Experimental analysis of heat prosumers under low temperature thermal network

Kim, Min-Hwi; Lee, Dong-Won; Kim, Duk-Won; Heo, Jaehyeok
Korea Institute of Energy Research, Daejeon, 34129, South Korea
dwlee@kier.re.kr

Abstract. This study investigated the applicability and thermal performance of heat prosumers in a bidirectional thermal network through experimental analysis. To realize the bidirectional thermal network and heat prosumers, the existing small-scale centralized district cooling and heating system was retrofitted to form a small-scale heat network with three thermal energy prosumers. The existing small-scale centralized district cooling and heating network consists of seven buildings: high schools, management center, childcare center, baby care center, youth center, library, and public health center. Among these, high school and childcare center were retrofitted from heat consumers to heat prosumers. Control logic for the proposed heat prosumer was also demonstrated. For the case study, the operation of the specific day was selected. The amount of heat supplied from the STES in the management center was 798.7 kWh that contained 17% of the total load. The heat supply from the TES connected to the heat pump in the management center was 2,270.5 kWh, the absorption heat pump for high school. The amount of heat supply for public buildings and schools was 824.0 kWh and 513.8 kWh, respectively, and the heat supply from the childcare center through geothermal heat pump was 295.2 kWh.

1. Introduction
The demand for 4th generation district heating based on low-temperature heat supply and heat energy trading/sharing is increasing in the power and thermal energy sectors [1-3]. This is because of the increased consumption of eco-friendly energy, such as new and renewable energy, and expansion of distributed energy systems. Heat energy transaction between buildings can be operated by sharing heat-source facilities for economic efficiency and eco-friendliness of heat source facilities, as well as when excess heat energy is generated in one building. Simply, heat source equipment installed according to the maximum load of each building is selectively operated in consideration of various conditions under partial load, and the produced heat energy is shared and used by several buildings. Such heat energy trading or sharing can increase the efficiency of the distributed energy system and utilization of new and renewable heat energy.

As centralized district heating based on large- and medium-sized cogeneration plants has limitations, research on distributed district heating in which thermal energy production facilities are installed in various places that are close to energy consumers or facilitate energy production has also attracted attention. With the distribution of the installation space of renewable and unused thermal energy systems, studies have been conducted to respond to thermal energy sharing [4-5]. Moreover, methods for implementing thermal energy prosumers to connect the thermal energy systems of individual buildings to district heating have also been actively conducted [6-10].
Various studies have been conducted on thermal energy prosumers for district heating. Brange et al. [6] investigated the application of small-scale prosumers to district heating and examined the environmental impacts of various building types. They found that the heat obtained through prosumers can cover 50%–120% of the annual thermal energy demand. Ancona et al. [7] implemented a connection method for constructing bidirectional thermal networks in four different district-heating thermal networks. Sanchez et al. [8] proposed a smart dual thermal network concept and performed analysis on a bidirectional heat supply between buildings for surplus thermal energy when a building with renewable energy systems is connected to the existing district heating.

In a previous study [9], two thermal energy prosumers were established and a method for modifying the pipe network for heat transactions was presented. The operation was conducted in the summer and winter seasons, while demonstrating the sharing of heat energy between buildings with different heat source facilities. The applicability of the bidirectional heat supply was verified. In this study, after incorporating the newly constructed public building in the Jincheon eco-friendly energy town into the existing network and converting it to another prosumer, the piping network was modified to enable two-way heat supply, and a control system was built. Consequently, a total of seven buildings, including three thermal energy prosumer buildings with different heat source facilities and four buildings without heat source facilities, were connected by a thermal network. Further, a demonstration operation on the sharing of heat energy between the buildings was conducted. Demonstration operation was performed in winter. To realize energy transactions or sharing on the thermal network in the future, we used network modification and control method.

2. Jincheon eco-friendly energy town overview

The Jincheon eco-friendly energy town was constructed as a water quality restoration center, nearby public buildings located in Jincheon-gun in Chungbuk Innovation City. It aims to achieve 100% self-sufficiency for the annual power and thermal energy demand by installing renewable and thermal energy systems as well as supplying eco-friendly energy to nearby public buildings. The energy produced is supplied to libraries, childcare centers, healthcare centers, youth centers, and high schools built by Jincheon-gun and Jincheon Office of Education, as well as other six buildings, including an integrated management center that is used as a machine and public relations room.

The eco-friendly energy town of Jincheon was constructed by the end of 2016 to supply thermal energy for heating and domestic hot water (DHW) throughout the year based on the 1,600 m² solar thermal system and 4,000 m³ seasonal storage tank (Figure 1). Three 175 kW heat pumps were also installed as auxiliary heat source systems, including geothermal and sewage source heat pumps. A heat pump for low-temperature surplus heat was installed in the seasonal storage tank as an evaporation heat source. A total of 850 kW photovoltaic systems were installed in public buildings, parking lot roofs, and unused sites. The generated power is sold, and the grid power is consumed to realize a net zero-energy town [9].

The 350 kW capacity geothermal and sewage source heat pumps used as auxiliary heat source systems can produce cooling water in summer to public buildings, except for a school with large air-conditioning loads. In the school, a separate approximately 1,000 kW gas combustion absorption heat pump has been installed and used as a cooling system. Therefore, the machine room in the school has a heat exchanger capable of receiving the supplied heat, and then channel it to supply the cooling water, produced by the absorption heat pump, to the interior of the school.
3. Bi-directional thermal energy trading method

The management center normally produced the cooling and heating water utilizing the various heat sources such as the solar thermal system integrated with seasonal thermal energy storage and multi sources heat pumps. And the high school consumes the heating energy supplied by the management center or produced by the absorption heat pump installed in the high school. The childcare center can consume heating and cooling energy produced by the geothermal source heat pump by itself, or it can be supplied by the other two heat prosumer buildings (high school and management center). High schools and childcare centers equipped their own heat production facilities and the other buildings used the heating and cooling energy supplied from the management center. Figure 2 shows the operating method of the three heat prosumer buildings to trading the cooling and heating energy.

During demonstration operations, it was determined whether the intended heat supply was properly performed while controlling each operation method according to an arbitrary schedule. A typical case of the valve and pump control methods based on each operation method is shown in Fig 2. As shown in Fig 2 (a), the childcare center can receive the heating and cooling energy from management center or high school. Fig 2 (b) shows a control method when the heat energy produced by the childcare center is shared with the other two buildings.
Figure 2. Overview of Jincheon eco-friendly energy town and solar thermal systems

4. Experimental results

4.1. Heating operation test results

Figure 3 shows a graph of the amount of real-time heat supply on a given day (February 16, 2021) during the heating period by dividing the supply entity. The measurement periods of temperature and flow rates are 30-seconds. The heat was supplied from the night-time thermal energy storage tank (TES) for a short period of time periodically from 11:00 pm to the next morning 6:00 am to prevent freezing of the thermal network. The heating energy produced by the heat pump in the management center and stored into the TES was supplied to the entire buildings from until 9 am. to 1 pm. During this periods, the temperature of the TES was higher than 48 °C. After the temperature of the TES is lower than the target temperature, the absorption heat pump of the high school is the heating of the high school and other public buildings until 5 pm. Then, the heat produced by the heat pump in the management center and childcare center was transferred to four buildings, including high schools, respectively. When the heat produced by the solar thermal system since morning accumulated in the seasonal thermal energy storage (STES) and the temperature of STES is above the target heating supply water temperature, the heating water was supplied by the STES. When all the heat accumulated into the STES was exhausted, the heat generated by the heat pump of the management center and stored in the TES were supplied again. After 5 p.m., when the heating load drastically decreased, the management center provided heating to
buildings, excluding the high school and childcare center; the two prosumer buildings performed self-heating mode. This operation was conducted until 9 p.m., the end of the heating supply.

For this particular day, the total thermal load for domestic hot water and heating energy of the town was 4,702.2 kWh. Among them, the amount of heat supplied to the STES in the management center (domestic hot water supply + heating) was 798.7 kWh that contained 17% of the total load, the heat supply of the TES connected to the heat pump in the management center was 2,270.5 kWh (48%), the absorption heat pump for high school. The amount of heat supply for public buildings and schools was 824.0 kWh (18%) and 513.8 kWh (11%), respectively, and the heat supply from the childcare center through geothermal heat pump was 295.2 kWh (6%).

5. Conclusion
In this study, based on a small-scale heat network (cooling and heating) of the Jincheon eco-friendly energy town, we proposed a network modification plan with three thermal energy prosumers and conducted a two-way heat supply demonstration operation. In this study, a childcare center, with its own heat source facility, was incorporated into the heat network. Piping and valves were supplemented so that the childcare centre could also act as a thermal energy prosumer. Thus, three thermal energy prosumers completed an extended thermal network that can supply thermal energy to seven buildings. A two-way heat supply demonstration operation was performed.
In this configured heat network, the desirable operation method is to first supply the heat produced by the solar thermal system integrated with STES of the management center. This method requires minimum operation cost during the heating period, and allows storage of the produced heat is stored into the TES by operation of the heat pump during the low electric cost period. This is an operation method that responds by operating an absorption heat pump at a high school or geothermal heat pump at a childcare center. During the cooling period, the heat produced by the solar thermal system is stored the heat into the STES and supplied only to the domestic hot water. First, the cooling energy produced by the heat pump, which uses a regenerative heat source during low cost electric bill times and stored into the TES, and then the absorption heat pump or geothermal source heat pump is used in the high cost electric bill times. This method responds by operating a time and electricity cost compared with the natural gas cost.

Therefore, the existing management center supplied heating and cooling energy to other buildings using solar thermal system, geothermal heat source, and sewage treatment water source heat pumps. It was confirmed that it is possible to various operation modes of supply the thermal energy to other buildings. The proposed method of constructing a bidirectional thermal network can be used to implement heat transactions between buildings on a heat network with multiple heat energy prosumers, and the results of the demonstration operation allow each thermal prosumer to appropriately share the amount of heat energy supply in consideration of economy and eco-friendliness. This can contribute to deriving an optimal bidirectional heat supply operation plan.

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