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Study on the optimal heat supply control algorithm for district heating distribution network in response to outdoor air temperature

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ABSTRACT

In the present study, a heat supply control algorithm was developed that minimizes the rate of heat loss in the heat distribution lines of district heating community buildings. This algorithm simultaneously controlled the supply water temperature and flow rate in response to the outdoor air temperature to minimize the heat loss rate in a distribution line. The total heat supply through the distribution lines of community buildings in Hwaseong, Gyeonggi, South Korea, was compared with the total heat consumption of all households. It was revealed that 24.1% of the heat supply to the community buildings was lost in the distribution lines. By simultaneously controlling the supply water temperature and flow rate in response to the outdoor air temperature, the developed algorithm could reduce the heat loss by 11.5%.

1. Introduction

While district heating heat supply systems have continuously been studied in Europe for several decades, they have recently also been studied actively in the US and Japan [1]. With its short history of district heating heat supply systems, Korea has relied heavily on foreign technology and has yet to sufficiently develop its heat supply control technology [2,3]. District heating heat supply control requires integrated control with overall consideration of the heat producing system, heat transmission, and heat distribution pipelines [4]. Such integrated heat supply control should satisfy the heating load while minimizing heat loss during heat transportation in a heat distribution pipeline. In addition, accurate measurement data of heat loss rates in heat distribution pipelines [5] are needed to identify the factors affecting heat loss rates in heat distribution pipelines [6]. Investigating the studies regarding the energy analysis for the district heating heat supply systems, Bøhm and Danig [7] analyzed the energy consumptions, pump efficiencies, and heat exchanger efficiencies of district heating heat supply apartment buildings in the Copenhagen region of Denmark. Lin et al. [8] analyzed the influence of energy consumption on the pipeline supply water temperature and return water temperature in district heating and cooling systems in China. Shimoda et al. [9] verified the merit of a district heating and cooling system through energy simulation, considering design parameters and operating conditions. Knutsson et al. [10] developed simulation methods to analyze regional heating energy according to the fuel utilized. Larsen et al. [11] simulated district heating system pipelines to optimize the supply water temperature, and used the results to compare the German and Danish methods in a district heating heat supply system model analysis. Bojic et al. [12] developed an optimization program to find the most effective way for a district heating heat supply system to distribute the heat supply for improved system performance. Nielsen and Madsen [13] suggested a mathematical modeling method (grey-box modelling) to model the variation in energy consumption of a district heating heat supply system according to climate changes in Denmark. These analytical studies focused on the effect of the supply water temperature on energy

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Nomenclature

A_R	total heat transfer area of return water line, m^2
A_S	total heat transfer area of supply water line, m^2
A_{Room}	total heat transfer area of apartment room floor coil, m^2
C	specific heat of hot water, kJ/kg K
$\dot{m}$	mass flow rate of hot water, kg/hr
$\dot{Q}$	heat rate, kJ/hr
T	temperature, K
U	overall heat transfer coefficient, kJ/m^2 K hr
NTU	number of transfer unit

Superscripts

b	hot water
h	heating load
L	limit

Subscripts

air	outdoor air
$Room$	room
Rm	room floor
S	supply
R	return
$loss$	heat loss
$R2o$	outlet of return water line
$R2i$	inlet of return water line
$S2i$	inlet of supply water line
$S2o$	outlet of supply water line
SR	distribution pipeline

consumption, but failed to consider the combined effect of the supply water temperature and supply water flow rate according to outdoor air temperature.

The preceding studies are mainly focused on the amount of energy consumption or the type of energy consuming behaviors in a single household and in an apartment building that recently have rapidly appeared in Korea [14–16]. Also, these studies focused on heat load prediction, considering outdoor air temperature to optimize facility operation and to determine the optimal facility capacity during project planning; however, these studies could not present an optimal system control.

In this study, by analyzing the collected heat loss rate data, we found a significant heat loss rate at the distribution line of the model district apartment building. We therefore developed an optimal heat supply algorithm for the district heating system of apartment buildings, which varies the supply water temperature and flow rate in order to meet the heating load and to minimize the distribution pipeline heat loss in response to the outdoor air temperature variation.

2. Heat supply condition in the investigated apartment building

2.1. Selection of apartment building

District heating apartment buildings built after 2005 in Hwaseong, Gyeonggi, South Korea were selected for the study, considering the accessibility of heat supply data. These apartment buildings had the following design specifications: primary side heat supply water temperature of 388.5 K, return water temperature of 338.5 K, secondary side heat supply water temperature of 333.5 K, return water temperature of 318.5 K, and hot supply water temperature of 328.5 K. The location, heat source, observation period, and heat supply state of each household are shown in Table 1 and Table 2.

Table 1
Specifications of the model district heating community buildings.

Items	Specifications
Object community building	D-community buildings
Number of households	1473
Period	2008.01.01–2008.12.31
Location	Hwaseong City, Gyeonggi-do, Korea
Heating source	District heating

Basic data from January 2008 ~ December 2008 and the annual heating load and hot-water supply load in response to outdoor air temperature variation were used. The pipeline heat loss rate was calculated from the data.

2.2. Analysis of heat supply condition in model district – heating apartment building

Fig. 1 shows a schematic diagram of the optimal heat supply control algorithm that varies the supply water temperature and mass flow rate in a district heating apartment building. Instantaneous data of the measured outdoor air temperature and heat characteristics of the heat distribution line of a district heating apartment building are used to calculate the supply water temperature and mass flow rate for optimal heat supply control.

A primary network of the district heating system supplies hot water of about 388.5 K to the machinery room of apartment buildings. Supplied energy from the primary network (transmission line) is exchanged to the secondary network (distribution line) at the heat exchanger. The district heating apartment building observed in this study has heat supply water temperature of 310.5 K–318.5 K during Spring and Autumn, and 310.5 K–323.5 K during Winter. In this study the difference between secondary heat exchanger outlet temperature and return water inlet temperature are minimized to reduce heat loss. Algorithm with variable supply water temperature and flow rate is utilized. The exit temperature of the heat exchanger and the mass flow rate are assumed to be controlled by the optimal heat supply control algorithm, as schematically shown in Fig. 1.

Fig. 2 shows a schematic of the secondary network in a district heating apartment building. Here, T_{S2i} is the secondary network heat-exchanger supply water temperature, T_{S2o} is the apartment building entrance supply water temperature, T_{R2i} is the apartment building exit return water temperature, and T_{R2o} is the heat-exchanger inlet return water temperature. The heat loss rate in the secondary network supply water pipeline is $\dot{Q}^S_{loss}$ and the heat loss rate in the return water pipeline is $\dot{Q}^R_{loss}$.

Fig. 3 shows a schematic of the heat exchange model of the Korean traditional floor heating system (Ondol), where $\dot{Q}_h$ is the heat transfer rate from the floor to the indoors, T_{air} is the outdoor air temperature, $\dot{m}_{h2}$ is the supply water flow rate, U_{Room} is the overall heat transfer coefficient between the Ondol (Korean traditional floor heating system) hot-water pipeline and the indoor air,