GROUND LOOP DESIGN OF GROUND SOURCE HEAT PUMP SYSTEM IN A SCHOOL BUILDING

Bon-Cheol Ku[1], Young-Man Jeong[1], Kyung-Min Koo[1], Jae-Keun Lee[1], Ja-Hyoung Koo[2], Dong-Hyuk Lee[2], In-Kyu Kim[2]

[1] Department of Mechanical Engineering, Pusan National University, Busan 609-735, Korea
[2] Digital Appliance Laboratory, LG Electronics, Gyeongnam 641-711, Korea

Abstract: The Ground source heat pump (GSHP) system of the water-to-refrigerant type is installed in a building to analyze in the technical and economical aspects. First of all, the heating and cooling load is evaluated by a simulation program (Visual DOE-2) and the peak load is calculated. In-situ thermal conductivity is measured and the ground heat exchanger is designed. We make a testing device for in-situ thermal conductivity measurement and thermal conductivity is evaluated by the solution of the Line Source problem. Finally, the ground heat exchanger is designed by commercial software (GLD). The required borehole length of ground heat exchanger is 3956 m and the number of boreholes is 24 (165 m depth borehole).

Key Words: ***Ground source heat pump (GSHP), heating load, cooling load, thermal conductivity, ground heat exchanger (GHE)***

1 INTRODUCTION

Recently, energy shortage and environmental pollution are problems all over the world [1]. The needs for the new renewable energy (NRE) have significantly increased. NRE is consist of the renewable energy (solar thermal, photovoltaic, biomass, wind, geothermal, etc) and new energy (fuel cell, coal gasification, hydrogen) [2]. Among the various new renewable energy systems, the ground source heat pump (GSHP) system has been spotlighted as an efficient building energy system. The GSHP system which consists of a ground heat exchangers (GHE) and the 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 [3]. 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. Main disadvantage of GSHP is the higher initial capital cost for installation [3].

Performance of the GSHP system is affected by the thermal conductivity and the temperature of ground, the type of the GHE and the heat pump. Performance of the GSHP is studied by Hepbasli et al.[5], Zhao[6], Nagano et al.[7] and Michopoulos et al.[8]. The water-to-water type heat pump systems are usually adopted for the GSHP systems. It supplies energy as cold and hot water made by heat pump to whole building by 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 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 FCU, so that the cost for the pump input power and its maintenance can be saved.
GSHP system of the water-to-refrigerant type is installed in a school building to analyze its technical and economical aspects under the actual operating condition. In this study, we carry out that in-situ thermal conductivity is measured and the ground heat exchanger is designed for the GSHP system of the water-to-refrigerant type.

2 EXPERIMENTAL

2.1 Heating and Cooling load

The heating and cooling loads of the building are carried out to optimize the size of the GSHP system. They are calculated by a simulation program, Visual DOE-2 [9]. The DOE-2 program is widely used by engineers, architects and utility managers to estimate the energy requirement for building. Basically DOE-2 program has a modeling and simulation code. It accepts building construction data, weather data, HVAC information, equipment, lights and people occupancies as input data. The program calculates the building hourly cooling and heating loads for the whole year.

Figure 1: Building of the Ground Source Heat Pump installed

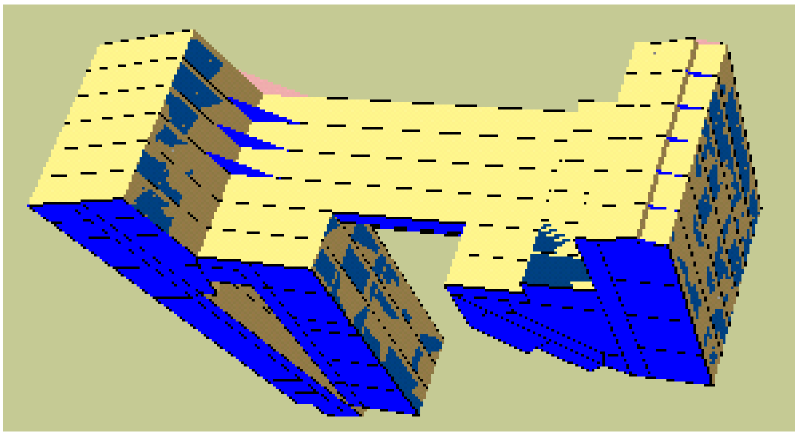

Figure 2: 3D view of the selected building

The GSHP system is installed in a school building. The building is constructed with two stories below and six floors above the ground as in Figure1. GSHP system covers the first and second floors, and the total floor area is 1,193 m^2.
A three-dimensional (3D) view of the building by Visual DOE-2 is shown in Figure 2. The heating and cooling loads are calculated by a simulation program (Visual DOE-2). The results of the peak load calculation are 128.7 kW in the cooling and 93.9 kW in the heating.

2.2 In-situ thermal conductivity test

In-situ thermal conductivity is the important item when designing the GHE. When absorption or extraction of thermal energy from the ground is accomplished by the GHE, Performance of the GSHP is influenced by the thermal properties of the ground. The operation of the GHE induces a simultaneous heat and moisture flow in the surrounding soil. The transfer of heat between the GHE and adjoining soil is primarily by heat conduction and to a certain degree by moisture migration. Therefore, it depends strongly on the soil type, temperature and moisture gradients [10]. These properties can be estimated in the field by installing a loop of approximately the same size and depth as the heat exchanger planned for the site.
Figure 3 shows the test apparatus [11] for in-situ thermal conductivity measurement. The test apparatus is composed of a heater with constant power (water tank), a circulation pump, a power meter, a flow meter and thermocouples connected to a data acquisition system. The boreholes are drilled down to a depth of 175 m with a diameter of 150 mm. The double U-pipes are made of polyethylene with an inside/outside diameter of 42/48 mm. The filling material of the tested borehole is the standard mixture of bentonite and quartz sand.
The evaluation method widely accepted for simplicity and reasonable accuracy is based on the solution of the Line Source problem [12]. The equation for the temperature field as a function of time and radius around a line source with constant heat injection rate [13] may be used as an approximation of the heat injection from the GHE.

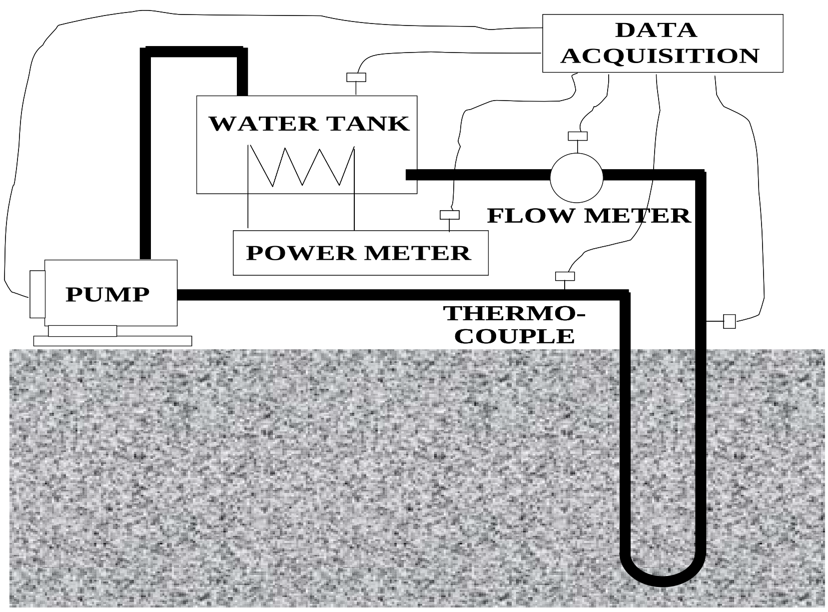

Figure 3: Thermal properties test apparatus

The thermal conductivity is related to the slope of the resulting line in a logarithmic time plot of the mean fluid temperature in the GHE. The fluid temperature can be written as equation (1).

$$\Delta T = A + (\frac{Q}{4\pi k})\ln(t) \qquad (1)$$

where ΔT is the average temperature difference(℃), A is constant, Q is the heat transfer rate(W).

Equation (1) can be re-written in the thermal conductivity (k) form as equation (2).

$$k = \frac{Q}{(4\pi \times L \times slope)} \qquad (2)$$

where k is the thermal conductivity(W/m℃), L is the borehole depth (m), $slope$ is the average loop temperature vs time(semi-log).

Figure 4 presents the experimental results for the In-situ thermal conductivity test. This graph shows the inlet, outlet and mean water temperature through to the ground heat exchanger. Figure 5 shows the slope of the associated regression line and the slope is 0.769. In equation (2), the thermal conductivity is 3.08 (W/m℃). In-situ thermal conductivity test results are summarized in Table 1.

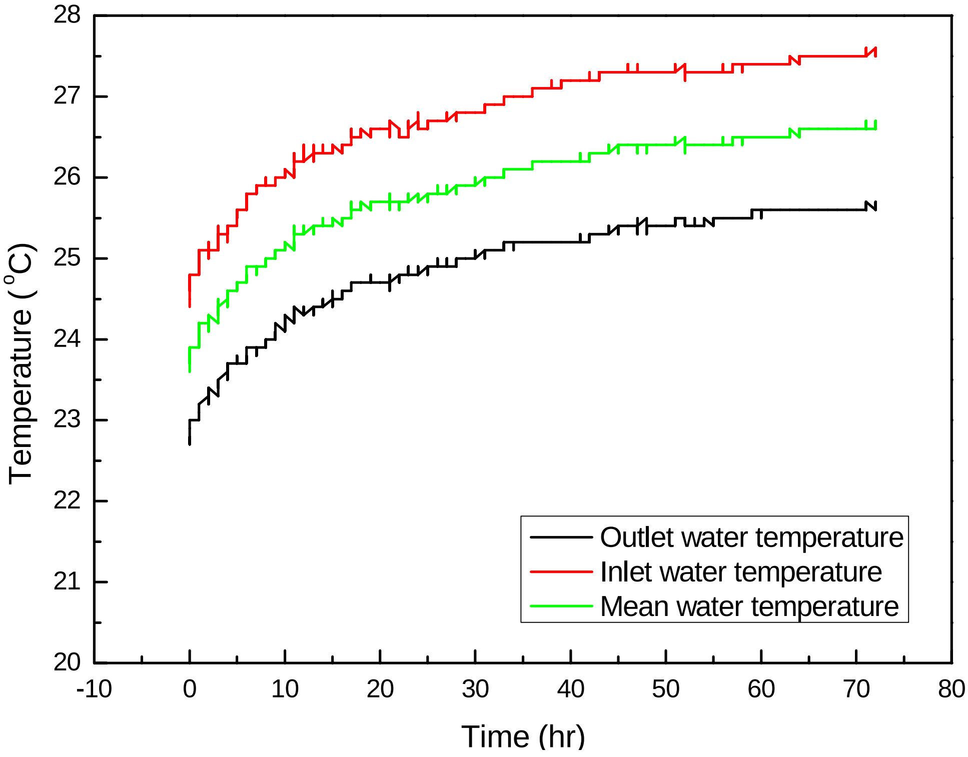

Figure 4: The water temperature of GHE as a function of time

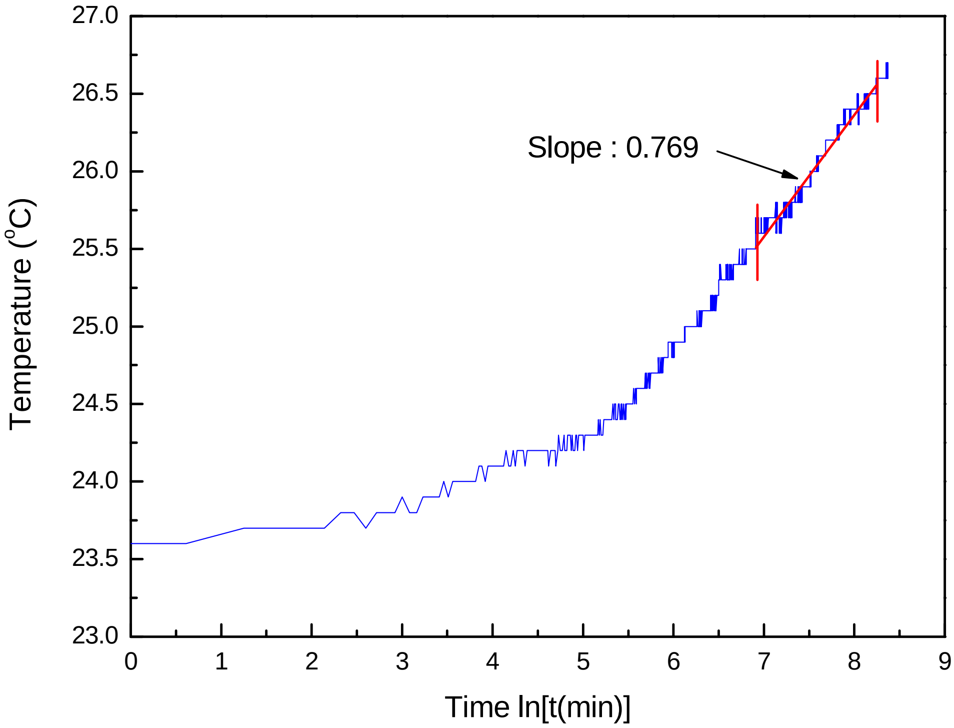

Figure 5: Logarithmic time plot of the mean fluid temperature

Table 1: Summary of in-situ thermal conductivity test

Items		Contents
Borehole	Depth [m]	175
	Diameter [mm]	150
Ground heat exchanger	Material	High density polyethylene
	Pipe size [mm]	40
Circulating fluid		Water
Power injection [kW]		5.2
Flow rate [m3/h]		2.4
Test duration time [hr]		72
Slope		0.769
Thermal conductivity value [W/m℃]		3.08

3 GROUND LOOP DESIGN

Finally, the ground loop for the ground heat exchanger could be designed from the commercial software such as the Gaia Geothermal's GLD (Ground Loop Design) program (Gaia Geothermal, 2005). This program allows the user to input various parameters with respect to the vertical borehole system and calculates results such as the required bore length, the inlet and outlet temperatures, the coefficient of performance (COP), etc., based on the input data.

The ground loop design values are determined from GLD program as in Figure 6. The required borehole length of ground heat exchanger is 3956 m and the number of boreholes is 24 (165 m depth borehole).

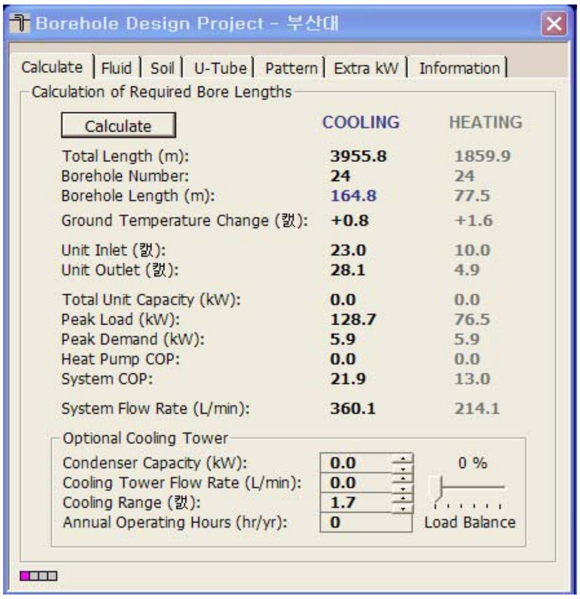

Figure 6: Ground loop design

4 CONCLUSION

In this study, we carry out that in-situ thermal conductivity is measured and the ground heat exchanger is designed for the GSHP system of the water-to-refrigerant type.

1. The heating and cooling loads are calculated by a simulation program (Visual DOE-2). The peak loads are 128.7 kW in the cooling and 93.9 kW in the heating.
2. The in-situ thermal conductivity is evaluated by the solution of the Line Source problem. The boreholes are drilled down to a depth of 175 m with a diameter of 150 mm. The double U-pipes are in polyethylene with an inside/outside diameter of 42/48 mm. The thermal conductivity is 3.08 (W/m℃).
3. Finally, the ground loop design for the ground heat exchanger is determined from commercial software (GLD). The borehole length of ground heat exchanger is 3956 m and the number of boreholes is 24 (165 m depth borehole).

5 ACKNOWLEDGEMENTS

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

6 REFERENCES

[1] Zhaho P. C., Zhaho L., Ding G. L., Zahang C. L. 2002. “Experimental research on geothermal heat pump system with non-azeotropic working fluids,” *Applied Thermal Engineering*, vol. 22: 1749-1761.

[2] Hwang K. I., Woo S. W., Kim J. H., Yang G. Y., Shin S. H. 2006. “An experimental study on the thermal performance change of horizontal type geothermal heat exchanger

with long term operation," *Proceedings of the SAREK 2006 Summer Annual Conference*, p. 725-730.
[3] Sohn B. H., Cho C. S., Shin H. J., An H. J. 2005. "Cooling and heating performance evaluation of a GSHP system," *Air-conditioning and Refrigeration Engineering*, Vol. 17, No. 1, pp.71-81.
[4] Hepbasli A. 2002. "Performance evaluation of a vertical ground-source heat pump system in Izmir, Turky," *Int. J. Energy Res.*, Vol. 26, pp.1121-1139.
[5] Hepbasli A., Akdemir O., Hancioglu E. 2003. "Experimental study of a closed loop vertical ground source heat pump system," *Energy Conversion and Management*, Vol. 44, pp.527-548.
[6] Zhao L. 2004. "Experimental evaluation of a non-azeotropic working fluid for geothermal heat pump system," *Energy Conversion and Management*, Vol. 44, pp.1369-1378.
[7] Nagano K., Katsura T., Takeda S. 2006. "Development of a design and performance prediction tool for the ground source heat pump system," *Applied Thermal Engineering*, Vol. 26, pp.1578-1592.
[8] Michopoulos A. , Bozis D., Kikidis P., Papakostas K., Kyriakis N. A. 2007. "Three-years operation experience of a ground source heat pump system in Northern Greece," *Energy and Building*, Vol. 39, pp.328-334.
[9] LBL. DOE-2 Reference Manual Parts 1 and 2. 1980. Version 2.1A with 2.1B Supplements. Lawrence Berkeley Scienti®c Laboratories, Available from NTIS, National Technical Information Service, USA.
[10] Hepbasli A. 2002. "Performance evaluation of a vertical ground-source heat pump system in Izmir, Turky," *Int. J. Energy Res.*, vol. 26: p. 1121-1139.
[11] Pahuda D., Matthey B. 2001. "Comparison of the thermal performance of double U-pipe borehole heat exchangers measured in situ," *Energy and Buildings*, vol. 33: p. 503-507.
[12] Roth P., Georgiev A., Busso A., Barraza E. 2004. "First in situ determination of ground and borehole thermal properties in Latin America," *Renewable Energy*, vol. 29 : p. 1947–1963.
[13] Carslaw HS, Jaeger JC.. 1993. Conduction of heat in solids, 2nd ed. Oxford: Clarendon Press.
[14] Ground Loop Design Manual, Version 3.0. 2005. Gaia Geothermal, America.