

COOLING PERFORMANCE OF A GROUND SOURCE HEAT PUMP SYSTEM

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Abstract: This present study is to evaluate the cooling performance of a water-to-refrigerant ground source heat pump system (GSHP) under the actually operating condition. 10 units which have the capacity of 29 kW are established in a building for the GSHP system and a ground heat exchanger (GHE) is the closed vertical type which has 24 boreholes with 175 m in depth. 1 unit is selected among 10 units of the GSHP in the building to analyze the performance, and its operation is monitored with a data acquisition system. Performance of GSHP is analyzed with data of August 16, 2007 when cooling load is the highest during the measurement period. The average cooling COP of heat pump at the partial load of 65% is 8.3, while overall system COP is 5.9.

Key Words: *Ground source heat pump (GSHP), Ground heat exchanger (GHE), Cooling performance, Coefficient of performance (COP)*

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 [1]. 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 [2]. 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 [3].

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.[4], Zhao[5], Nagano et al.[6] and Michopoulos et al.[7]. 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 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 as in Figure1. The GSHP system covers the first and second floors, and the total floor area is 1,193 m².

10 units (LRW-N2900D, LG Electronics, Korea) which have the capacity of 29 kW are established in this building for the GSHP system. Figure 2 shows an overview of the water-to-refrigerant type heat pump system with 4 indoor units. 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 shown in Figure 1 has the offices, the seminar rooms and the professor rooms.



Figure 1: Building of the Ground Source Heat Pump installed

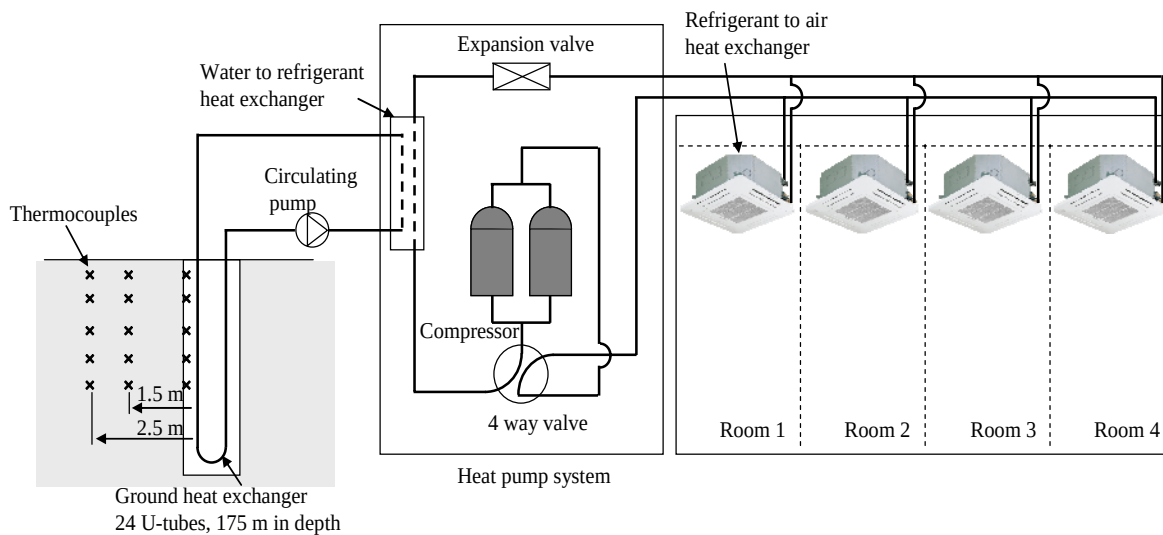


Figure 2: System diagram of ground source heat pump

To analyze cooling performance, we selected 1 unit of the GSHP which is connected in the office. Figure 2 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, Korea) for the GSHP system. One office area is 43.2 m² and the total office area is 172.8 m².

The temperatures of the ground corresponding to the depth are measured with T-type thermocouple. The inlet and outlet temperatures of the circulated water through 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 cooling performance 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 mode is calculated by the following equation (1).

$$COP_{hp} = \frac{\dot{Q}_{sl}}{\dot{W}_c} \quad (1)$$

where $\dot{Q}_{sl}$ is the space cooling load, $\dot{W}_c$ is the power input to the compressor.

The overall coefficient of performance of the system is calculated by

$$COP_{overall} = \frac{\dot{Q}_{sl}}{\dot{W}_c + \dot{W}_p + \dot{W}_f} \quad (2)$$

where $\dot{W}_p$ is the power input to the circulating pump of the GHE, $\dot{W}_f$ is the power input to the fan of indoor unit.

where $\dot{Q}_{sl}$ the space cooling load can be calculated as follows

$$\dot{Q}_{sl} = \dot{m}_{air} (h_{o,air} - h_{i,air}) \quad (3)$$

$$\dot{m}_{air} = \rho_{air} \dot{V}_{air} \quad (4)$$

where $\dot{m}_{air}$ is the mass flow rate of air, $\dot{V}_{air}$ is the volumetric flow rate of air, ρ_{air} is the density of air.

And $h_{o,air}$ is the enthalpy of evaporator outlet, $h_{i,air}$ is the enthalpy of evaporator inlet.

3 RESULTS AND DISCUSSION

3.1 Ground temperature

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 at 1.5 m, 2.5 m in depth to analyze thermal diffusion property of the GHE in Figure 2. Figure 3 shows the ground temperature variations corresponding to the depth ranging from the surface to 30 m.

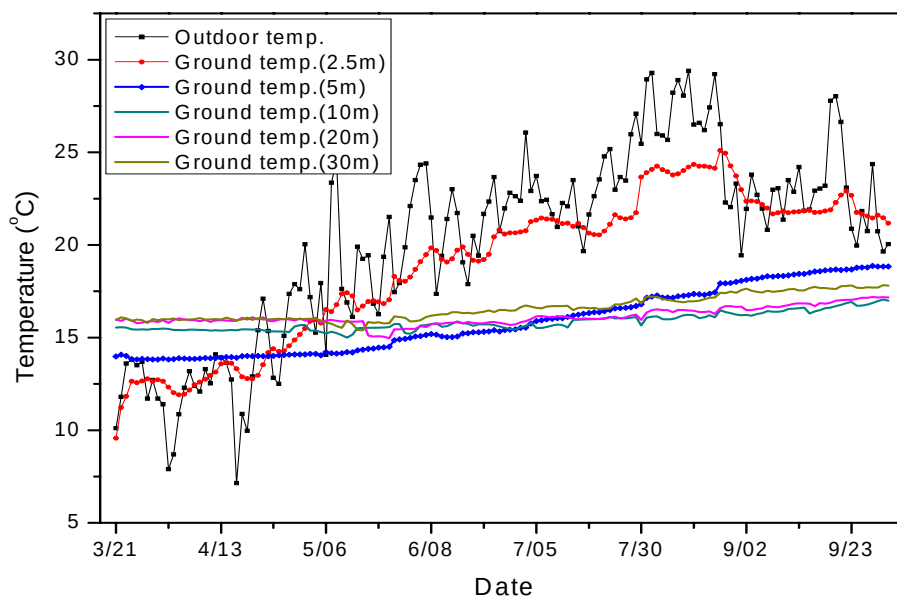


Figure 3: The daily average ground temperature and outdoor temperature variations from March, 2007 to September, 2007

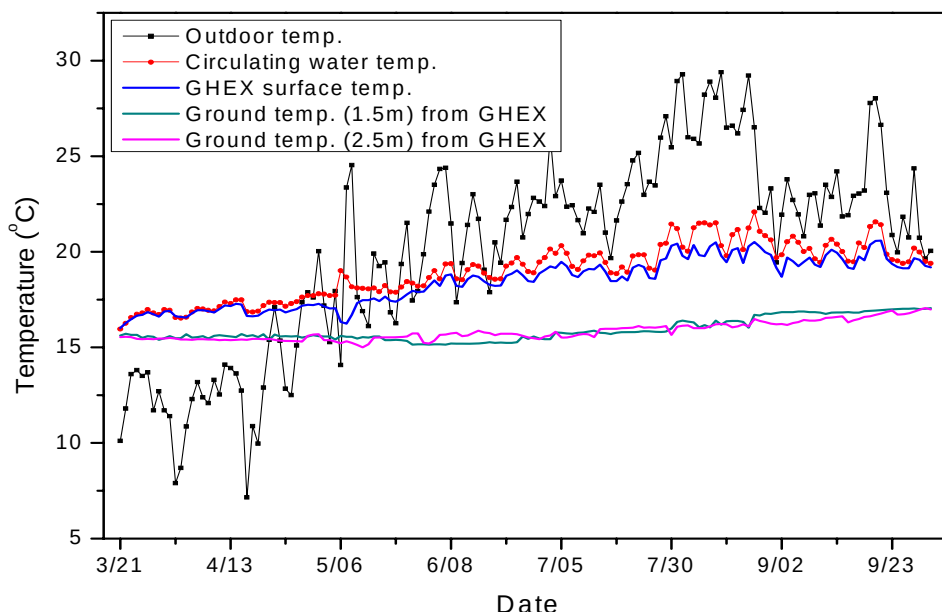


Figure 4: The daily average outdoor temperature, inlet water temperature and outlet water temperature of the ground heat exchanger (GHE) from March, 2007 to September, 2007

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 10m in depth but the average ground temperature increases 1.5°C in September 30 (17.3°C) compared to that in March 21 (15.8°C). Figure 4 shows the circulating water temperature of the GHE and the ground temperature. We measure the ground temperature at 1.5m, 2.5m away from the GHE to observe the change of the ground temperature by the circulating water. The average temperature of circulating water is 19.7°C during the operating of the system in the cooling mode. It increases up to 22.1°C according to the outdoor air temperature and the cooling load. The surface temperature of the GHE varies according to the temperature of circulating water. But the ground temperature at 1.5 m, 2.5 m far from the GHE is not changed in accordance with circulating water temperature.

3.2 Cooling performance

In this research, the performance of the GSHP is analyzed with data of August 16, 2007 when cooling load is the highest during the measurement period. Figure 5 shows temperature change of the circulating water at inlet and outlet of heat exchanger (condenser) of the heat pump. Inlet temperature of circulating water is almost constant (21.5°C in average). Outlet temperature of circulating water changes according to the cooling load. Temperature difference between inlet and outlet of circulating water is maximum 5.0°C and appears 3.1°C in average. Figure 6 shows the cooling load that 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.

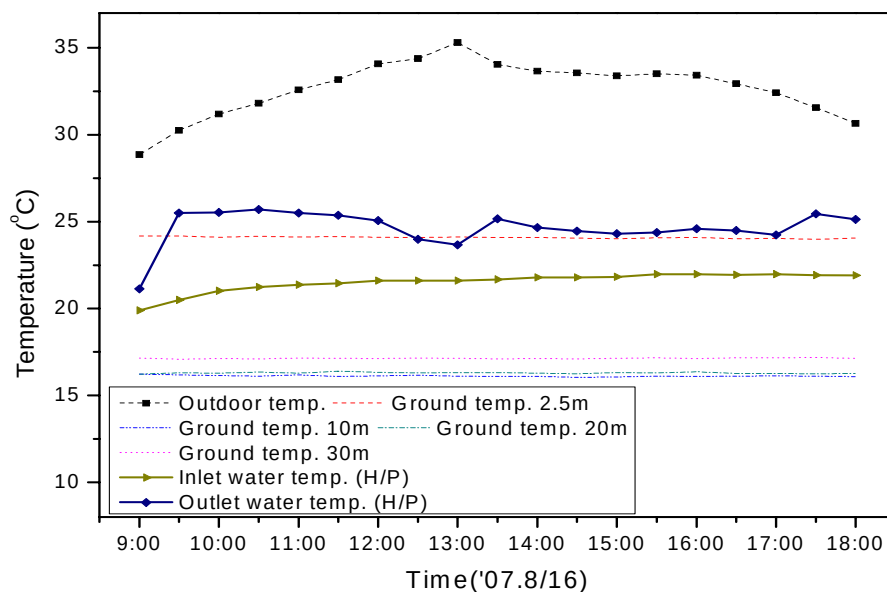


Figure 5: The variation of the water temperature at the condenser inlet and outlet of the ground source heat pump

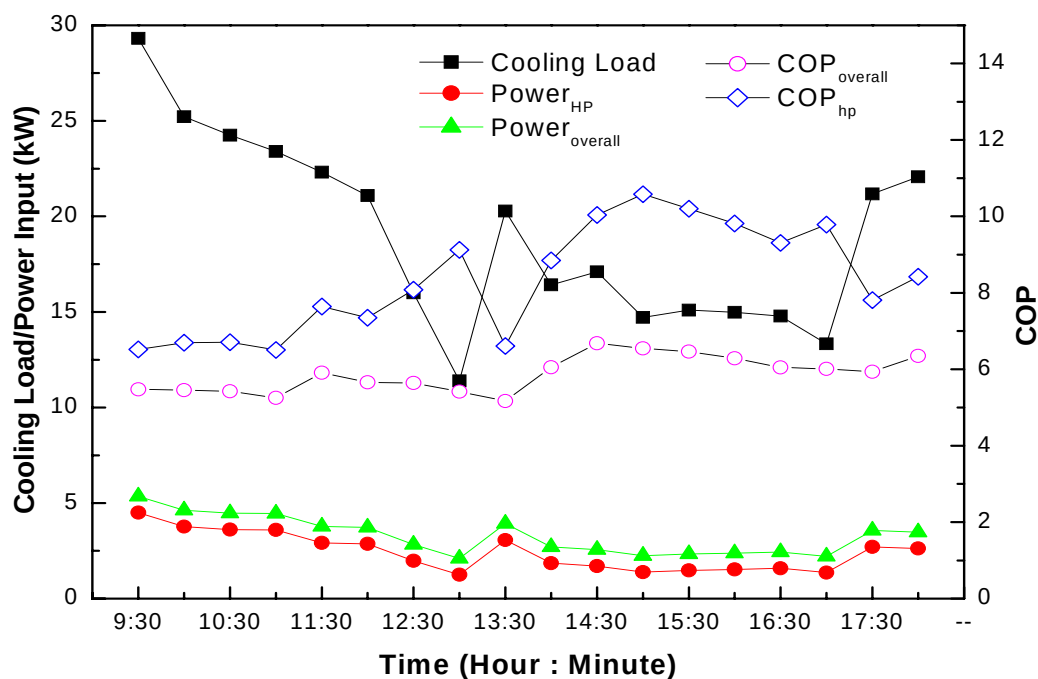


Figure 6: The variation of space cooling capacity and power consumption.

4 CONCLUSION

In this study, the GSHP system of the water-to-refrigerant type is installed in a school building. Cooling 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 at 1.5 m, 2.5 m in depth 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 but the average ground temperature increases 1.5°C in September 30 (17.3°C) compared to that in March 21 (15.8°C).

(2) The performance of the GSHP is analyzed with data of August 16, 2007 when cooling load is the highest during the measurement period. Inlet temperature of circulating water is almost constant (21.5°C in average). Outlet temperature of circulating water changes according to the cooling load. Temperature difference between inlet and outlet of circulating water is maximum 5.0°C and appears 3.1°C in average. 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.

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