OPTIMIZATION OF GROUND SOURCE AIR-CONDITIONING SYSTEM CONFIGURATION AND OPERATION

R.Li[1*] and R.Ooka[2]

[1]Graduate School of Engineering, the University of Tokyo,
Tokyo 153-8505, Japan
[2]Institute of Industrial Science, the University of Tokyo,
Tokyo 153-8505, Japan

ABSTRACT

Geothermal is a fast-growing alternative heat source for HVAC systems due to higher energy efficiency than conventional heating and cooling systems. There are two ways to use geothermal sources: direct utilization of geothermal sources (DUGS) and ground source heat pumps (GSHP).

In order to predict the performance of these two different geothermal systems under Tokyo weather conditions, computer modelling and simulation was carried out using the TRNSYS software package. Models of borehole heat exchangers (BHE), a water-to-water heat pump, a fan coil unit (FCU) and chilled ceiling panels were implemented in TRNSYS. Modelling of both DUGS (BHE + FCU/Panel), and GSHP system (U-tube + GSHP + FCU) was carried out.

A case study is presented to show the cooling performance of these systems during summer. A model room was built as one classroom in a university building with one external wall. The external wall and window were set according to Japan Energy Saving Standard 1999.

The results indicate that the BHE + Panel system cannot meet the cooling load of the model room with the supplied 22℃ water. We attribute this to the chilled panels only covering 45% of the ceiling. However, DUGS connected to a FCU cooling system is able to handle the sensible cooling load on most summer days, except during the hottest period in August. To improve DUGS performance on the hottest days, we adjusted the air volume of the FCU. The cooling capacity successfully met the cooling load when the air volume was set to 160% of the FCU's rated value.

Further simulations were conducted to evaluate the energy performance of both DUGS and GSHP cooling systems. The analysis showed that DUGS connected to a FCU system performs better than a traditional GSHP cooling system. The electricity consumption of the DUGS system was found to be less than 1/2 of the GSHP system.

[*] Corresponding author email: lirl@iis.u-tokyo.ac.jp

Lastly, the electricity consumption of the GSHP system was calculated in two cases with different temperature of supplied cold water: 7℃, 15℃. The result showed that when the heat pump supplies 15℃ water, the system is 4% more energy efficient than when it supplies 7℃ water. Although the heat pump water chiller is 12% more efficient when supplying 7℃ water, the pump and fan use more electricity as the volume of water and air increases.

KEYWORDS

Ground Source Air-conditioning System, System Configuration, TRNSYS

INTRODUCTION

Geothermal is a widely available and increasingly utilized source of sustainable and renewable energy. Development of geothermal energy not only means the elimination of pollutants such as particulates and greenhouse gases but also reduction in heat island effect (Lund, et al. 2010, Nam and Ooka 2009). Unfortunately, most countries do not have abundant geothermal resources that can be tapped for direct use. However, with the increased interest in ground source heat pumps (GSHP), geothermal energy can now be developed anywhere, both for heating and cooling. (Rybach and Sanner 2000).

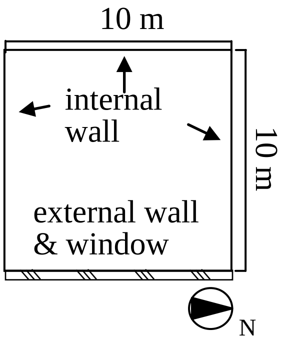
However, GSHP still uses electricity to extract geothermal energy from the ground. A passive way like direct utilization of geothermal sources (DUGS) is more efficient than GSHP system (Ono, et al. 2011).

In May 2011, a new building was completed at the University of Tokyo, our goal is to make it a zero energy building (ZEB) (Yashiro, et al. 2011). In this building, a ground source cooling/heating system is utilized, and both DUGS and GSHP systems are available. Currently, we are working on finding the best operating schedule to minimize the energy consumption of the system.

Here, we present simulations of these two different geothermal systems under Tokyo weather conditions. These simulations were made to predict the performance of the system used in our experimental project.

RESEARCH METHODS

Based on the experimental building, we built our simulation model in TRNSYS. A 100 m^2 classroom with an east-facing external wall was used as the objective room. The details of the room are shown in figure 1. Models of borehole heat exchangers (BHE), a fan coil unit (FCU) and chilled ceiling panels were also implemented in the simulation model. The initial ground temperature was set to the annual average atmosphere temperature of Tokyo; the BHE was assumed to supply a thermal power of about 50 W/m and the installation area of the chilled ceiling is 45% of the total ceiling area (Sako et al. 2012). Modelling of both DUGS (BHE + FCU/Panel), and GSHP (BHE + GSHP + FCU) systems was carried out. The weather data used in this study gained from the AMeDAS supplied by Japan Meteorological Agency (Anon). The relevant parameters and conditions are summarized in Table 1.



Function:	Classroom
Construction:	RC
Floor to floor height:	4 m
Ceiling height:	2.8 m
External wall:	Japan Energy Saving Standard 1999 (Area Ⅳ), K=0.385 W/(m^2・K)
Window:	Low-e glass, K=1.7 W/(m^2・K)
Window area ratio:	55%

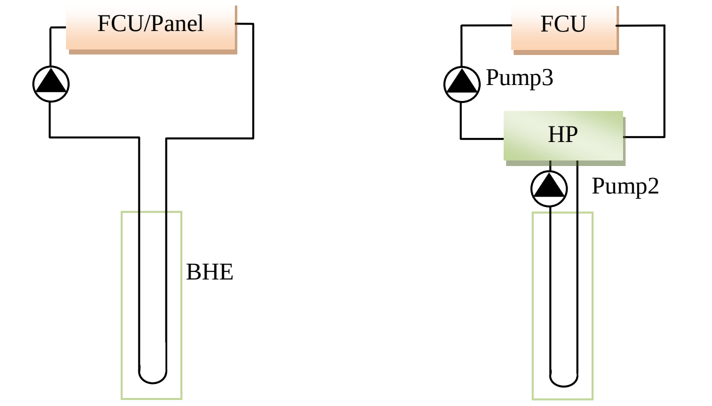
Figure 1. *The model room*

Table 1. *Equipment specifications & calculation conditions*

Equipment specifications		
Heat source	Borehole heat exchangers (BHE) initial ground temperature: 17℃; Storage volume: 3500 m^3; Borehole depth: 100 m; number of boreholes: 2; Single U-tube plastic pipes, parallel connection; Thermal conductivity: 1.85 W/(m・℃); Heat capacity: 3.3 MJ/(m^3・℃)	
Cooling terminal	FCU Rated cooling capacity: 14 kW; under the condition of 7-12℃ water circulation; Rated water flow rate: 55.6 L/min; Rated air flow rate: 3520 m^3/h	Chilled ceiling panels Installation area: 45 m^2; Rated cooling capacity: 4.13 kW with the supply water temperature of 19℃ and indoor air temperature of 26℃; Rated water flow rate: 29.5 L/min; Temperature difference between supply water and return water: 2℃
Calculation conditions		
Cooling time: 8:00-17:00; set temperature: 28℃		
Persons	Normally 30 people , 3 people during12:00-13:00; Seated, very light writing	
Lighting	19W/m^2, fluorescent tube	

Figure 2 shows the models of the systems calculated in this study. (a) is the DUGS system in which cooling water is transferred to the FCU or chilled ceiling directly from the BHEs without using heat pump. (b) is the GSHP system in which water circulated in BHEs is used as cooling water for the heat pump; the heat pump makes cold water (usually 7℃) for space cooling. The rated values of energy consumption of the equipments are shown in table 2. These systems are designed to meet the sensible cooling load only; a dehumidification system is assumed to handle the latent cooling demand.

We calculated these systems in June and August; June is the start of the cooling season and August is the month with the highest cooling load. Table 3 shows the cases we calculated. For June, we simulated two cases labelled case 1 (BHE connected with chilled ceiling) and case 2_Jun (BHE connected with FCU) and for August four other cases labelled case2_Aug (BHE connected with FCU), case 3 (BHE connected with FCU), case 4 (heat pump connected with FCU) and case 5 (heat pump connected with FCU) were simulated. The results were compared to find the most efficient system for both periods.



(a) BHE + FCU/Panel (b) Heat pump + FCU

***Figure 2**. System models*

***Table 2.** Rated power consumption*

Items	*Motor [kW]*	*COP*
Pump1	0.4	-
Pump 2	0.25	-
Pump 3	0.15	-
Fan	0.32	-
Heat pump	-	4.9

***Table 3.** Calculation cases*

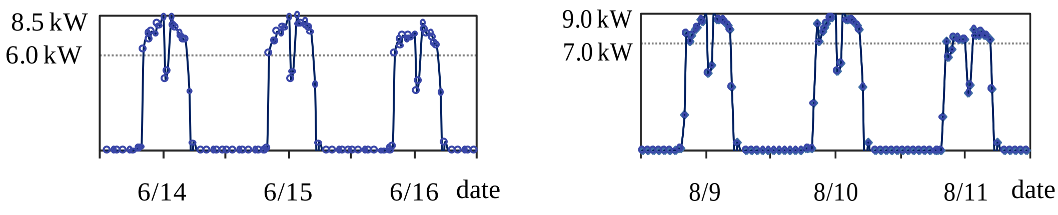
System pattern	*Heat source*	*Cooling terminal*	*Calculation period*		*Case configuration*
			Jun	Aug	
DUGS	BHE	Chilled ceiling	Case 1	-	-
		FCU	Case 2_Jun	Case 2_Aug	FCU: rated air flow rate
			-	Case 3	FCU: increased air flow rate
GSHP	Heat pump	FCU	-	Case 4	Supply cold water set temperature: 7℃
			-	Case 5	Supply cold water set temperature: 15℃

RESULTS

1. Cooling ability in June

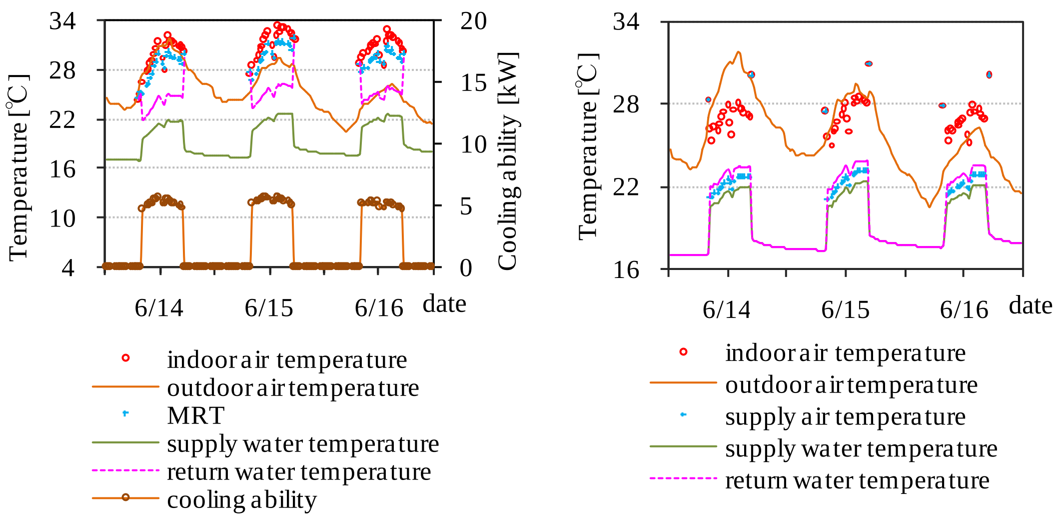
In June, the sensible cooling load in the room was between 6.0 kW and 8.5 kW (Figure 3). To find the minimum electrical power required to meet the heat load in June we first simulated two DUGS systems. The results are shown in Figure 4. In case1 (BHE+ chilled ceiling), the temperature of the supplied cooling water was 20-22℃ and the indoor air temperature was above 28℃, both are higher than the design temperature of 19℃ and 26℃ respectively (Table 1). Furthermore, the chilled ceiling supplied about 5kW cooling energy which is more than its rated value.

In case 2 however, the indoor air temperature approached the set temperature during the peak heat load time. The FCU supplied enough cooling energy, although the water temperature exceeded the rated value in this case too. The temperature of the cooling water was about 22℃, which is significantly higher than the design value of 7-12℃; the temperature difference between supply and return water is only 2℃, which is smaller than the design value of 5℃. This result shows that the BHE + FCU system is a viable system for space cooling in June.



(i) cooling load in Jun *(ii) cooling load in August*

***Figure 3**. Sensible heat load of the model room*



(i) Case 1 (BHE + chilled ceiling) *(ii) Case 2_Jun (BHE + FCU)*

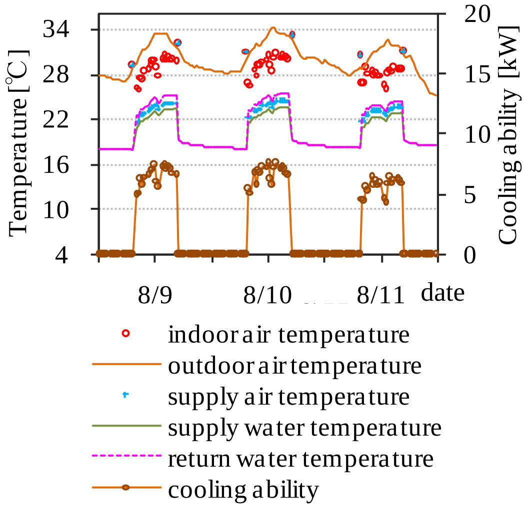
***Figure 4**.Cooling ability in June*

2. Cooling ability in August

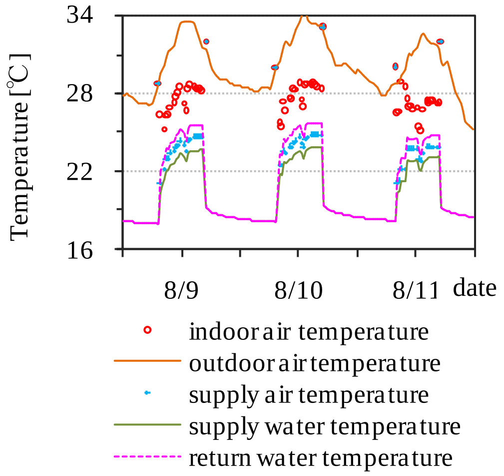
In August, the sensible cooling load in the room is about 7.0-9.0 kW (Figure 3). Two systems were evaluated in four cases for August weather; the results are shown in Figure 5. First, the DUGS system with BHE + FCU that met the room heat load in June (case 2) was applied to August weather conditions. The results are shown in Figure 5(i). The cooling energy supplied by the FCU is around 8 kW which cannot meet the peak heat load of 9 kW. Therefore, the indoor air temperature surpassed the set point for most of the cooling time. The temperature difference of cooling water was about 1.5℃.

In case 3, we tried to increase the temperature difference by adjusting the air volume of the FCU. As a result, we found that when the FCU's air volume is set to 160% of the rated value, the set temperature can be met. Figure 5(ii) shows the calculation results.

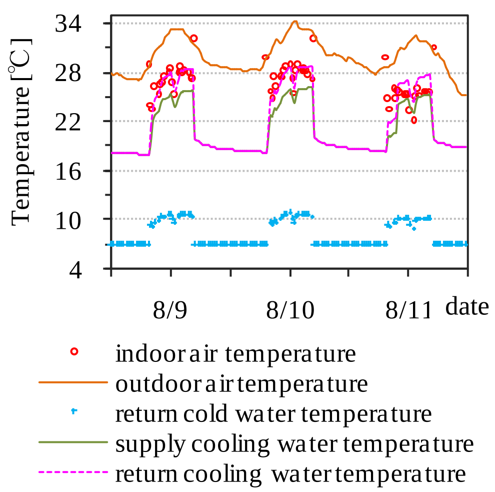
The GSHP system was simulated as case 4 and case 5. The supply cold water temperature was set at 7℃ in case 4 and 15℃ in case 5. Initially the air flow rate and cold water flow rate of the FCU were set to the rated values shown in table 1. This caused over cooling. As a consequence both parameters were adjusted to meet the model room's cooling heat load. Table 4 lists the parameters which gave the simulation results shown in Figure 5(iii) and (iv). Both case 4 and 5 are viable for space cooling in August.



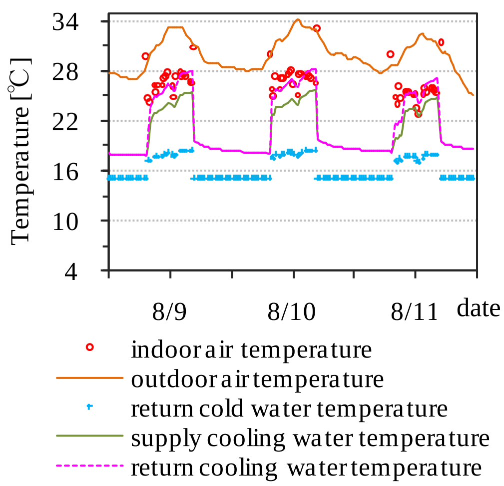
(i) Case 2_Aug (BHE + FCU)



(ii) Case 3 (BHE + FCU with increased air flow rate)



(iii) Case 4(Heat pump + FCU with 7℃ supply cold water)



(iv) Case 5(Heat pump + FCU with 15℃ supply cold water)

***Figure 5**. Cooling ability in August*

Table 4. *Adjustment of FCU*

Case	*Items*	*Value*	*Ratio of rated value*
Case 4	Air flow rate	1160 m^3/h	33%
Case 4 & Case 5	Cooling water flow rate	33.4 L/min	60%
Case 5	Air flow rate	2006 m^3/h	57%

3. Energy consumption

The energy consumption of case 3, 4 and 5 is shown in table 5. The DUGS system of case 3 used about 8 kWh/day while the GSHP system of case 4 and 5 needed about 17kWh/day to supply the same amount of cooling energy. In the DUGS system, the electricity consumption of the fan is more than 50% of the total value, while in the GSHP system the heat pump used almost 70% of the total energy consumption.

Case 4 and 5 showed that when the GSHP system supplies 15℃ water, it is about 4% more energy efficient than when supplies 7℃ water. Also the heat pump cold water chiller was 12% more efficient.

Table 5. *Average electricity consumption over 3 days in August*

System pattern	*Case*	*Electricity consumption [kWh/day]*			
		Total	*Fan*	*Pump*	*Heat pump*
DUGS	*Case 3 (BHE + FCU with increased air flow rate)*	7.8	4.3	3.5	-
GSHP	*Case 4 (Heat pump + FCU with 7℃ supply cold water)*	17.1	0.9	3.4	12.8
	Case 5 (Heat pump + FCU with 15℃ supply cold water)	16.4	1.5	3.3	11.4

DISCUSSION

From the results of cases 3-5, we know that the DUGS system can meet peak cooling load when using a big air volume FCU. The cases also show that this DUGS system is more energy efficient than the examined GSHP system. In this calculation, 5632 m^3/h air was circulated by FCU in a 300 m^3 room. To use this DUGS system with a big air volume FCU, we have to ensure that the air velocity will not exceed the limits of thermal comfort standards and that there will be no noise issues.

The efficiency of the modelled heat pump increases by 12% when increasing the supply cold water temperature form 7℃ to 15℃. This is significantly lower than the 78% increase an ideal Carnot heat pump cycle would give. Thus, the modelled heat pump is not very efficient in this simulation. We believe the model is a good first approximation of the real building's HP but more experimental data is needed to verify and extend this model.

However, the total energy consumption is only decreased by 4%, because the pump and fan use more electricity as the flow rate of water and air increase. In this simulation, the increment/decrement sequencing method is adopted for controlling the pumps. The water flow rate is turned up when the outdoor air temperature is above a certain value, for example 30℃; at the same time the energy consumption also increases. In HVAC systems, other control methods are used too. For example, PID control is widely used to cut down the power consumption in fluid loops. We assume the electricity consumption of pumps would change if the control method changed.

CONCLUSION AND IMPLICATIONS

The BHE + chilled ceiling system supplied with 22℃ water cannot meet the cooling load of the model room in June. We attribute this to the chilled panels only covering 45% of the ceiling. However, another DUGS system with the BHE connected to a FCU is able to handle the sensible cooling load most summer days except during the hottest period in August. To improve DUGS system performance on the hottest days, we adjusted the air volume of the FCU. The cooling ability met the cooling load when the air volume was set to 160% of its rated value. However, for the GSHP system, simulations show that the FCU is oversized.

Further simulations were conducted to evaluate the energy performance of both DUGS and GSHP cooling systems. The analysis showed that DUGS connected to a FCU system performs better than a traditional GSHP cooling system. The electricity consumption of the DUGS system was found to be less than 1/2 of the GSHP system during the hottest month of the year.

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