2010

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ABSTRACT

This paper presents the performance of a water-to-refrigerant type ground source multi-heat pump (GSHP) system installed in a school building in Korea. The evaluation of the performance has been conducted under the actual operating conditions of the GSHP system. Ten units with the capacity of 10 HP each were installed in the building. Also, a closed vertical typed-ground heat exchanger with 24 boreholes of 175 m in depth was constructed for the GSHP system. For analyzing the performance of the GSHP system, we monitored various operating conditions, including the outdoor temperature, the ground temperature, and the water temperature of inlet and outlet of the ground heat exchanger. Simultaneously, the capacity and the input power were evaluated for determining the performance of the GSHP system. The average cooling coefficient of performance (COP) of the heat pump was found to be 8.3 at 65% partial load condition, while the overall system COP was found to be 5.9. The average heating COP of the heat pump was found to be 5.1 at 45% partial load condition, while the overall system COP was found to be 4.2.

1. INTRODUCTION

Concerns about application of the GSHP systems increase due to the shortage of fossil fuels and environmental pollution problems all over the world (Zhaho et al., 2002). The GSHP system which consists of ground heat exchangers (GHE) and heat pumps is recognized to be outstanding cooling and heating system. In the heating system, the GSHP absorbs heat from the ground and uses it for heating the house or building. In the cooling system, heat is absorbed from the conditioning space and transferred to the earth through the GHE (Sohn et al., 2005). The merit of this system is less consumption of energy for operating than an air source heat pump (ASHP) system. Because the ground temperature that acts heat sink and heat source of heat pump is more stable than outdoor temperature, the GSHP system has superior performance. Main disadvantage of the GSHP is the higher initial capital cost for installation (Hepbasli, A., 2002 and Hwang et al., 2007).

Performance of the GSHP system is affected by the thermal conductivity and temperature of ground, the type of the GHE and the heat pump. The GSHP performance is studied by Hepbasli et al. (2003), Zhao (2004), Nagano et al. (2006) and Michopoulos et al. (2007). The water-to-water type heat pump systems are usually adopted for GSHP systems. It supplies energy as cold and hot water made by heat pump to whole building by the fan coil unit (FCU). A water-to-refrigerant type heat pump system has been developed for the GSHP lately. In the water-to-refrigerant type heat pump system, the GHE is the same as the water-to-water type, but the indoor units exchange heat by air to refrigerant. In the water-to-water type heat exchanger, it needs for a circulating pump to send water to the FCU, the maintenance is regularly needed due to corrosion of water pipe and leakage problem. However, in the water-to-refrigerant type, the circulating pump is not needed to send water to the FCU, so that the cost for the pump input power and its maintenance can be saved.

In this study, the GSHP system of the water-to-refrigerant type is installed in a school building. Cooling and heating performance of heat pump itself and the whole system is estimated. And we measure the ground temperature variation when the GSHP system is operating.

2. EXPERIMENTAL

2.1 Experimental apparatus

The GSHP system is installed in a building at Pusan National University to analyze its technical and economical aspects under the actually operating condition. The building is constructed with two stories below and six floors above the ground. The GSHP system covers the first and second floors, and the total floor area is 1,193 m^2.

10 units (LRW-N2900D, LG Electronics, Korea) which have the capacity of 29 kW are established in this building for the GSHP system. Figure 1 shows an overview of the water-to-refrigerant type heat pump system with 4 indoor units and the specifications of the components were summarized in Table 1.

The GSHP system of the water-to-refrigerant type has higher efficiency with the compressor of inverter type and it has a good performance in partial load. The GHE is the closed vertical type which has 24 boreholes with 175 m in depth. The building where the GSHP was installed has the offices, the seminar rooms and the professor rooms.

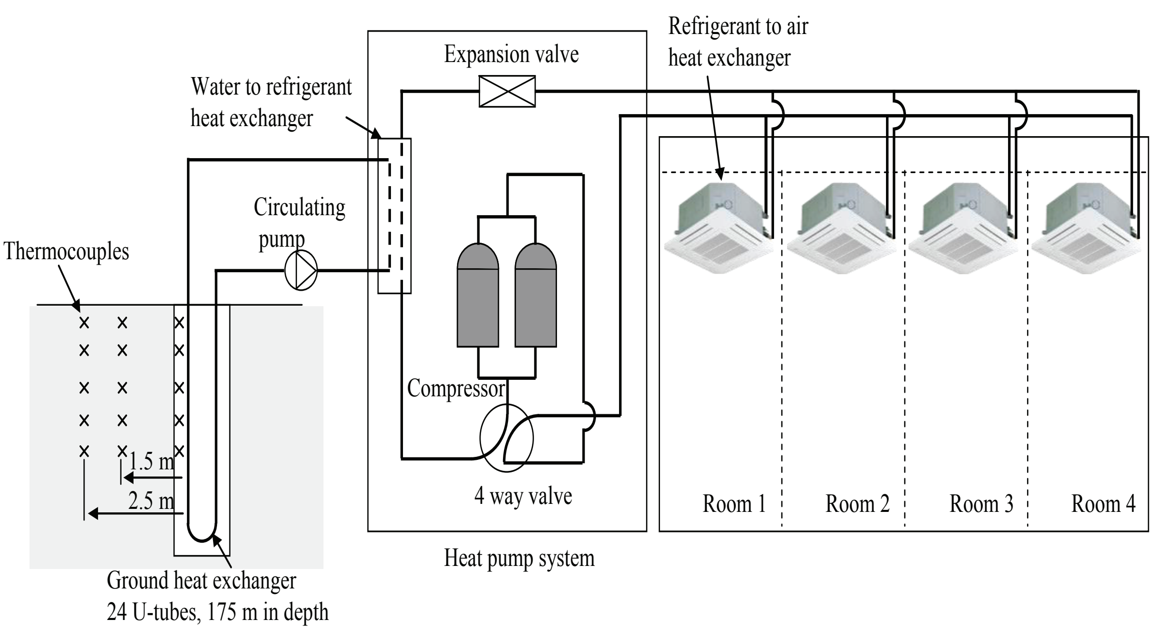

Figure 1: System diagram of the ground source multi-heat pump

Table 1: Specification of the components consisting of the GSHP system

Main circuit	**Component**	**Specification**
Ground coupling circuit	Ground heat exchanger	Vertical-closed U-bend type Borehole diameter: 150 mm Internal diameter of U-bends: 42 mm Borehole depth: 175 m, Material: polyethylene
	Circulating pump	Volumetric flow rate: 45~130 m^3/h Power:7.5kW, Speed: 1750 rpm
Heat pump circuit (Manufacturer: LG Electronics; model: LRW-N2900D)	Heat exchanger	Capacity: 32.6 kW Type: Plate heat exchanger
	Compressors	Type: Rotary Refrigerant: R-410A 1. Inverter type: 4.2 hp (3.1 kW) 2. Fixed type: 4.2 hp (3.1 kW)
	Indoor unit	Manufacturer: LG Electronics Model:LRD-N725T Cooling capacity: 7.2 kW

To analyze the performance of the heat pump, we selected 1 unit of the GSHP which is connected in the office. Figure 1 shows the schematic diagram of the system to analyze the performance of the GSHP system and the ground temperatures. Each office has one indoor unit (LRD-N725T, LG Electronics) for the GSHP system. One office area is 43.2 m^2 and the total office area is 172.8 m^2.

The temperatures of the ground corresponding to the depth are measured with T-type thermocouple. The inlet and outlet temperatures of the circulating water through the heat pump are measured with the resistance temperature detector (RTD Pt-100). The indoor temperatures and humidity to evaluate the cooling load are measured with thermocouple and hygrometer (EL-2, LASCAR). The power consumption of the system (i.e. the electric power input to the compressor, water circulating pump and the fan of indoor unit) is measured by a wattmeter (MWT-340S, Hanguk micronics). In addition, the power consumption of the compressor for the performance of the heat pump is measured by another wattmeter (WT1600, Yokogawa). All measured quantities are regularly recorded in every 1 minute with the data acquisition system.

2.2 Data analysis

Generally performance of the GSHP is represented by the coefficient of performance (COP). COP of heat pump in the cooling and heating mode is calculated by the following equation (1).

$$COP_{hp} = Q / W_c \tag{1}$$

Where Q is the space cooling or heating load, W_c is the power input to the compressor.

The overall coefficient of performance of the system is calculated by

$$COP_{overall} = Q / (W_c + W_p + W_f) \tag{2}$$

Where W_p is the power input to the circulating pump of the GHE, W_f is the power input to the fan of indoor unit.

Where Q the space cooling or heating load can be calculated as follows

$$Q = m_{air} (h_{o,air} - h_{i,air}) \tag{3}$$

$$m_{air} = \rho_{air} V_{air} \tag{4}$$

Where m_{air} is the mass flow rate of air, V_{air} is the volumetric flow rata of air, ρ_{air} is the density of air. And $h_{o,air}$ is the enthalpy of outlet, $h_{i,air}$ is the enthalpy of inlet in the heat exchanger of the indoor unit.

3. RESULTS AND DISCUSION

When absorption or extraction of thermal energy from the ground is accomplished by using the GHE, Performance of the GSHP is influenced by the thermal properties of the ground. Therefore, we installed thermocouples under the ground to analyze thermal diffusion property of the GHE in Figure 1. Figure 2 shows the ground temperature variations corresponding to the depth ranging from the surface to 20 m.

The ground temperature at 2.5 m in depth is greatly dependent on the outdoor air temperature. The ground temperature at 5m in depth is also affected by outdoor air temperature. Variation of temperature is stable below 10 m in depth. The average temperature of circulating water is 20.2 ℃ during the operating of the system in the cooling mode. And it is 15.3 ℃ during the operating of the system in the heating mode.

Figure 3 shows the monthly operating load of the heat pump. It is observed that the system was in operation about 9 h/day from May, 2007 to June, 2008. It was cooling season from May to September and cooling load was the highest in August. It was heating season from November to March and heating load was the highest in January. There was no load in April so the heat pumps were not operated. The operating load of the heat pump was average 65% in August when cooling load was the highest during cooling period. And it was average 45% in January when heating load was the highest during heating period. There was a difference according to partial load of the heat pump in performance of heat pump. In general, it is announced that good performance of heat pumps are obtained at low partial load. In this research, we estimated the performance of GSHP in January (heating period) and August (cooling period) when the load of heat pump was the highest. Figure 4 shows performance of cooling and heating. The performance of GSHP is calculated using equation (3) and it is measured from the indoor units. The cooling load of these space is 19.1 kW in average, which is 65% partial load compared to full load (29 kW) of the GSHP. Average COP of heat pump is 8.3, while average COP of whole system is 5.9. The heating load of these space is 14.7 kW in average, which is 45% partial load compared to full load (32.6 kW) of the GSHP. Average COP of heat pump is 5.1, while average COP of whole system is 4.2.

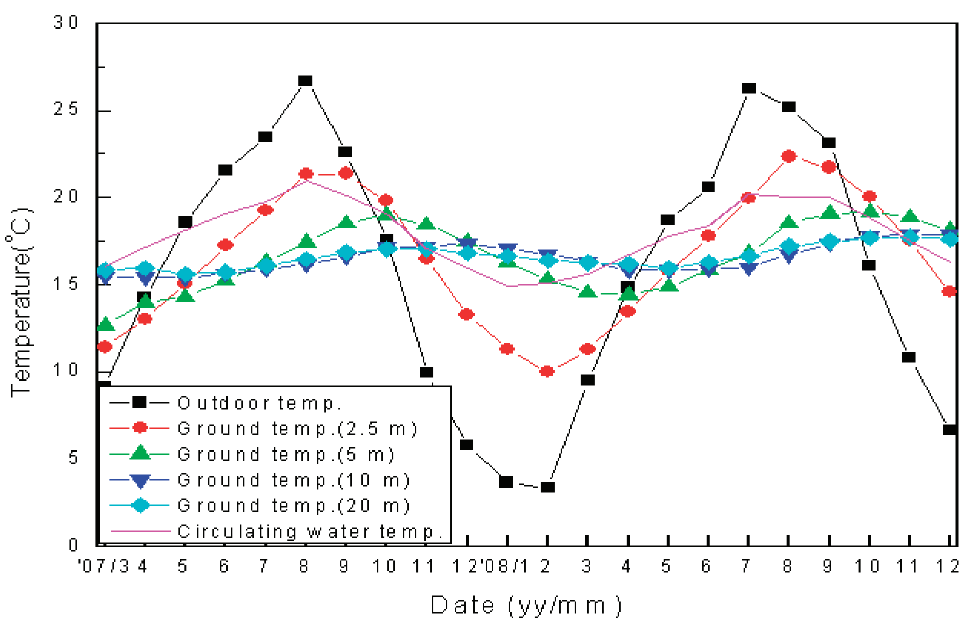

Figure 2: The monthly average ground temperature, outdoor temperature and circulating water temperature variations from March, 2007 to December, 2008

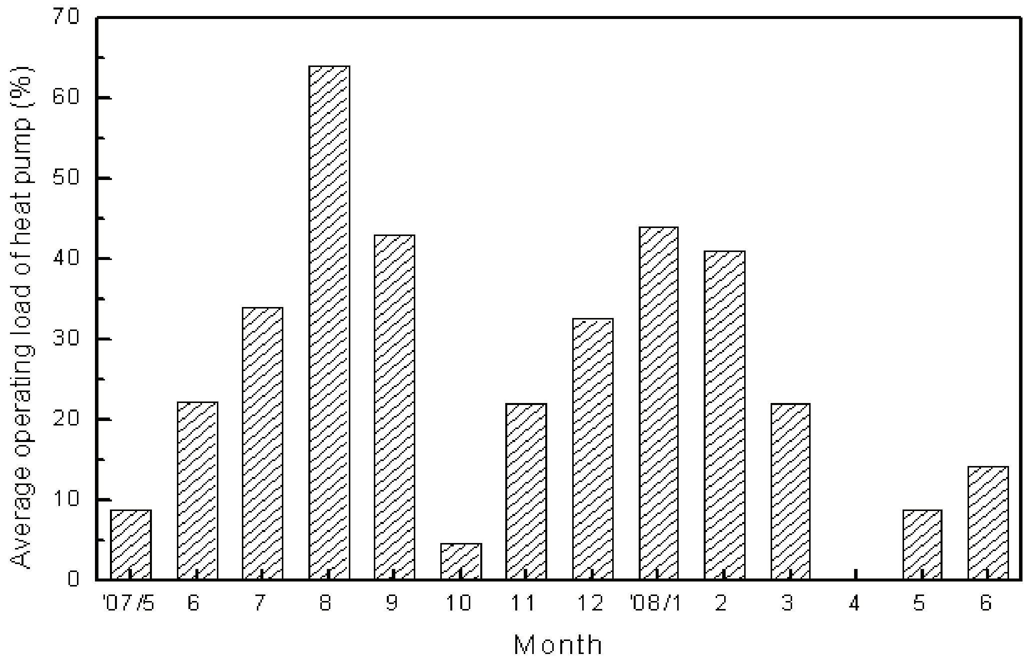

Figure 3: The monthly average operating load of the ground source multi-heat pump from May, 2007 to June, 2008

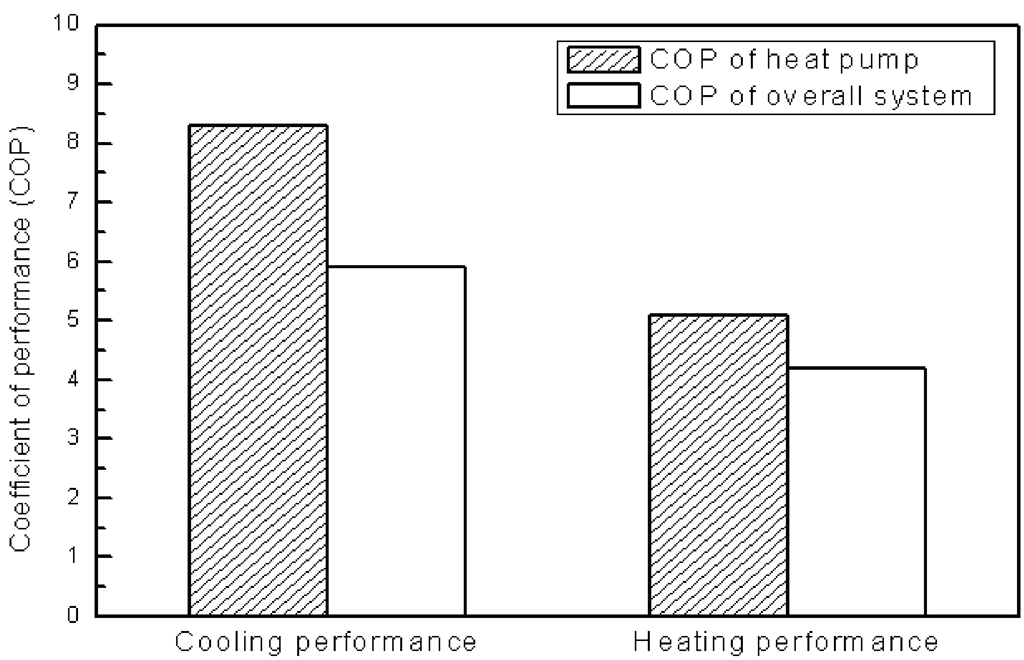

Figure 4: The cooling performance (partial load 65%) and the heating performance (partial load 45%) of the ground source multi-heat pump

4. CONCLUSIONS

In this study, the GSHP system of the water-to-refrigerant type is installed in a school building. Performance of heat pump itself and the whole system is estimated. And we measure the ground temperature variation when the GSHP system is operating.
(1) We installed thermocouples under the ground to analyze thermal diffusion property of the GHE. As the result, the ground temperature at 2.5 m in depth is greatly dependent on the outdoor air temperature. The ground temperature at 5 m in depth is also affected by outdoor air temperature. Variation of temperature is stable below 10 m in depth.
(2) We estimated the performance of GSHP in January (heating period) and August (cooling period) when the load of heat pump was the highest. The cooling load of space is 19.1 kW in average, which is 65% partial load compared to full load (29 kW) of the GSHP. Average COP of heat pump is 8.3, while average COP of whole system is 5.9. The heating load of space is 14.7 kW in average, which is 45% partial load compared to full load (32.6 kW) of the GSHP. Average COP of heat pump is 5.1, while average COP of whole system is 4.2.

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ACKNOWLEDGEMENT

This research achieved with under supports of Korea Energy Management Corporation (KEMCO), LG Electronics and Department of Facilities in Pusan National University.