Design of Air Conditioning System with a Ground-Coupled Heat Pump for a Gravity Meter Room

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SUMMARY – The air conditioning system with a ground-coupled heat pump for a gravity meter room was designed by carrying out numerical simulations. The parameters of simulations were room temperature, a flow rate of heat extraction medium and the length of the Downhole Coaxial Heat Exchanger (DCHE). As a result of this investigation, the optimal values for room temperature, flow rate of heat extraction medium and the length of the DCHE were determined to be 18 degree C, 5 l/min and 12 m, respectively. The average COP (coefficient of performance) of the system over the first operation year was estimated to be 5.85 under the designed conditions. Also, it was shown that the system could be operated at stable performances over the long duration.

1. INTRODUCTION

Research of continuous gravity measurements in our laboratory shows that influence of seasonal change of temperature to the sensor of gravity meter cannot be compensated completely. Therefore, it was considered that a thermostatic room is necessary for gravity meter measurements in the new campus of Kyushu University. Recently, air conditioning systems and snow-melting systems with ground-coupled heat pumps are getting attention in Japan because of environmental and energy issues. Assuming the air conditioning system with a ground-coupled heat pump for a gravity meter room, the authors have carried out numerical simulations for designing the air conditioning system.

2. THE GRAVITY METER ROOM AND THE AIR CONDITIONING SYSTEM

2.1 Gravity meter room

The plan view of the gravity meter room and its surrounding rooms are shown in Fig. 1. The gravity room is in the bottom floor. The area of the gravity meter room is 26 m^2 and the room has good heat insulation. The maximum cooling and heating loads are 0.56 kW and 0.68 kW, respectively.

2.2 Air Conditioning System

A conceptual figure of the air conditioning system is shown in Fig. 2 (Morita, 1999; Morita, 2001). This system consists of a DCHE and a heat pump.

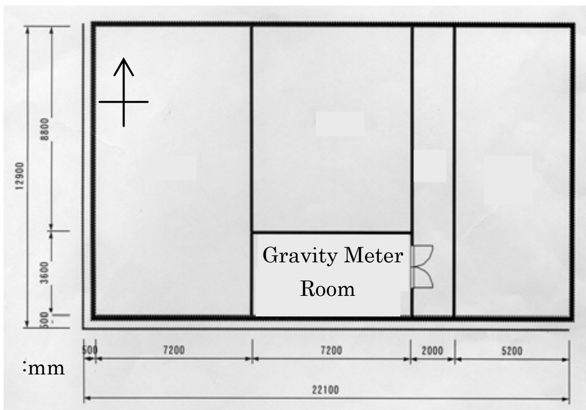

Fig. 1 The plan view of the gravity meter room and its surrounding rooms.

3. DESIGN OF AIR CONDITIONING SYSTEM

3.1 Numerical Simulator

The numerical simulator is developed by National Institute of Advanced Industrial Science and Technology (Morita et al., 1984; Morita et al., 1992). If we gave the data about stratum, DCHE, heat pump, operating condition and cooling and heating load as input data to the simulator, the simulator outputs the data about temperature distribution of the stratum, inside pressure and temperature of the DCHE, thermal output of the DCHE, COP and electric consumption.

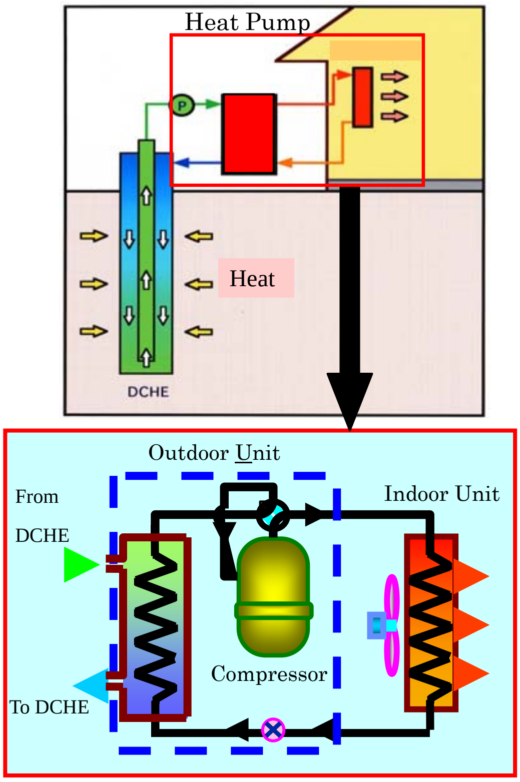

Fig. 2 Concept of the air conditioning system (Morita, 1999; Morita, 2001).

3.2 Input Data

(1) Cooling and heating load

The Graduate School of Human-Environment Studies of Kyushu University calculated cooling and heating load using the calculation program 「HASP/ACLD/8501」. The room temperature of the gravity meter room is fixed in all seasons and it is the parameter of the simulation. The simulation was carried out at 16, 17, 18, 19 and 20 degrees C, respectively. This range of temperatures is based on preliminary simulations. Change in the cooling and heating load over the first operation year in the case of indoor setting temperature of 18 degrees C, is shown in Fig. 3. The cooling load is expressed by the negative sign and the heating load is expressed by positive sign.

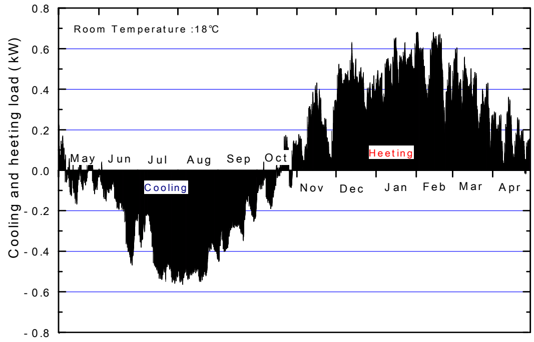

Fig. 3 Change in cooling and heating load over the first operation year.

(2) Operation time of the system

We assumed that the system is always operated normally. However, when the cooling and heating load is very small (heating load < 80 W, cooling load < 55 W), the system is not operated because of the characteristic of the assumed heat pump.

(3) Structure of the DCHE

Structure of the DCHE is shown in Fig. 4 (Morita et al., 2001). The length of the DCHE is usually 150 m. However the cooling and heating load is very small in this study and a regular DCHE is too large for the system. Therefore we made the length of the DCHE a parameter of the simulation. Thermophysical properties of materials composing the DCHE are shown in Table 1.

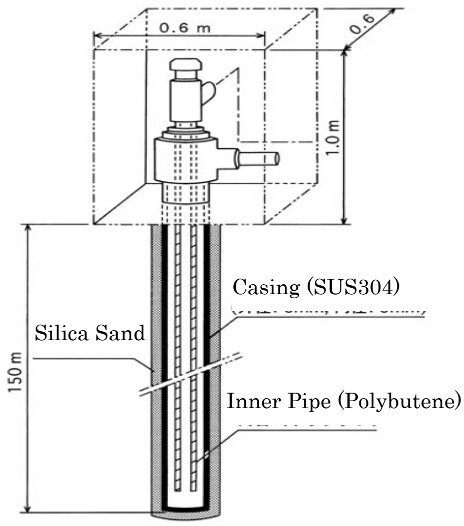

Fig. 4 Structure of the DCHE (Morita et al., 2001).

Table 1 Thermophysical properties of materials composing the DCHE.

Materials	Density (kg/m^3)	Specific Heat (kJ/kg・K)	Thermal Conductivity (W/m・K)	N.B.
	7920	0.50	16.0	Casing
Polybutene	920	2.09	0.205	Inner Pipe
Silica Sand	2040	1.41	2.3	Filling Material

(4) Structure and initial temperature profile of the ground beneath the gravity meter room

Assumed thermophysical properties of the ground beneath the gravity meter room are shown in Table 2. The ground beneath the gravity meter room mainly consists of granodiorite. We divide the ground into three layers. Layer A is 0 to 7 m depth and mainly consists of strongly weathered granodiorite. B is 7 to 22 m depth and consists of moderately weathered granodiorite. C is deeper than 22 m depth and consists of fresh granodiorite.

Table 2 Thermophysical properties of the ground beneath the gravity meter room.

	Thermal Conductivity (W/m・K)	Specific Heat (kJ/kg・K)	Density (g/cm^3)
A	1.50	1.438	2.10
B	2.13	1.152	2.37
C	2.76	0.866	2.61

The assumed initial temperature profile of the ground under the gravity meter room is shown in Fig. 5. The initial temperature profile is assumed using average temperature at Fukuoka and the temperature gradient calculated by assumed thermal conductivity and heat flow at Fukuoka (Ehara, 1984).

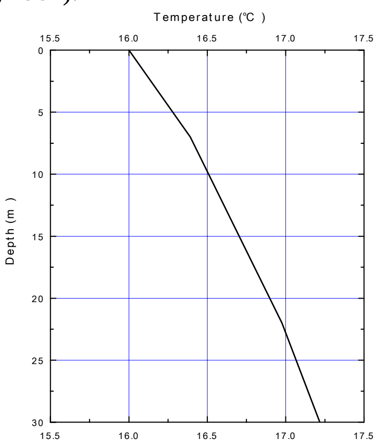

Fig. 5 Assumed initial temperature profile of the ground under the gravity meter room

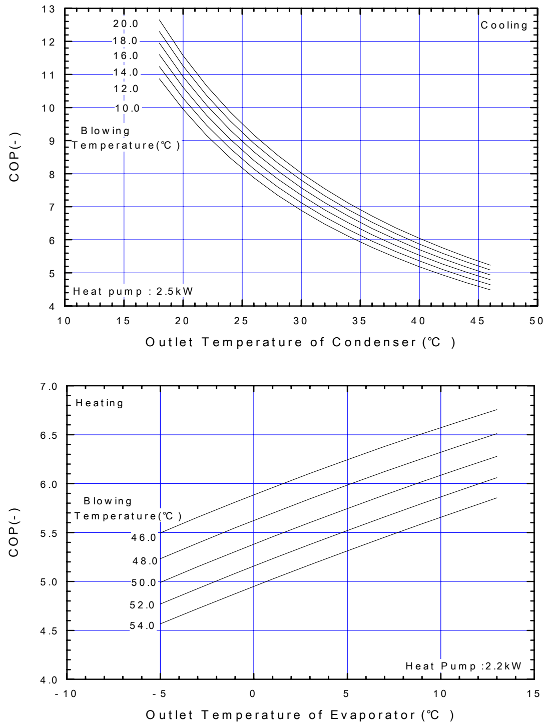

Fig. 6 COP of the assumed heat pump.

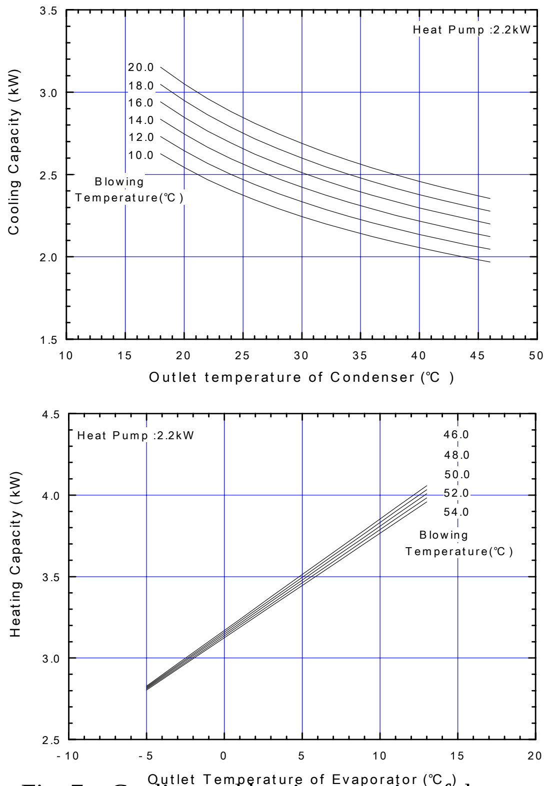

Fig. 7 Cooling and heating capacity of the assumed heat pump.

(5) Other input data

Other input data for simulations are shown in Table 3.

3.3 Determination of the Optimal Values for Room Temperature, Flow Rate of Heat Extraction Medium and the Length of DCHE

(1) Main judgment criteria

Main judgment criteria are heat balance of the ground, operating temperature of heat pump (-10 to 43 degrees C), COP (> 5.27: target value in 2004 under Japanese law of energy-saving), and economic efficiency.

(2) The optimal value for room temperature

We simulated with five different room temperatures (16, 17, 18, 19 and 20 degrees C). Heat balance of the ground is the main criterion in judgment of room temperature. Relation between ground heat budget and room temperature over the first operation year is shown in Fig. 8. The heat extraction medium flow rate and the length of the DCHE are 5 l/min and 12 m, respectively. Thermal extraction and thermal injection balance between 18.0 and 17.5 degrees C. Heat balance of the ground is best in this temperature range. The minimum setting temperature range of the assumed heat pump is one degree C. The average COP of the system over the first operation year in the case of 18 degrees C is 5.85. Therefore 18 degrees C is decided as the optimal value of the room temperature.

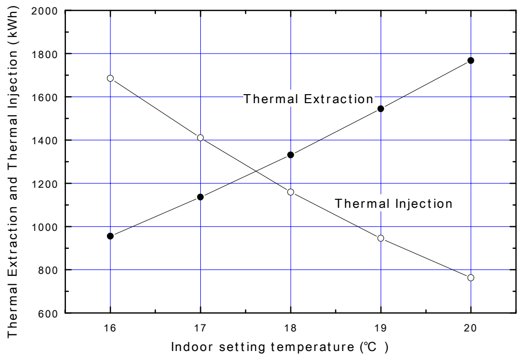

Fig.8 Relation between ground heat budget and room temperature over the first operation year.

(3) The optimal value of flow rate of heat extraction medium

We simulated with five different flow rates of heat extraction (4, 5, 6, 7 and 8 l/min). COP is main criterion in judgment of flow rate of heat extraction. Change of the average COP over the first operation year with change of flow rate of heat extraction medium is shown in Table 4. The room temperature and the length of the DCHE are 18 degrees C and 12 m, respectively. The smaller flow rate of heat extraction becomes, the larger COP becomes in the simulated range. The minimum operation flow rate of the smallest ready-made circulation pump is 5 l/min. Therefore, 5 l/min is decided as the optimal value of flow rate of heat extraction medium.

Table 3 Other input data for simulations.

Terms	Values
Power for Circulation Pumps	0.0047 (kW)
Power for control system and heat pump's crank case heater	0.005 (kW)
Efficiency of circulation pumps	0.35

Table 4 Change of the average COP over first operation year.

Flow rate of heat extraction medium (l/min)	4	5	6	7	8
Average COP over the first operation year (-)	6.00	5.85	5.61	5.30	4.94

(4) The optimal value of the length of the DCHE
We simulated with five different lengths of the DCHE (8, 10, 12, 14 and 16 m). Operating temperature of the heat pump is main criterion in judgment of the length of the DCHE.

(5) Heat extraction medium
We assumed a 42 % solution of Nybrine as heat extraction medium. The freezing point of a 42 % solution of Nybrine is -10 degrees C. We set the flow rate of the heat extraction medium as a parameter of the simulation.

(6) Heat pump
COP of the assumed heat pump and heating and cooling capacity of the assumed heat pump are shown in Fig. 6 and 7, respectively.

Change in the inlet temperature of the DCHE over the first operation year with change of the length of the DCHE is shown in Table 5. The room temperature and the heat extraction medium flow rate are 18 degrees C and 5 l/min, respectively. When the length of DCHE is 8 m, the maximum inlet temperature of the DCHE (50.8 degrees C) exceeds the upper limit of the operating temperature of the heat pump (43 degrees C). When the length of the DCHE is 10 m, the maximum inlet temperature of the DCHE (42.2 degrees C) almost reaches the upper limit of the operating temperature of the heat pump. If the accuracy of input data is taken into consideration, the maximum inlet temperature of the DCHE may be 43 degrees C or higher at a 10 m DCHE. There is no advantage in economic efficiency in using a longer DCHE. Therefore 12 m was chosen as the optimal value of the length of the DCHE.

3.3 Behavior of the System

(1) Change in thermal output of the system over the first operation year is shown in Fig. 9. The histogram shows total thermal output, and the black and gray parts of the histogram show thermal outputs supplied by the DCHE and the heat pump, respectively. The most thermal output is supplied by the DCHE.

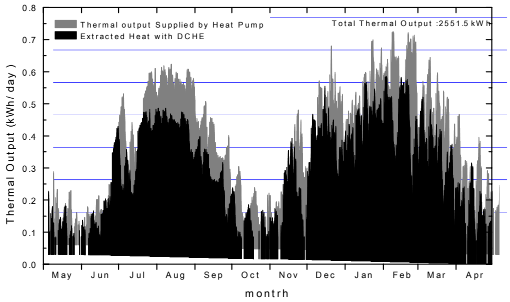

Fig. 9 Change in thermal output of the system over the first operation year.

(2) Change in COP over the first operation year
Change in COP over the first operation year is shown in Fig. 10. The average COP of the system during this period was estimated to be high value (5.85).

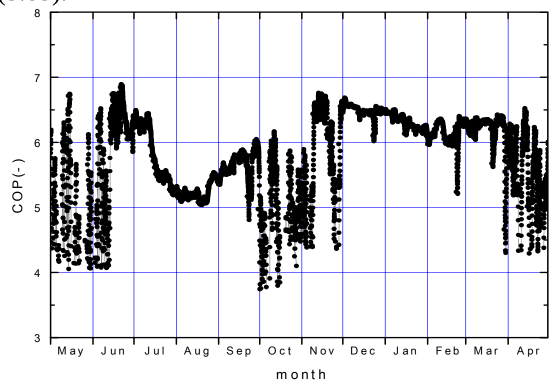

Fig. 10 Change in COP over the first operation year.

(3) Long-term change in bottom-hole temperature of the DCHE
Long-term change in the bottom-hole temperature of the DCHE is shown in Fig. 11. The convex upward part corresponds to the cooling season and the convex downward part corresponds to the heating season in Fig. 11. The bottom-hole temperature decreases little in 15 years.

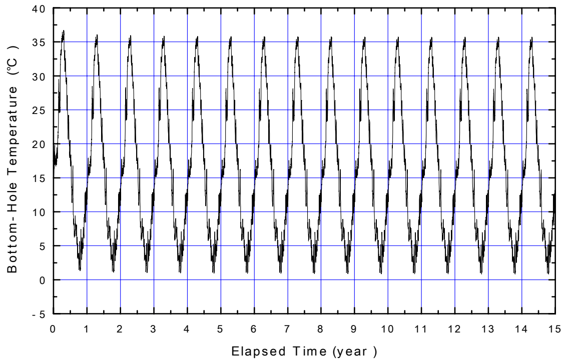

Fig. 11 Long-term change in the bottom-hole temperature of the DCHE.

(4) Long-term change in minimum and maximum inlet temperatures of the DCHE

Long-term change in minimum and maximum inlet temperatures of the DCHE is shown in Fig. 12. Inlet temperature of the DCHE changes little and it is in the range of operating temperature of the heat pump in long-term.

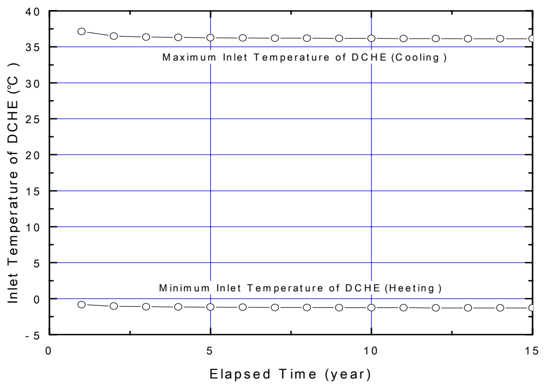

Fig. 12 Long-term change in minimum and maximum inlet temperatures of the DCHE.

(5) Long-term change in COP

Long-term change in COP is shown in Fig. 13. COP also changes little in long-term. The system may keep high value of COP in long-term.

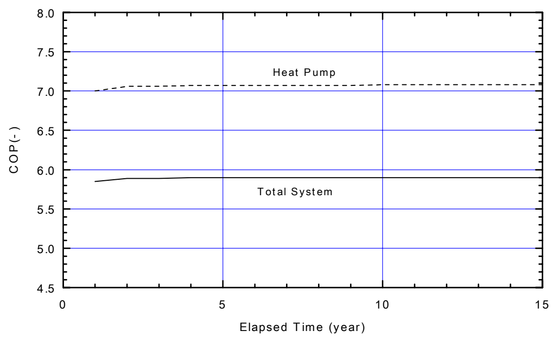

Fig. 13 Long-term change in COP.

4. CONCLUSION

The authors have carried out numerical simulations of the air conditioning system with a ground-coupled heat pump for a gravity meter room. As a result of this investigation, the optimal values for the room temperature, flow rate of heat extraction medium and the length of the DCHE were determined to be 18 degree C, 5 l/min and 12 m, respectively, from the viewpoints of heat balance of the ground, the operating temperature of the heat pump, COP, and economical efficiency. The average COP of the system over the first operation year was estimated to be 5.85 under the designed conditions. Also, it was shown that the system could be operated at stable performances over a long duration.

6. REFERENCES

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Table 5　Change in inlet temperature of the DCHE over the first operation year.

Length of DCHE （m）	8	10	12	14	16
Minimum inlet temperature of DCHE （degrees C）	-9.7	-4.4	-0.8	1.6	3.5
Maximum inlet temperature of DCHE （degrees C）	50.8	42.2	37.1	33.8	31.5