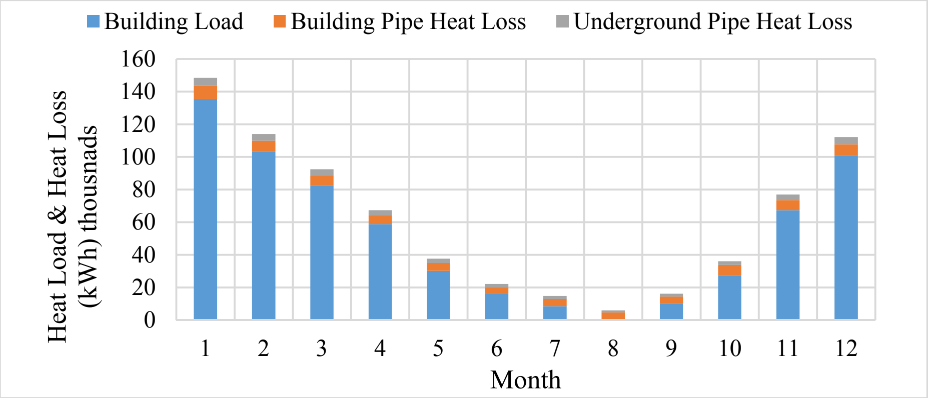


Figure 7. Component of heat loss with respect to total load

4. Heat pump model

The heat pump performance data of commercial heat pumps is used to develop an empirical correlation of COP of heat pump using regression analysis and can be reposted as eq. (7) & (8).

$$P_{el} = \frac{Q}{COP\ (T_{e,i}, T_{c,o}, \dot{m}_c, \dot{m}_e)} \quad (7)$$

$$COP = C_1 T_{e,i} + C_2 T_{c,o} + C_3 {T_{e,i}}^2 + C_4 {T_{c,o}}^2 + C_5 T_{e,i} T_{c,o} + C_6 \dot{m}_c + C_7 {\dot{m}_c}^2 + C_8 \dot{m}_c \dot{m}_e + C_9 \dot{m}_e + C_{10} {\dot{m}_e}^2 \quad (8)$$

The coefficients of used in prediction of equation (8) are presented in table 3.

Table 3. Coefficient of regression equation

C1	0.06233097	**C4**	0.000555618	**C7**	-0.23095988	**C10**	-0.00442447
C2	-0.14968569	**C5**	0.000160963	**C8**	0.001611807		
C3	-0.00080224	**C6**	3.20265706	**C9**	0.069420396		

5. Economic Analysis

The project economic feasibility was assessed by considering the capital costs of equipment and electricity billing. Following assumptions were made for the analysis:

- Project life is 30 years
- Inflation rate is 5%
- Two pipe system has been selected for secondary network
- Distance of substation is 3km
- Price of pipes, heat and labour expense is based on local market of Korea

The capital investment cost includes the cost of DH pipe network, heat pump and network connection, labor and materials. The capital cost of the primary side pipe network is based on the local Korean market and the table 4 and 5 present the cost estimation of primary side and secondary side pipe.

Table 4. Capital cost of pipe for primary pipe network [3]

Type	Pipe Standard	Price	Carrier Pipe		Insulation	Casing Pipe	
			Inner	Outer	Thickness	Thickness	Outer Dia.
		₩/m	mm	mm	mm	mm	mm
PEX	150A	253300	154.2	165.2	38.4	4	250
	125A	163800	129.6	139.6	39.1	3.5	225
	100A	124000	104.5	114.3	39.4	3.5	200
	80A	103200	80.1	89.1	32.2	3.2	160
	65A	84300	67.3	76.3	28.7	3.2	140
	50A	67600	52.7	60.5	29.1	3.2	125
	40A	49200	41.2	48.6	27.7	3	110
	32A	38300	35.5	42.7	30.7	3	110
	25A	32990	27.2	34	25.5	2.5	90
	20A	29600	21.4	27.2	28.9	2.5	90

Table 5. Capital cost of pipe for secondary pipe network

Type	Pipe Standard	Price	Carrier Pipe		Insulation	Casing Pipe	
			Inner	Outer	Thickness	Thickness	Outer Dia.
		₩/m	mm	mm	mm	mm	mm
STS (SCH 10)	100A	83780	114.3	108.2	50	0	158.2
	80A	67730	89.1	83	50	0	133
	65A	51550	76.3	70.2	50	0	120.2
	50A	46040	60.5	54.9	50	0	104.9
	40A	41220	46.8	41.2	50	0	91.2
	32A	36400	42.7	37.1	50	0	87.1
	25A	32250	34	28.4	50	0	78.4
	20A	29600	27.2	23	50	0	73

The different cost quotations have been obtained and an average cost has been chosen for heat pump based on its capacity in kW.

$$Cost\ of\ Heat\ Pump = 450\ \$/kW$$

This cost is based on the price quotations that are valid for heat pump size of 30kw to 300kW.

For comparison purpose of the LTDH with gas heating, an average price of condensing gas boiler for single family unit is also considered. The considered cost of condensing boiler is $1200 with 90% efficiency and operating cost of 21₩/MJ.

The operating cost of the low temperature districting heating is the cost of heat supplied and heat loss, pumping power cost, and the electricity cost utilized by heat pump. For the simplification, a flat rate of 83.5 ₩/MCal has been used in the present simulation. The cost of heat loss is also based on this flat rate.

The cost of electricity is presented in table 6.

Table 6. Electricity price for industrial usage

Energy charge (₩/kW)			
Time Period	Summer	Spring/Fall	Winter
Off-Peak	55.2	55.2	62.5
Mid-Peak	108.4	77.3	108.6
On-Peak	178.7	101.0	155.5

The pipe sizing for secondary network is presented in the table 7.

Table 7. Pipe sizing for secondary network

Pipe Description			**Standard**	**Length (m)**
Underground	Supply		80A	160
	Return		80A	160
Basement	Supply		80A	42.6
	Return		80A	85
Vertical	Supply	1-2 Floor	65 A	5.6
		3-8 Floor	50A	16.8
		9-11 Floor	40A	8.3
		12-15 Floor	32A	11.1
	Return	1-2 Floor	65 A	5.6
		3-8 Floor	50A	16.8
		9-11 Floor	40A	8.3
		12-15 Floor	32A	11.1

The pumping power was estimated by calculating the pressure drop in the piping network. The distribution piping accessories like elbow and tee were considered to calculate the pressure drop. The pump performance curves were used to calculate the electric power requirement against the required mass flow rate and pressure drop.

The flat rate for heating is provided in section before. The same rate is considered for billing from the consumer. The capital costs, operating costs and inflation factors are summed and balanced against the incomes generated from the consumer to find the payback period which is given in Eq. 9 below.

$$\text{Payback Period} = (\text{Cost of the investment} + \text{annual operating costs}) / (\text{Annual net cash flow}) \qquad (9)$$

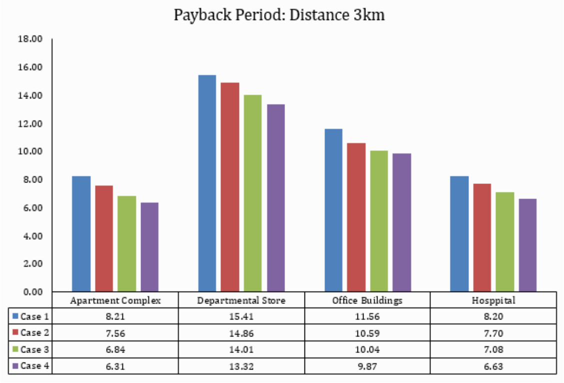
Similarly, internal rate of return was calculated by considering the mentioned 30 years of system operation and summation of incomes and expenses generated monthly.

The particulars of simulation scenarios considered in economic analysis are presented in table 8.

Table 8. Simulation Scenario for economic analysis

Case	**Primary Network**		**Secondary Network**		**Heat Pump**
	Heat Loss	**Pumping Power**	**Heat Loss**	**Pumping Power**	**Electric Power**
1	Included	Included	Included	Included	Included
2	Not Included	Included	Included	Included	Included
3	Included	Included	Not Included	Included	Included
4	Not Included	Included	Not Included	Included	Included

6. Results & Discussion



	Apartment Complex	Departmental Store	Office Buildings	Hosppital
■ Case 1	8.21	15.41	11.56	8.20
■ Case 2	7.56	14.86	10.59	7.70
■ Case 3	6.84	14.01	10.04	7.08
■ Case 4	6.31	13.32	9.87	6.63

Figure 8. Payback period of system for the mentioned scenarios and type of building

	Apartment Complex	Departmental Store	Office Buildings	Hosppital
■ Case 1	11.03%	4.56%	7.61%	10.82%
■ Case 2	12.08%	4.93%	8.07%	11.65%
■ Case 3	13.66%	5.48%	8.77%	12.91%
■ Case 4	14.68%	5.83%	9.21%	13.73%

Figure 9. Internal Rate of Return of system for the mentioned scenarios and type of building

Fig 8. Present the payback period for the system with various simulation scenarios and types of buildings. It can be observed that the payback for residential buildings is less than the other types. The major reason is load demand. Fig 9 represents the internal rate of return and again apartment complex and hospital type buildings are suitable choices but departmental stores yield smaller IRR due to their smaller load demand. The concept of heat pump and low temperature network integration has mature technology and market. The network design for low temperature district heating has been already successfully implemented in EU.

The economic analysis of different buildings shows that economic feasibility is very high for high heat density buildings [ration of heat supplied to land area], for example apartment complex and office buildings. The fluctuation of the building heat load results in lower COP and higher electric power consumption. Therefore, buildings with high heat density and low load fluctuation are favorable for low temperature district heating.

The rate of return of residential building varies from 5~6 years, for office 9~10 years, for hospital 5~7 years, and for departmental store 12~ 14 years depending on various cases considered in economic analysis. The internal rate of return varies from 11~15% for residential building, 5~6% for departmental store, 8~10% for office building, 13~15% for hospital. Decrease of return temperature from 45C~30C results in double saving of electric power per kW of heat production. Similarly 37% reduction in heat loss, supply T reduced 90 to 60C. These benefits will definitely double the economic benefits and profit for low temperature district heating.

7. CONCLUSION

In this study, the concept of cascade utilization of surplus energy in district heating network is newly suggested by utilizing the return water of HTDH as a heat source for LTDH and its feasibility is assessed for different types of buildings. Especially this cascade types of LTDH model is believed to be more favorable to propagating it into the market against the existing LTDH, i.e. isolated low temperature district heating or converting the existing HTDH model to LTDH one. The economic analysis for different types of buildings shows that economic feasibility is very high for high heat density buildings, for example apartment complex and office buildings. It is also shown that the fluctuation of the building heat load results in lower COP of the heat pump and higher electric power consumption. Consequently it has negative effect on techno-economic benefits of the model. Therefore, buildings with high heat density and low load fluctuation seem to be very appropriate conditions for creating new customer in the vicinity of the HTDH network. In this work, the applicability and feasibility of the model is carried out from the view point of expanding the existing DH network to a neighboring building. In forthcoming study, the feasibility analysis between the thermal networks, i.e. to build complex connected by the low supplying temperature network, will be carried out and its result will be presented.

8. ACKNOWLEDGEMENT

This paper covers a topic from IEA DHC Annex TS1

9. REFERENCES

[1] Bordin C, Gordini A, Vigo D. An optimization approach for district heating strategic network design. Eur J Oper Res 2016;252:296–307. doi:10.1016/j.ejor.2015.12.049.

[2] Dalla Rosa A. The development of a new district heating concept 2012;R-269:238.

[3] http://www.pipeteckorea.co.kr/ [Feb 2015]