INVESTIGAITON ON OPERATION IMPROVEMENT OF THE GROUND SOURCE HEAT PUMP SYSTEM ACCOMMODATING THERMAL ENERGY

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Abstract: The demonstration project of the performance analysis of the GSHP system accommodating thermal energy in the dormitory in Kitakyushu City is introduced in this paper. Performance prediction tool for the GSHP system accommodating thermal energy combined water source heat pumps for air-conditioning and hot-water supply was developed. Using the performance prediction tool and the result of first year's operation, the optimum operation method for the GSHP system accommodating thermal energy in the second year's operation was investigated. The result indicated that the optimum operation time and operation period of the GSHP for HW, which minimize the total energy consumption of the system, were 24 h and for 6 months, respectively. The temperature at the inlet of GSHP in the primary side T_{1in} is lower than 30 °C during the cooling period and higher than 10 °C during the heating period. As the result, that the optimum operation method is effective to the GSHP system accommodating thermal energy.

Key Words: ***Ground Source Heat Pump, Accommodating Thermal Energy, Performance Analysis and Operation Improvement, Performance Prediction Tool***

1 INTRODUCTION

Recently the worlds important topic is saving energy from the view point of economize power. The heat pumps system accommodating thermal energy is paid attention as one of the economize power methods. The system yield higher heat pump efficiency because of utilizing the exhaust heat generated by the heat pump unit for air-conditioning as the heat source for hot water (HW). Furthermore, the system with ground heat exchangers (GHEX system) can use be in stone with thermal where ground. Therefore the ground source heat pump system (GSHP system) accommodating thermal energy can absorb margin of hot-water supply and air-conditioning demand. However it is important conduct to performance validation because the system complicated.

In this paper, the concept and advantage of the GSHP system accommodating thermal energy are firstly explained. Then the demonstration project of the performance analysis of the GSHP system accommodating thermal energy in the dormitory in Kitakyushu City, which is the first step for the practical application in the land area, is introduced.

2 GROUND SOURCE HEAT PUMP SYSTEM ACOOMMODATING THERMAL ENERGY

2.1 System Concept

Figure 1 shows an example of the conventional accommodating thermal energy system. The system consists of several types of the heat pump units, the additional heat sources such as the cooling tower, boiler, solar collector, etc. The equipment is connected to each other in the one water loop as shown in Figure 1. This system has the advantage of energy saving by using the exhaust heat. For example, the exhaust heat generated from heat pump units for

cooling is used for other heat pump units for supplying hot water (HW). This improves the efficiency of not only the heat pump unit for HW but also the heat pump units for cooling. However, the additional heat sources are used when the time difference between heating load and cooling load is generated.
The GSHP system accommodating thermal energy shown in Figure 2, which has the ground heat exchangers (GHEXs), can utilize the thermal storage effect of the ground and absorb the exhaust heat even in the case where the time difference is generated. Thus, it is possible for the system to reduce the energy consumption from the additional heat sources. Using the GSHP system accommodating thermal energy in the land area, the exhaust heat generated by cooling for the office buildings can be used for HW to the hospitals or hotels. In addition, the exhaust heat from the subway and sewage water is utilized for the distinct heat. The GSHP system accommodating thermal energy installed in the dormitory in Kitakyushu City, whose details are explains in the next section, is the scale down model of the system in the land area. The demonstration project of the performance analysis in the dormitory is the first step for the practical application in the land area.

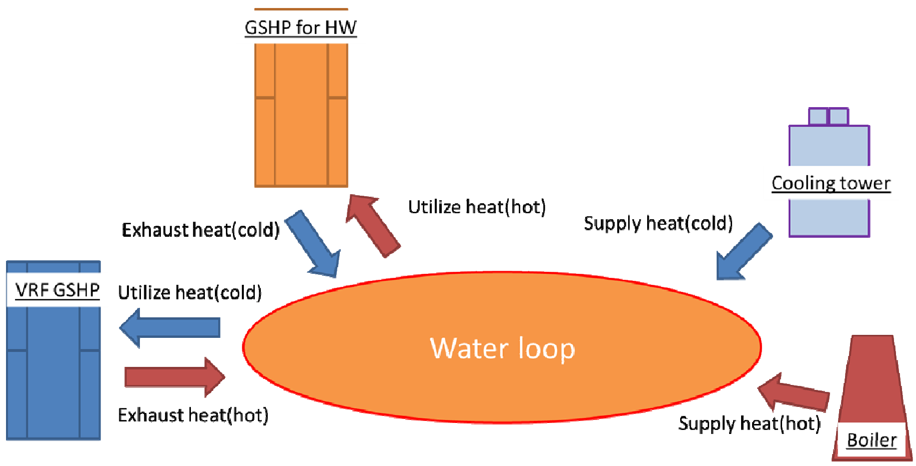

Figure 1 Example of conventional accommodating thermal energy system

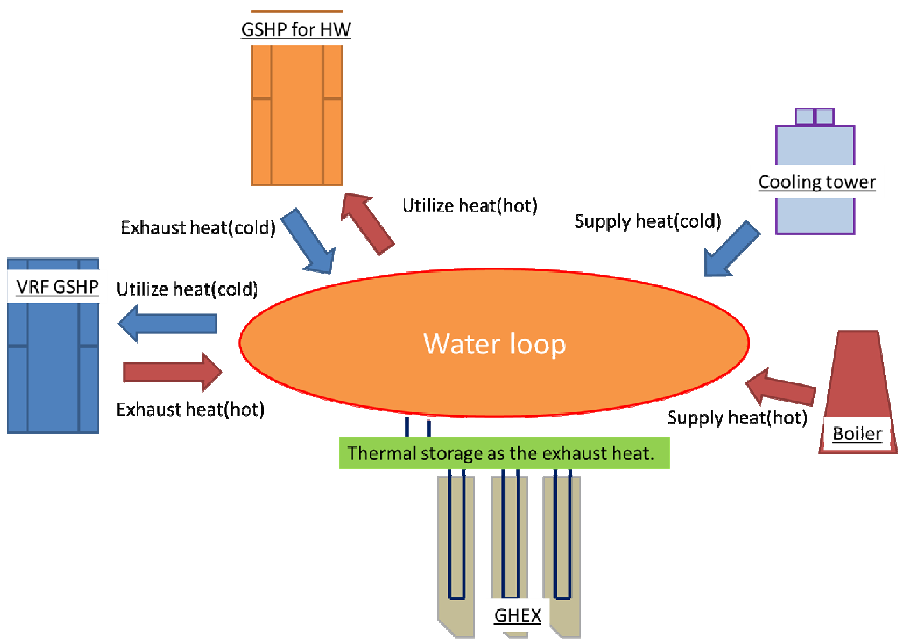

Figure 2 Example of ground source heat pump system accommodating thermal energy

3 OUTLINES OF OBJECT BUILDING AND GROUND SOURCE HEAT PUMP SYSTEM ACOOMMODATING THERMAL ENERGY

3.1 Outlines of Object Building

The dormitory shown in Figure 3 was completed in Kitakyushu City in February 2012. The building has seven stories and the total floor area is 9,374 m^2. The energy-saving technologies that utilize the natural energy such as the solar heat, the wind, and the underground heat have been installed for decrease the negative environmental impact. The GSHP system accommodating thermal energy is also installed in the building.

Figure 3 Appearance of dormitory

3.2 Outlines of Ground Source Heat Pump System Accommodating Thermal Energy

Figure 4 shows the schematic diagram of the GSHP system accommodating thermal energy and the hot water supplying system. In addition, the specifications of equipment in the systems are shown in Table 1. The GSHP system utilizes 68 numbers of the steel foundation piles as the GHEXs. The steel piles have the diameter of 400~700 mm and effective length as the GHEX of 7~10 m. The GHEXs are connected to the two water-cooled VRF GSHP air conditioning systems. The one water-cooled VRF GSHP system covers air-conditioning for the entrance and the other covers air-conditioning for the kitchen. The GHEXs are also connected to the ground source heat pump (GSHP) unit for HW. This means that it is possible to accommodate the thermal energy between the water-cooled VRF GSHP systems and the GSHP unit for HW in the one water loop. Additionally, a cooling tower and a thermal storage tank are connected to the water loop in order to prevent a temperature increase or decrease of the water in the loop. The cooling tower can control the fan motor’s revolution speed. The water in the thermal storage tank is heated by the solar collector in usual and the thermal energy stored in the tank is used for HW and heating the water loop. The air source heat pump (ASHP) units and gas boiler, which are separated from the GSHP system, are also equipped for HW. The heating capacities of ASHP unit and gas boiler are sufficiently large compared to the heating load for HW in the building. Therefore, it is possible to operate the GSHP unit for HW optionally.

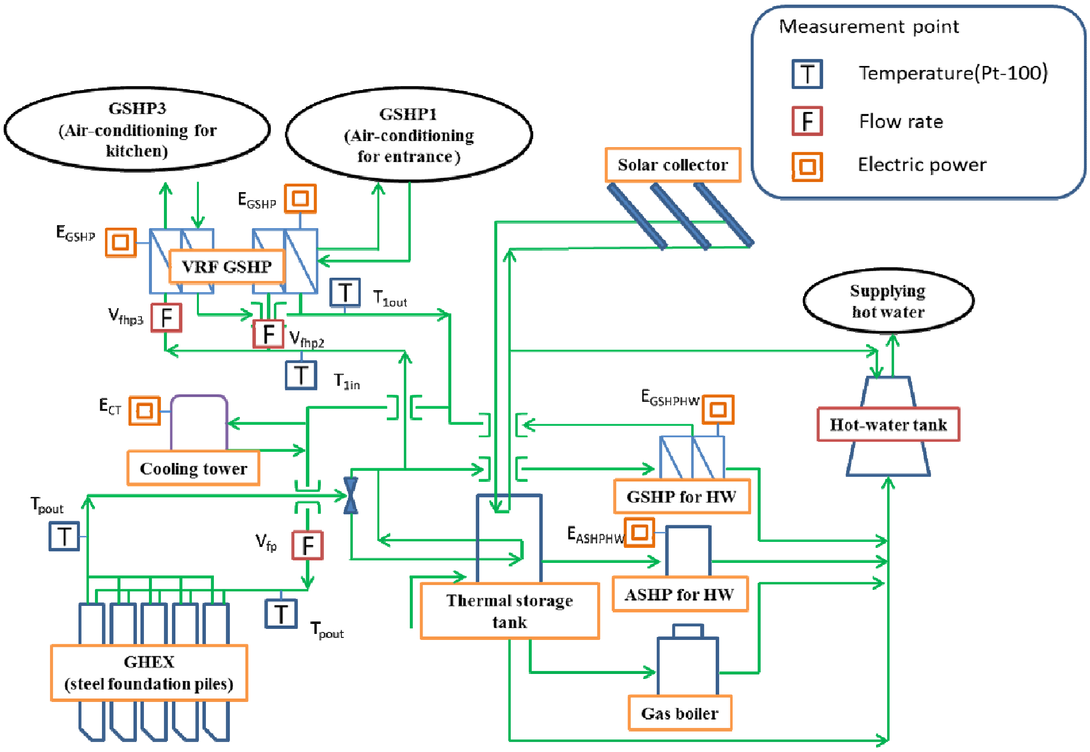

Figure 4 Schematic diagram of GSHP system accommodating thermal energy and hot water supplying system

Table 1 Specifications of equipment in system

Heat source equipment and subsystem	Water-cooled VRF GSHP for air-conditioning (×2)	Water-cooled VRF Compressor 40 Horsepower Cooling output 50kW、Heating output 56kW Electric power 10.5kW
	Pump of circulation around primary side	Ratings circulation flowing quantity: 384L/min Ratings power consumption: 3.7kW
	GSHP for HW (×1)	Water source heat pump Compressor 15 Horsepower Heating output 38.5kW Electric power 11.5kW
	Pump of circulation around primary side	Ratings circulation flowing quantity: 76L/min Ratings power consumption: 0.75kW
	The second pump of circulation around side	Ratings circulation flowing quantity: 46L/min Ratings power consumption: 0.75kW
	Cooling tower	Cooling output 138.8kW Electric power 1.5kW
	ASHP for HW (×4)	Air source heat pump Heating output 77kW Electric power 20.7kW
	Thermal storange tank	Capacity 5m^3
	Solor collector (×90)	Area 1.91m^2 Rated heating 1.3kW
GHEX	Specification	Double U tube in steel pile
	Steel pile dianeter	Outside diameter: 0.4~0.7 m
	Fi material	Water
	U tube specification	25A
	Length and number	7~10m, 68piles

3.3 Simulation Model for Ground Source Heat Pump System Accommodating Thermal Energy

In order to performance analysis, the authors developed a simulation model (performance prediction tool) for the GSHP system accommodating thermal energy shown in Figure 5. The simulation model consists of the ground model, GHEX model, heat pump (water-cooled VRF GSHP, GSHP for HW, and ASHP for HW) model, pump model, cooling tower model, solar collector model and thermal storage tank model. In the simulation model, the heating or cooling load, outside air temperature, and air humidity are given. Then, the energy consumption in the system, temperature of heat carrier fluid and temperature in the ground surrounding the GHEXs are calculated. The details of calculation are described in the previous papers (Katsura et al., 2011, Katsura et al., 2009, Katsura et al., 2008, Nagano et al., 2006).

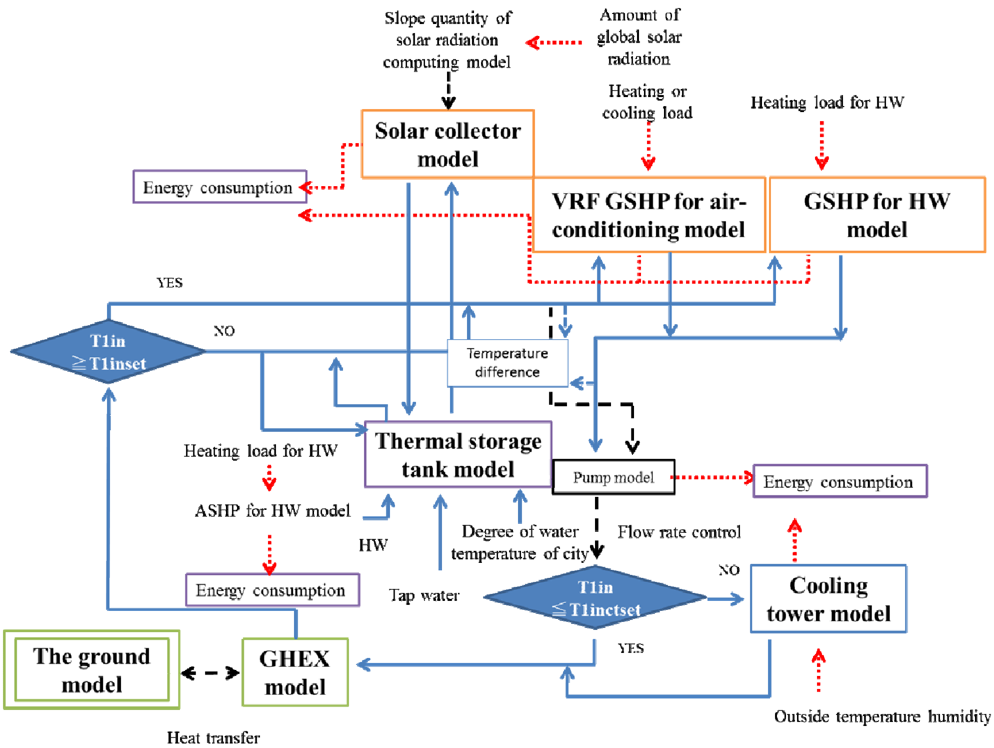

Figure 5 Simulation model (performance prediction tool) for GSHP accommodating thermal energy

4 PERFORMANCE ANALYSIS IN THE FIRST YEAR'S OPERAITON AND OPERATION IMPROVEMENT

4.1 Process of Performance Analysis and Operation Improvement

Using the performance prediction tool and the result of first year's operation, the performance analysis and operation improvement are carried out as shown in Figure 6. In the final analysis, the optimum operation method for the GSHP system accommodating thermal energy is calculated. The optimum operation method minimizes the energy consumption of the GSHP system as shown the following.

$$\min ET_{system} \tag{1}$$

In order to improve the simulation's precision, the process 1~3 indicated in Figure 6 is carried out.

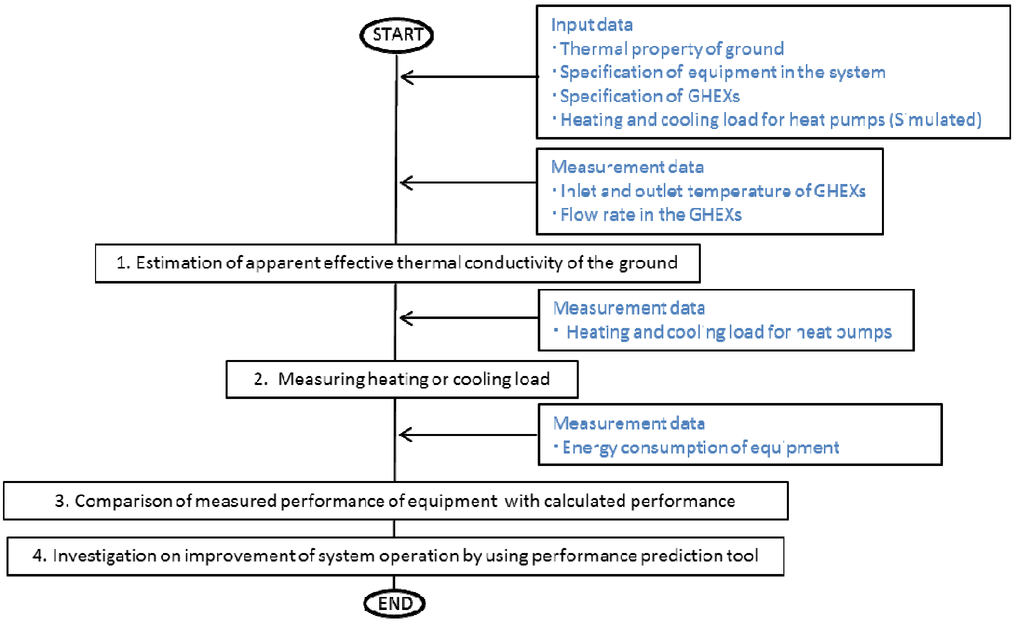

Figure 6 Process of performance analysis and operation improvement by using performance prediction tool

4.2 Estimation of apparent effective thermal conductivity of ground

The apparent effective thermal conductivity of the ground is estimated by using the GHEX model in Figure 5. Giving hourly inlet temperature of the GHEXs T_{pin} and hourly flow rate in the GHEXs V_f (The measurement points are pointed in Figure 4), hourly outlet temperature of the GHEXs T_{pout} is calculated. The calculation is carried out several times by changing the ground effective thermal conductivity λ_s. The other calculation conditions are shown in Table 2. The ground temperature is given as 18.8 ℃, which is obtained from the temperature measurement at an observation well.
Figure 7 shows a comparison of the measured T_{pout} and calculated T_{pout} from Mar. 14, 2012, to Sep. 30, 2012. Good agreement with the measured outlet temperature and the calculated one is observed when the apparent effective thermal conductivity is given as 3.3 W/m/K. Therefore, the apparent effective thermal conductivity of the ground can be estimated at approximately 3.3 W/m/K.

Table 2 Calculation conditions

GHEX	Specification	Double U tube in steel pile
	Steel pile diameter	Outside diameter : 0.4~0.7 m
	Fi material	Water
	U tube specification	25A
	Length and number	7~10m, 68piles
Soil condition	Underground temperature	18.8℃
	Soil heat conductivity	3.3W/m・K
	Density of soil	1500kg/m^3
	Specific heat of soil	2.0kJ/(kg・K)

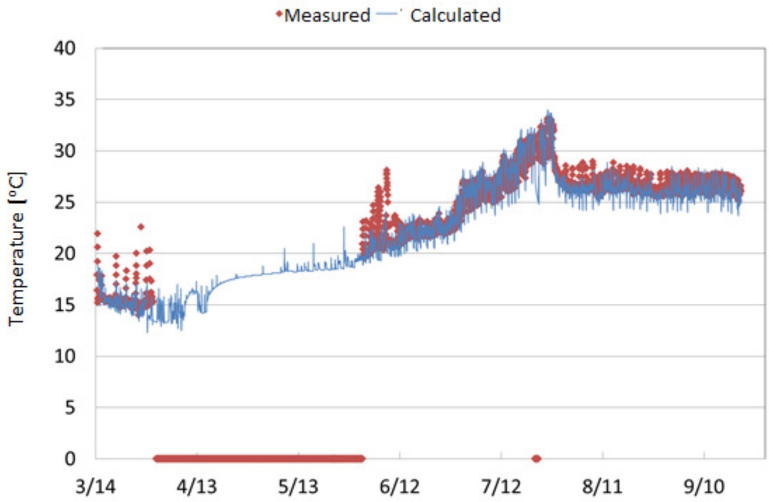

Figure 7 Variations in measured T_{pout} and calculated T_{pout} from Mar. 14, 2012, to Sep. 30, 2012

4.3 Hourly heating or cooling load of water-cooled VRF GSHP system

Figure 8 shows the variations in the measured heating and cooling load of the GSHP system. Here, the heating load is calculated by using the following equation and giving the measured values pointed in Figure 4.

$$Q_{hph} = c_f \rho_f V_f (T_{1in} - T_{1out}) + E_{hp} \tag{2}$$

Also, the cooling load is calculated by the following equations.

$$Q_{hpc} = c_f \rho_f V_f (T_{1out} - T_{1in}) - E_{hp} \tag{3}$$

The total cooling load is approximately 1.5 times the total heating output. The measured maximum cooling load and heating load are 105 kW and 75 kW, respectively.

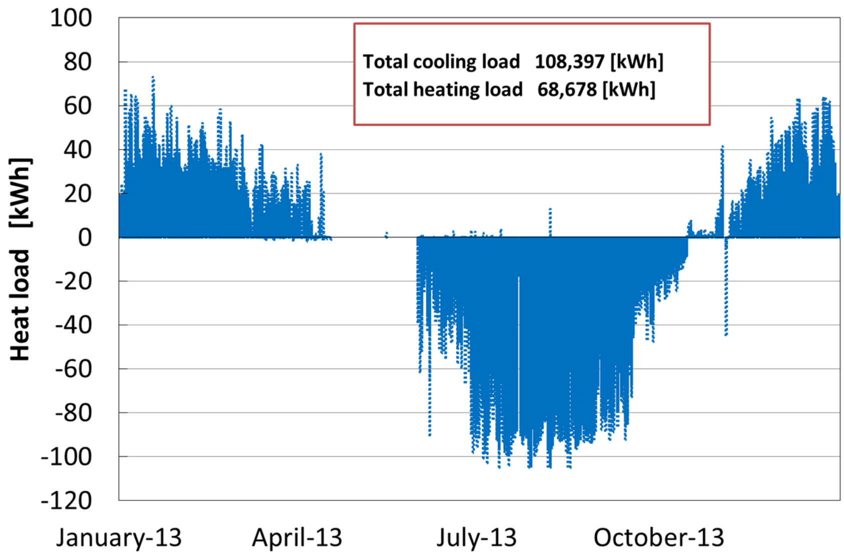

Figure 8 Variations in heating and cooling load of water-cooled VRF GSHP system

4.4 Comparison of measured heating or cooling COP with calculated COP

Shown in Figure 9 are the measured heating and cooling COPs of the water cooled VRF GSHP air conditioning systems according to the heating or cooling load. The COP is obtained by using the following equation.

$$COP = Q_{hp} / E_{hp} \tag{3}$$

The heating and cooling COPs calculated by using the heat pump model (Li et al., 2009) in Figure 5 and giving the measured T_{1in}, Q_{hp}, and V_f are also drawn in Figure 9. The measured heating and cooling COPs are smaller than the calculated ones except for the low values of cooling and heating load. Thus, correction of the calculation model is important in the final analysis.

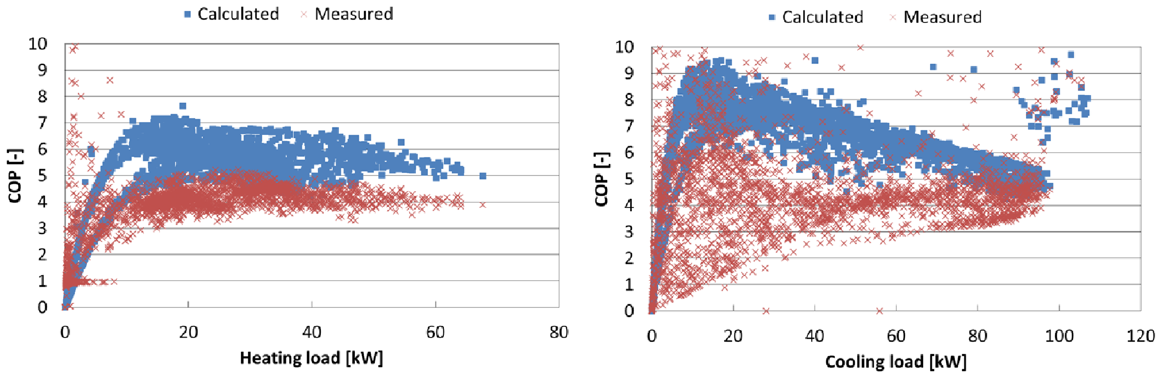

Figure 9 COPs according to heat load (Left: Heating, Right: Cooling)

4.5 Investigation on Optimum Operation Method of Ground Source Heat Pump System Accommodating Thermal Energy Using Performance Prediction Tool

The optimum operation method for the GSHP system accommodating thermal energy is calculated by using the performance prediction tool. The optimum operation method minimizes the total energy consumption of the system written as Equation (1). The total energy consumption of the system is expressed as

$$ET_{system} = ET_{GSHPh} + ET_{GSHPc} + ET_{GSHPHW} + ET_{ASHPHW} + ET_{CT} + ET_{th} \tag{4}$$

In this simulation, the restrains written in Equation (5) are placed.

$$\begin{aligned} & T_{1in} \leq 30\ ^{\circ}\text{C},\ T_{1in} \geq 10\ ^{\circ}\text{C} \\ & Q_{GSHPc} = Q_{bc}\text{、}\ Q_{GSHPh} = Q_{bh} \\ & Q_{GSHPHW} + Q_{ASHPHW} = Q_{bHW} \\ & T_{tw} \geq 15\ ^{\circ}\text{C} \end{aligned} \tag{5}$$

The restrains in the first line are given by setting the range in which the heat pumps can maintain the heating and cooling capacities. The second line means that the heating and cooling output of the water-cooled VRF GSHP systems have need to satisfy the heating and cooling load. In the third line, it is required that the sum of the heating and cooling output of GSHP for HW and ASHP for HW satisfies the heating load for HW. The last line means that the water temperature in the thermal storage tank needs to be kept equal or more than 15 °C in order to heat the water loop. If T_{tw} decrease less than 15 °C, the ASHP for HW is operated for heating the water in the thermal storage tank and the energy consumption ET_{th} is increased.

In order to investigate the optimum operation method, the simulation of the GSHP system accommodating thermal energy is carried out several times by changing the parameters of operation time and operation period of the GSHP for HW. The conditions of operation time and operation period are indicated in Table 3.

In the simulation, the measured heating and cooling loads shown in Figure 8 is given. The COP obtained by the calculation model of heat pump is corrected by the following equation.

$$COP_{corrected} = COP_{calc} \times CCOP \tag{6}$$

Here, COP_{calc} is the calculated hourly COP in the simulation. The values of $CCOP$ are obtained as the ratio of average COP (Measured) and average COP (Calculated) and given as 0.53 for heating operation and 0.65 for cooling operation, respectively. Also, the effective thermal conductivity of the ground is set at 3.3 W/m/K and the other calculation conditions shown in Table 1 and Table 2 are given.

Figure 10 shows the total energy consumptions of the system according to the conditions of operation time and operation period of the GSHP for HW. The energy consumption is the smallest in CASE1-6. The results suggest that it is better to increase the operation time and operation period.

Table 3 Conditions of operation time and operation period of GSHP for HW

	Operating period of GSHP for HW	Operating time of GSHP for HW	Fan motor's revolution speed of CT		Operating period of GSHP for HW	Operating time of GSHP for HW	Fan motor's revolution speed of CT
CASE1-1	August (1month)	24 hours	30%	CASE2-1	July~September (3month)	18 hours	30%
CASE1-2	July～August (2month)			CASE2-2	June~ September (4month)		
CASE1-3	July～September (3month)			CASE2-3	June~October (5month)		
CASE1-4	June～September (4month)			CASE2-4	May~October (6month)		
CASE1-5	June～October (5month)			CASE3-1	June~October (5month)	12 hours	
CASE1-6	May～October (6month)			CASE3-2	May~October (6month)		
				CASE4-1	-	0 hours	100%
				CASE4-2	-	0 hours	30%

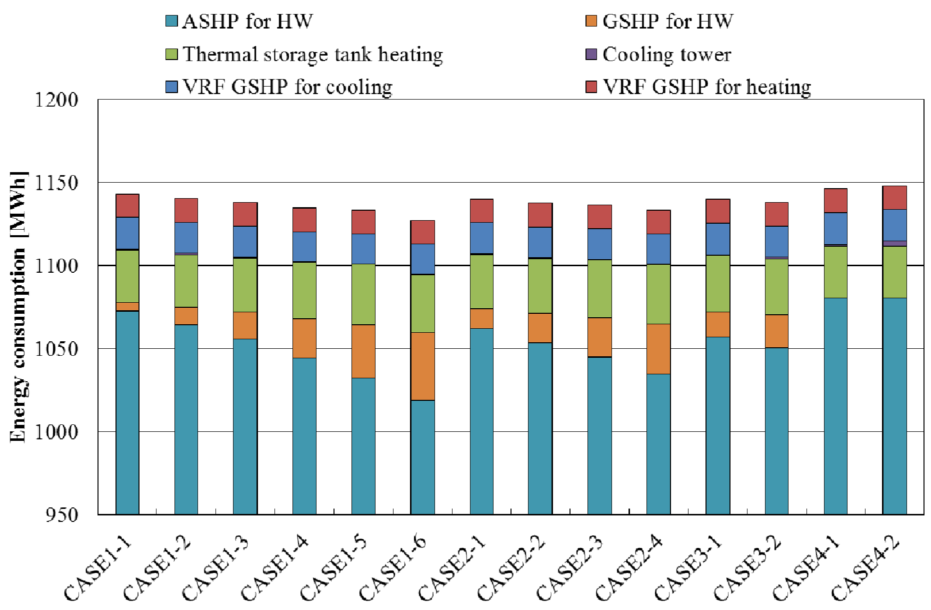

Figure 10 Total energy consumptions of system according to conditions of operation time and operation period of GSHP for HW

5 PERFORMANCE ANALYSIS IN THE SECOND YEAR'S OPERAITON AFTER OPERATION IMPROVEMENT

5.1 Result of Cooling Period in the Second Year

The optimum operation time and operation period of the GSHP for HW were 24 h and for 6 months (From May 1st to Oct. 1st), respectively. The second year's operation was conducted basis on the simulation result.
Figure 11 compares the measured heating or cooling outputs, electric power consumptions and COPs of the each heat pump unit in the cooling period (From May. 1st to Oct. 31st). The GSHP for HW is hardly operated in the first year. Thus, the heating output of GSHP for HW in the second year drastically increased compared to the one in the first year. However, the heating output of GSHP for HW in the second year was smaller than the one calculated in CASE1-6. The reason is that the HW demand is smaller than expected.
Shown in Figure 12 is amount of the exhaust heat from the water cooled VRF GSHP air conditioning systems and amount of the injected exhaust heat via the GHEXs, cooling tower and GSHP for HW. The GSHP for HW absorbs 11% of the exhaust heat in the second year. This reduces the rate of injected exhaust heat via the cooling tower from 43 % to 37 %. As, the result, the electric power consumptions of cooling tower in the second year is 2 MWh smaller than the one in the first year.

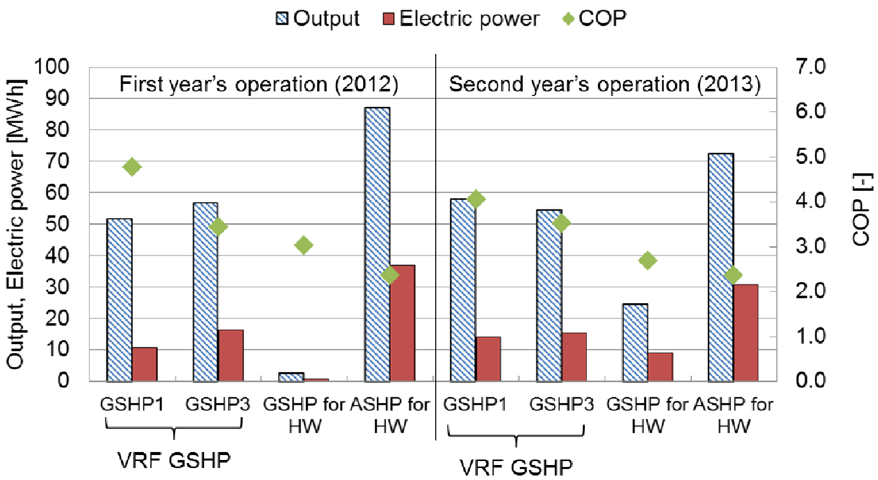

Figure 11 Measured heating or cooling outputs, electric power consumptions and COPs of the each heat pump unit in the cooling period

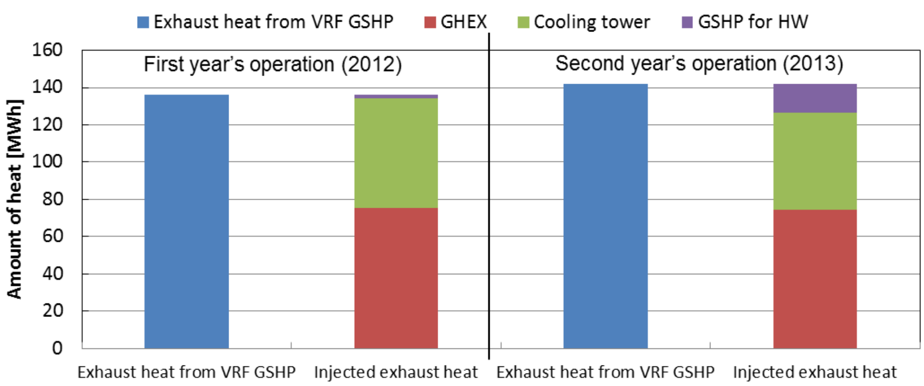

Figure 12 Amount of the exhaust heat from the water cooled VRF GSHP and amount of the injected exhaust heat

5.2 Temperature Variation in Water Loop

The variation of temperature at the inlet of GSHP in the primary side T_{1in} indicated in Figure 4 is demonstrated in Figure 13. In the second year, the temperature T_{1in} is lower than 30 °C during the cooling period and higher than 10 °C during the heating period. This result indicates that the optimum operation method is effective to the GSHP system accommodating thermal energy.
The GSHP for HW is not operated during heating season in the first and second year. The reason is that the electric power consumption for heating the water in the thermal storage tank is generated when the temperature T_{1in} decreases less than 10 °C and the water loop is heated by the water in the tank. However, even if the GSHP for HW is operated during heating season, the temperature T_{1in} might not decrease less than 10 °C. Thus, the authors will carry out the simulation for the optimum operation including the operation of the GSHP for HW during heating season.

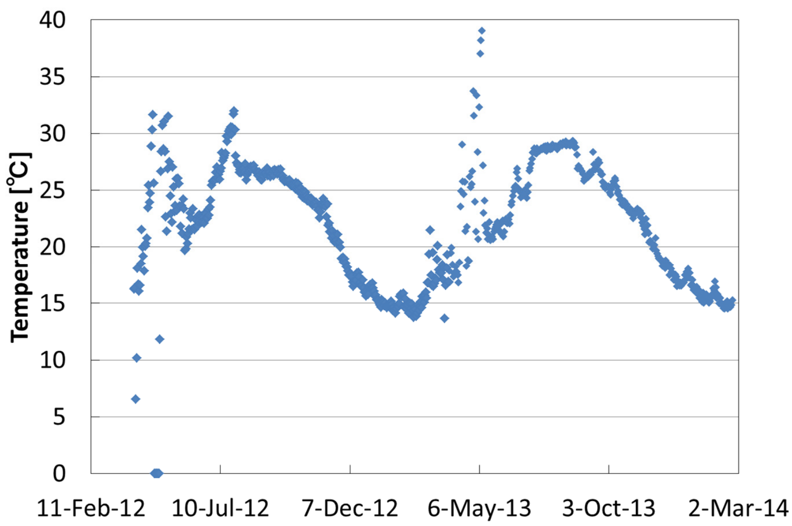

Figure 13 Variation of temperature in T_{1in}

6 SUMMARIES

1) The authors explained the concept and advantage of the GSHP system accommodating thermal energy. In addition, the demonstration project of the performance analysis of the GSHP system accommodating thermal energy in the dormitory in Kitakyushu City, which is the first step for the practical application in the land area, was introduced.
2) Using the performance prediction tool and the result of first year's operation, the optimum operation method for the GSHP system accommodating thermal energy in the second year's operation was investigated. The result indicated that the optimum operation time and operation period of the GSHP for HW, which minimize the total energy consumption of the system, were 24 h and for 6 months, respectively.
3) The GSHP for HW absorbs 11 % of the exhaust heat in the second year. This reduces the rate of injected exhaust heat via the cooling tower from 43 % to 37 %.
4) The temperature at the inlet of GSHP in the primary side T_{1in} is lower than 30 °C during the cooling period and higher than 10 °C during the heating period. As the result, that the optimum operation method is effective to the GSHP system accommodating thermal energy.

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NOMENCRATURE

c: Specific thermal capacity [J/kg/K], *E*: Electric power [W], *ET*: Total electric power [Wh], *V*: Flow late [m^3/s], *Q*: Heating or cooling output [W], *T*: Temperature [^{o}C], *ρ*: Density [kg/m^3], *λ*: Effective thermal conductivity [W/m/K]

Subscript

ASHPHW: Air source heat pump for HW, *bc*: Cooling in building, *bh*: Heating in building, *bHW*: HW in building, *CT*: Cooling tower, *f*: Thermal medium, *GSHPc*: Ground source heat pump for cooling, *GSHPh*: Ground source heat pump for heating, *GSHPHW*: Ground source heat pump for HW, *hp*: Heat pump, *hpc*: Heat pump cooling operation, *hph*: Heat pump heating operation, *p*: Pump, *pin*: Inlet of ground heat exchanger, *pout*: Outlet of ground heat exchanger, *s*: soil, *system*: system, *th*: Storage tank heating, *1in*: Inlet in the primary side, *1out*: Outlet in the primary side