DEVELOPMENT OF HYBRID HEAT PUMP SYSTEM USING MULTI SOURCES OF GROUNDWATER AND AIR

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The groundwater heat pump systems (GWHP) are open-loop systems that draw water from a well or surface water, pass it through a heat exchanger and discharge the water into an injection well or nearby river. By utilizing the relatively stable temperature of groundwater, they can achieve a higher coefficient of performance and can save more energy than conventional air-source heat pump (ASHP) systems. However, it is difficult for only ground heat source to meet the heating and cooling loads with an annual balance. In order to optimize the operation of GWHP systems, it is necessary to develop a system using both groundwater and air sources according to the condition of building loads. Furthermore, groundwater should be used only as a heat source by circulating in one or two wells to prevent the ground subsidence and save the boring cost. This research has developed a hybrid system that employs a heat pump system with groundwater circulatory wells using multiple heat sources, groundwater and air source. In this paper, experimental analysis with real-scale equipments and numerical analysis have been described. The coefficient of system performance and the effects on subterranean environments have been evaluated by the experiments using standing column wells. Furthermore, a numerical analysis model using 3 dimension heat and water transfer simulation code has been developed to predict the heat exchange rate and the temperature of groundwater. Analysis results were compared with the experimental results, and the validity of the simulation model developed in this study was confirmed.

Keywords: Hybrid heat pump system, Experimental Analysis, Numerical analysis

1. INTRODUCTION

The groundwater heat pump systems (GWHP) are open-loop systems that draw water from a well or surface water, pass it through a heat exchanger and discharge the water into an injection well or nearby river. By utilizing the relatively stable temperature of groundwater, they can achieve a higher coefficient of performance and can save more energy than conventional air-source heat pump (ASHP) systems. However, they need a certain amount of pumping to exchange heat with groundwater but, due to strict regulations for pumping in the centre of city, it is difficult to acquire an amount which meets the heating and cooling loads. Furthermore, in intermediate season (for example, spring or autumn), in which heating and cooling loads are not so much, GWHP system is not more efficient than ASHP system according to conditions of temperature. In order to optimize the operation of GWHP systems, it is necessary to develop a system using both groundwater and air sources according to the conditions of temperature and building loads.

Furthermore, the use of groundwater should be conducted carefully to prevent the ground subsidence and maintain system performance for a long period. In general, groundwater in GWHP system, once pumped from a well, is discharged to the well or the others. However, a long-term pumping and injecting used to cause a clogging at the wells, which is a major problem for the use of groundwater in well. In field of civil engineering, “reverse circulation” is used to solve this problem but it is just for temporary improvement of injection not for a long-term use.

This research has developed a hybrid system that uses multiple heat sources (groundwater and air source) and employs groundwater circulatory wells for long-term performance. In this paper, experimental analysis with real-scale equipment and numerical analysis have been described. The coefficient of system performance and the effects on subterranean environments have been evaluated by the experiments using standing column wells. Furthermore, a numerical analysis model using three-dimensional heat and water transfer simulation code has been developed to predict the heat exchange rate and the temperature of groundwater.

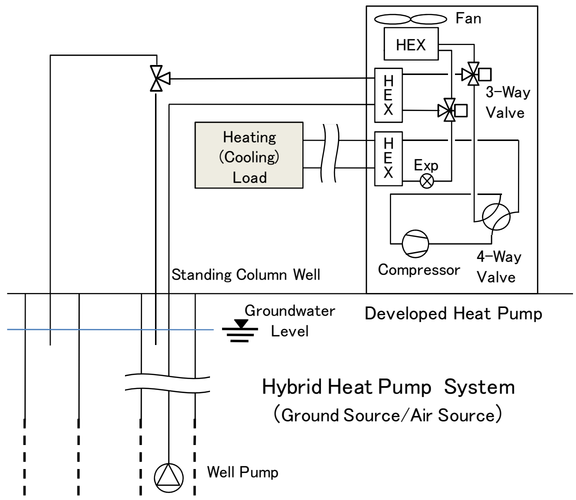

Fig. 1. Image of developed system

2. Real-scale Experiment

Developed System Summary

Fig.1 shows an image of the system developed in this research. Multi-source heat pump which has one compressor, one expansion valve and three heat exchangers can automatically adopt groundwater or air as an alternative heat source according to the condition of temperature. Groundwater is circulated by a pump in one or two wells and utilized only as a heat source. The heat pump has been made in this research and real-scale experiments for the estimation of system performance have been conducted.

Experimental Summary

An experimental facility has been installed on-site at Chiba experimental station, belonging to the University of Tokyo. Chiba is the east of Tokyo, and the average annual air temperature is about 15.4°C; the average air temperature is about 26.4°C in August and 5.4°C in January. The layout plan of the experimental facility and the system configuration are shown in Fig. 1 and Fig. 2. This facility has seven wells (diameter 100 mm, depth 20 m) of which two are utilized for pumping and injection, and two rooms in which an indoor unit and a room air-conditioner (artificial load) are installed respectively. A multi-source heat pump (14.0kW in cooling, 15.7kW in heating) has been installed.

The wells consist of polyvinyl chloride (PVC-U) pipes (Ø100 mm) and a screen manufactured with a slit (Ø10 mm) 9.2 m below ground level. In the production well, a submersible pump (lift 23 m, 47 L/min, 600 W) and a U-type strainer to remove sand from the groundwater were installed. Piping (PE25A) was installed from the heat pump to every well to a buried depth of 0.5 m. Furthermore, in order to detect an overflowing by clogging at the return well, water level sensor has been installed. When a clogging is detected, the system automatically switch the production well and the return well. The cooling experiment was conducted from June 14th to July 21st. Table 1 shows the experiment schedule. The heat pump was operated from 9:00 to 18:00 in period a), as in typical office buildings. Well Nos. 2 and 4 were used as the production and return wells respectively, at a distance of 16 m apart. The temperature of heat source and refrigerant is measured

Table 1 Experiment Schedule

Period	Heat Source	Operation Schedule
a) 6/14 14:00 ~ 6/25 17:00	Groundwater	9:00~18:00
b) 6/25 17:00 ~ 7/2 11:00	Ambient Air	24 hours
c) 7/2 11:00 ~ 7/4 18:00	Alternative According to Temp.	24 hours

Table 2 Measurement Items

Item	Equipment	Location
Groundwater temperature	T-type thermo couples	Inlet/Outlet at HP Well A & B
Refrigerant temperature	T-type thermo couples	Pipes in Heat pump
Groundwater level	Micro-pulse water gage	Well Nos. 1, 4, 5 Well A & B
Refrigerant pressure	Pressure gage	Pipes in Heat pump
Electric consumption	Electric power meter	Power panel
Pumping rate	Flow meter	In the pipe
Outside temperature, relative humidity, wind velocity, wind direction, quantity of solar radiation, rainfall		

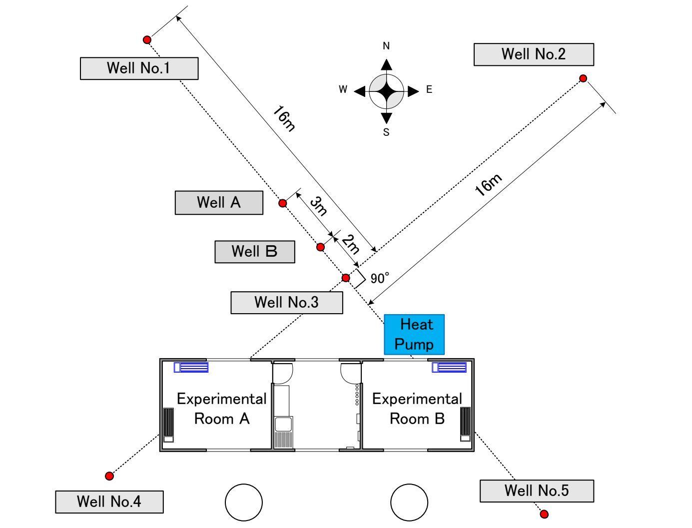

Fig. 2. Layout plan of experimental equipments

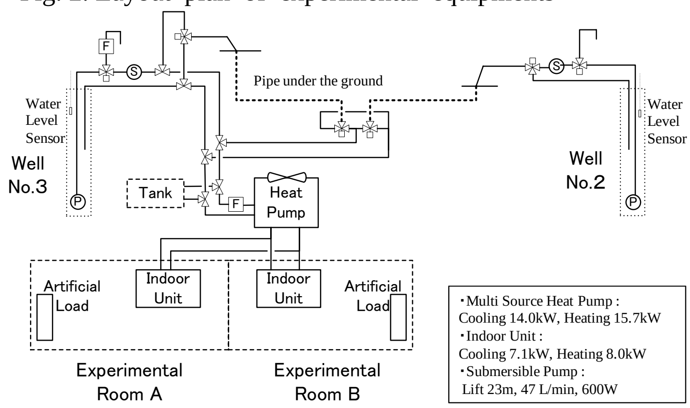

Fig. 3. System configration

by T-type thermo-couple installed in heat pump. Groundwater level is also measured by micro-pulse water gage at wells. Table 2 shows measurement item, equipment and location.

Experimental Results

Figs. 4 to 6 show the results of the cooling experiment,

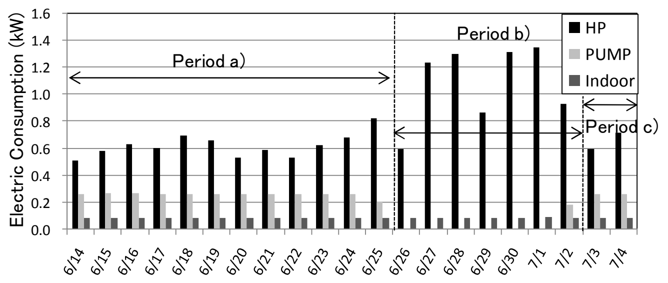

Fig. 4. Experiment result (Electric consumption)

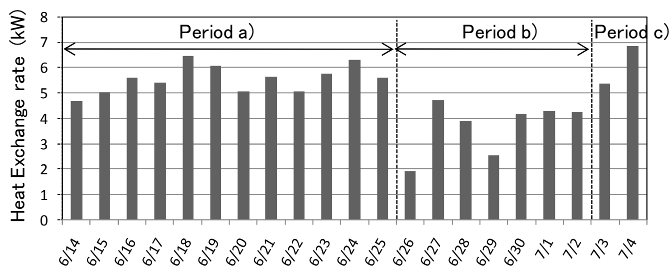

Fig. 5. Experiment result (Heat exchange rate)

equipment electricity consumption, heat exchange rate and system COP (Coefficient of performance). The heat exchange rate was calculated from the pumping rate of the groundwater and the temperature difference between the inlet and outlet at the heat pump. During period a),in which only groundwater was used as heat source, the average heat exchange rate could achieve 5.5 kW with an average pumping rate of 21.5 L/min and an average electric consumption of 0.9 kW (heat pump + pump). However, period b) using only air heat source achieved the heat exchange rate of 3.7 kW with an average electric consumption of 1.1 kW including a fan. In the result, system COP of period a) was higher than that of period b), which presents an efficiency of groundwater use as heat source in summer. During period c), the system set to adopt an alternative operation mode which select more efficient heat source of both air and groundwater, and groundwater was finally selected in this period.

3. Numerical Analysis

Analysis Summary

In this research, a numerical simulation was conducted to develop an analysis model to predict the heat exchange rate and to estimate the effect of this system on the underground environment. In this analysis, FEFLOW is used, which can simulate groundwater flow and heat transfer in the ground and is widely used in the field of hydrology, geology, and geotechnical engineering. FEFLOW is based on mass, momentum, and energy conservation equations for the combination of soil particles, liquid water, and gas. The analysis model shown in Figure 5 has five wells located at 16 m distance in an 80 m × 80 m × 40 m domain. Groundwater is at a depth of 10.85 m and the groundwater flow velocity is given by Darcy's equation with the water level gradient. A screen is installed 10 to 20 m underground, and the groundwater flow is set the same as the amount of pumping. Heat flow is calculated from the temperature and the pumping rate for the assumed cooling and heating load, which is given at the return well (No.3). The soil properties and other analysis conditions are shown in Table 3. These conditions are based on the results obtained from a boring test at this site. In this paper, calculation on the conditions of the cooling experiment and comparison of both results were conducted.

Table 3 Calculation conditions

Depth (m)	0 6 12 40			Gravel
Porosity	0.8	0.4	0.35	0.3
Hydraulic conductivity (10^{-4} m/s)	0.1	1.3	2.1	100
Heat conductivity (W/mK)	1.7	2.4	2.7	2.7
Heat capacity (10^6 J/m^{3}K)	3.9	3.0	2.9	2.9

Analysis Results

Fig.8 shows the variation in groundwater temperature at the observation point (Depth -18 m at well B), and compares the simulation and experimental results. During period a), the groundwater temperature slightly increases by discharging heat at return well but during period b), in which ambient air is used as a heat source, it decreases gradually. The simulation result shows fairly good agreement with the experiment result.

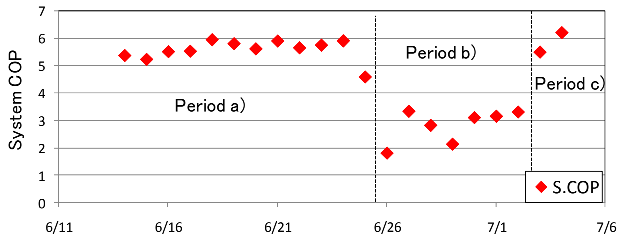

Fig. 6. Experiment result (System COP)

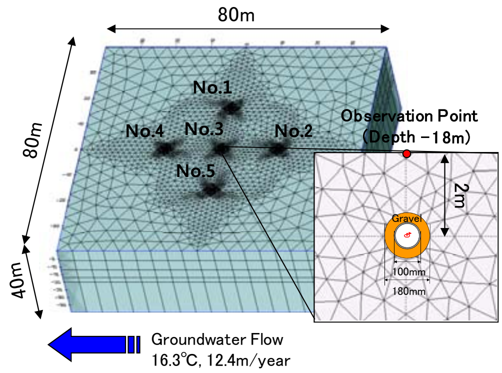

Fig. 7. Simulation model

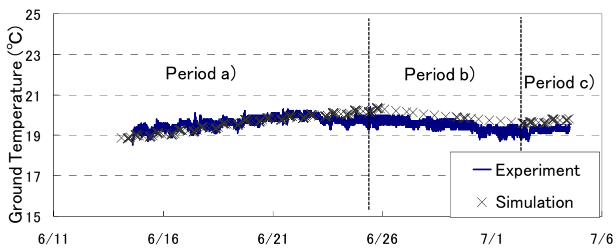

Fig. 8. Comparison of simulation and experiment result

4. CONCLUSIONS

In this research, water and air multi-source heat pump system using groundwater circulatory wells has been developed. The superior performance of this system has been confirmed by a real-scale experiment. In the result, system COP can be achieved about 5.5. Furthermore, a numerical analysis using 3 dimension heat and water transfer simulation code has been conducted to predict the heat exchange rate and the temperature of groundwater. Analysis results were compared with the experimental results, and the validity of the simulation model developed in this study was confirmed.

ACKNOWLEDGEMENT

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