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# Performance Expectation of a Geothermal Heat Pump System using a Numerical Model

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## ABSTRACT

The aim of this study is to determine the expected the long-term performance of a geothermal heat pump system by simulation with a numerical model and monitored data. In three ground heat exchangers (GHEs) the entering and leaving fluid temperatures and GHE flow rates were monitored during a period of system operation. The monitored data were used to calculate heat transfer rates of the GHEs. From the weekly and seasonal variations of heat transfer rates, we defined the characteristics of cooling and heating loads of the building. A simplified numerical model of borehole heat exchanger was applied to simulate heat transfer rate of GHEs and the validity of the model was approved by comparing with the heat exchange rates of measured data. The numerical model is used to predict long-term performance and the stability of the system.

## 1. INTRODUCTION

In this study field-scale approaches and the monitoring system were applied for the matching with numerical simulation result (Figure 1). Some studies with regards to the system modeling of GHEs have been conducted on the thermal and hydraulic characteristics (Fujii et al, 2005, Kim et al., 2010). In the study site 28 GHEs (200 m deep) and 79 heat pump units are connected with three main circuit pipes for air-conditioning at each floor. The data of the three monitored GHE were automatically transmitted to a monitoring system and were selected to calculate borehole heat exchange rate.


**Figure 1: Schematic diagram of GHE array and a photo of the site. The object system is located at the Earthquake Research Center building of KIGAM, Korea.**

## 2. MONITORING

Figure 2 represents indoor and outdoor air temperature variation for the summer and winter season in an office of the building. The system typically runs from July to August in the summer season and from December to the next February in the winter season.

## 3. NUMERICAL MODEL OF GHES

For the 3D simulation of the field-scale area, FEFLOW (finite element groundwater flow and heat transport simulation model; Diersch, 2009) is applied. The horizontal area of the model is extended over 128×135 and 11 layers of 20 m thickness were used with a total thickness of 220 m. The geometry of the installed GHP is simplified and the model was constructed to a multi-well model that includes 28 borehole heat exchangers (Figure 3). In the BHE grid model, the installed double U tube pipe is modeled as a triangle grid which has equivalent surface area per unit depth. The total depth is divided by layers corresponding to the geothermal gradient as initial boundary condition and no groundwater flow condition is used from hydrogeologic and groundwater level data (Shim et al., 2006, Shim and Song, 2007). Thermal parameters of the ground were obtained from the analysis of rock core samples of the study site and horizontal hydraulic conductivities were measured from injection tests (Table 1). Initially in/out transfer rate was estimated with the analytical method and the parameter is tested by the numerical model with the sensitivity analysis.

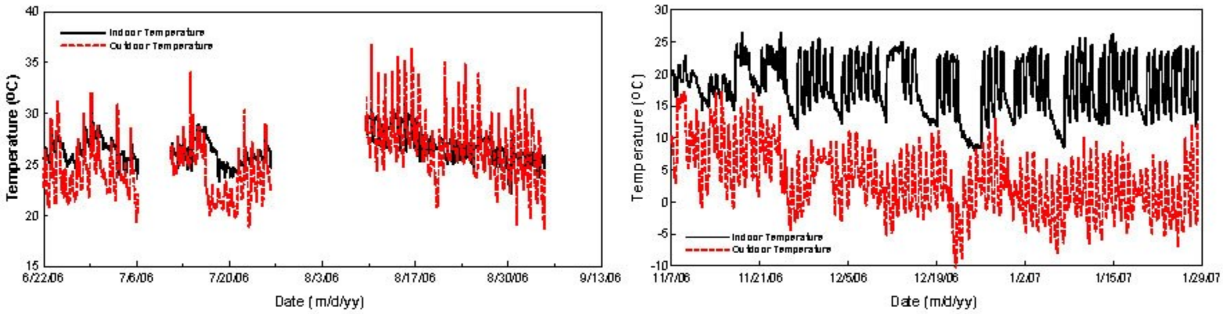


**Figure 2: Indoor and outdoor temperature monitored data at the building at summer (left) and winter (right) periods.**

**Table 1. Input parameters and the used values for the simulation model**

| | |
|---|---|
| Porosity [1] | 0.014 |
| Volumetric heat capacity of fluid [J/m$^3$/K] | $4.2\times10^6$ |
| Volumetric heat capacity of solid [J/m$^3$/K] | $2.214\times10^6$ |
| Heat conductivity of fluid [W/m-K] | 0.65 |
| Heat conductivity of solid [W/m-K] | 2.75 |
| Longitudinal dispersivity [m] | 1.0 |
| Transversal dispersivity [m] | 0.5 |
| In/out transfer rate [J/m$^2$/d/K] | $2.2\times10^6$ |
| Horizontal hydraulic conductivity [m/s] | $2.31\times10^{-6}$ |
| Vertical hydraulic conductivity [m/s] | $4.62\times10^{-7}$ |

From the measured inlet and outlet fluid temperature and the flow rate of GHEs, heat exchange rates of GHE can be obtained with the equation q=ρ×cp× (Tin-Tout) ×V. Where q is the heat exchange rate between formation and heat exchanger (W), ρ is the density of circulation fluid (kg/m3), cp is the specific heat of circulation fluid (J/kg-K), Tin is the entering water temperature (K), Tout is the leaving water temperature (K), and V is the flow rate (m3/s). However in the numerical model the heat exchange rate were calculated with the equation: Qheat = A×Φ× (Tref-T). Where Qheat is inflow or outflow to/from the model, A is relevant area, Φ is transfer rate, Tref is reference temperature and T is current temperature in groundwater. Monitored average fluid temperatures of the GHE are applied as a reference temperature in transient condition (Figure 4). Therefore the input boundary conditions of the GHEs at the model are a time-varying function. The data selection during the summer and winter seasons were conducted in order to compare the heat exchange rates of GHEs in the summer and winter seasons, respectively. The Qheat was validated using q (from monitored data) in three monitoring locations of GHEs.

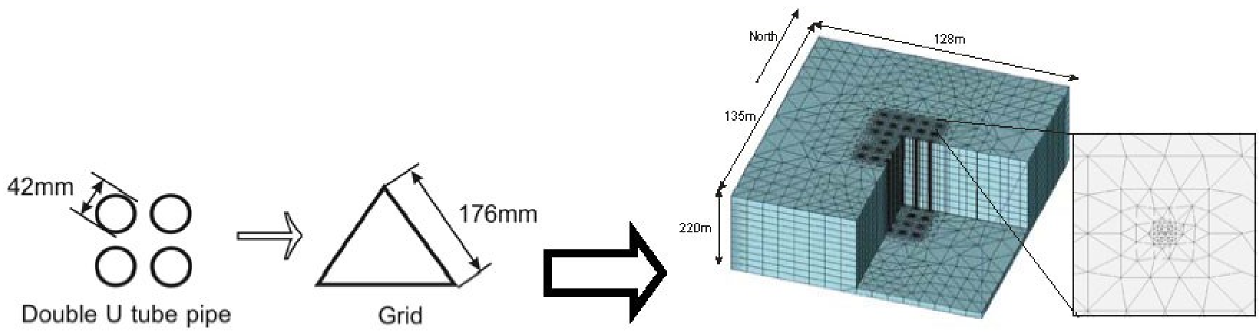


**Figure 3: Schematic diagram of a field-scale GHE numerical model setup process.**

For the simulation scenario we set the periodic air-conditioning load for 20 years. Seasonal heat transfer simulation was conducted by each 3 months cyclic rotation with heat source (summer), stop, sink (winter) and stop. Obtained seasonal heat exchange rates show a little bit different trend at each floor but all figures show stable cyclic rates according to the simulation period (Figure 5). The GHP performance could be sustainable during the long period if the air-conditioning loads are similar. The numerical model can be used to predict long-term performance or efficiency for the design of GHE.

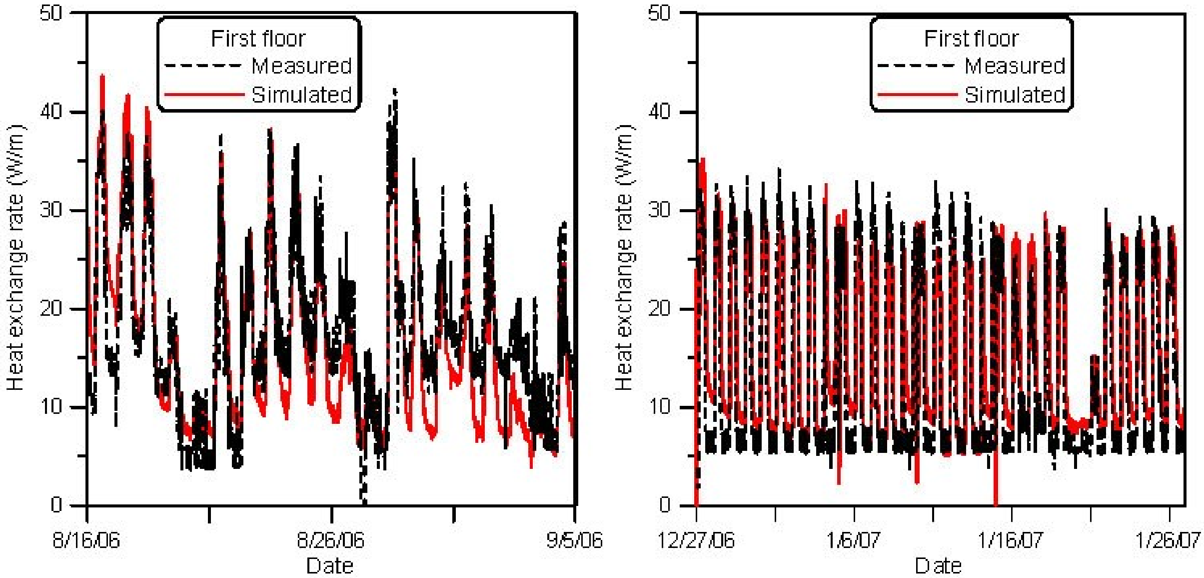


**Figure 4: Comparison between simulated (Qheat) and monitored heat exchange rates (q) at cooling (left) and heating (right) seasons by air-conditioning.**

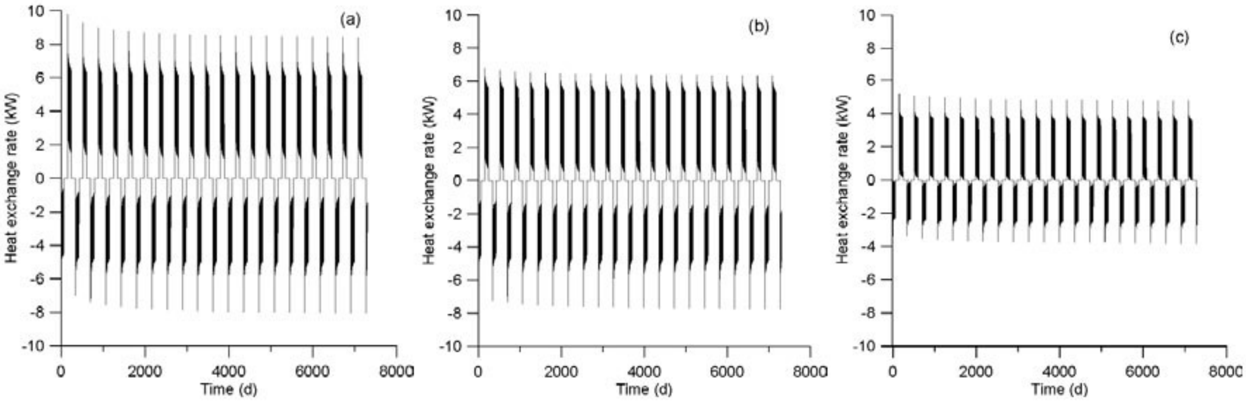


**Figure 5: Simulated heat exchange rate fluctuation during 20 years corresponding cooling and heating operations periodically. a, b and c represents the results from first, second and third floor of the building respectively.**

## 3. CONCLUSION

We characterized the air-conditioning load to the ground by defining the running style of GHP in winter and summer period with monitored data. The data were used to set up a simplified field-scale numerical model. The thermal and hydraulic parameters were used and the heat transfer rate was validated by thermal response test and numerical model by sensitivity analysis. The comparison results from the simulated heat exchange rates and the monitored one were shown to be in good agreement. The heat transfer rates on simulation shows that the GHP performance could be sustainable in the long period. The development of numerical model can be used to predict long-term performance or efficiency for the design of GHE.

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