

# GEOTHERMAL HEAT PUMP SYSTEM INSTALLED IN MAIN BUILDING OF OBAYASAHİ CORPORAITON TECHNICAL RESEARCH INSTITUTE

*Kenji Mikoda, Research engineer, Obayashi Corporation, Tokyo, Japan*  
*Takashi Tsuchiya, Research engineer, Obayashi Corporation, Tokyo, Japan*

**Abstract:** The main building of Obayashi Corporation Technical Research Institute was built in Kiyose City, Tokyo in September, 2010. The ground source heat pump (GSHP) system was adopted for radiant heating-cooling and desiccant air-conditioning in workplace. Three kinds of unique ground heat exchangers (GHEs) are used as heat exchanger; vertical double U-tube GHE with highly conductive backfill material, vertical single U-tube GHE which has been tied to H steels of the earth retaining wall, and horizontal GHE under the basement foundation. They were developed for the purpose of the cost reduction or improvement of the heat extraction/injection performance. This paper reports the thermal performance of the GSHP systems in winter season (Dec.2010~Feb.2011).

As a result, outlet brine temperatures of all GHE types were higher than outside air temperature. When we compared the ratios of heat extraction performance of GHEs, vertical GHE using double U-tube was the highest of three kinds of GHEs. The heat extraction rate of vertical GHE with highly thermal conductive backfill has increased compared with that of vertical GHE with normal backfill.

**Key Words:** ground source heat pump, ground heat exchanger, backfill material

## 1 INTRODUCTION

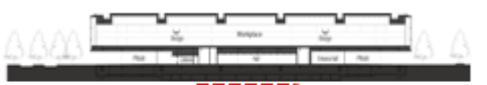
Main building of Obayashi Corporation Technical Research Institute was built in Kiyose-City, Japan in September 2010. The important concept of the building is most-advanced environment friendliness, and it has been planned to achieve the 55% reduction of CO<sub>2</sub> emissions when compared to a typical office building (Ito et al. 2011). In order to achieve the highest level of energy savings and CO<sub>2</sub> reduction, we used natural energy willingly, such as sunlight, seasonal wind and underground thermal energy, and adopted many energy-saving technologies. GSHP system was adopted as a part of heat source/sink and three kinds of GHEs were installed in ground, earth retaining wall and under basement foundation. GSHP systems are not widespread in Japan because of high installation costs. We have developed the methods that can reduce installation costs of GHE. Besides, we have developed the method that can improve the heat extraction or injection performance.

## 2 BUILDING AUTOLINE

Figure 1 shows a building appearance. The vast lawn locates south side of the building, and 10 borehole type vertical GHEs were buried under the lawn at intervals of 6m. A cross-sectional view and floor plan are shown in Figure 2 and Figure 3. The building is steel structure with three stories above ground. The building area is 3,370m<sup>2</sup> and a total floor area is 5,535m<sup>2</sup>. GSHP system is utilized for air-conditioning of the workplace on the 2nd floor. The horizontal heat exchangers are buried under basement foundation and vertical pipe is tied to H steels of the earth retaining wall on south side.

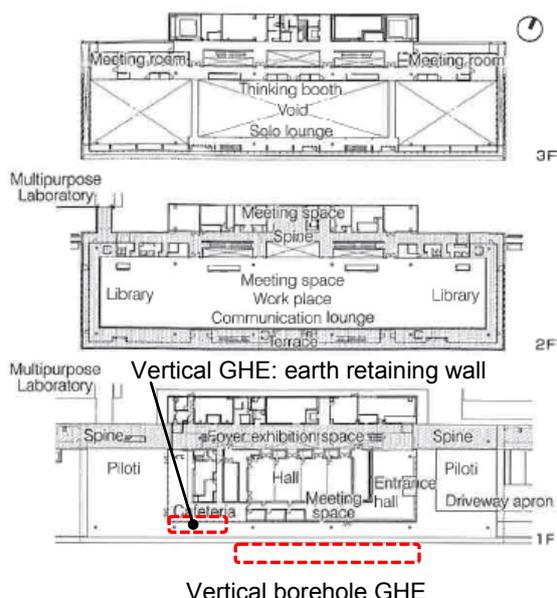


**Figure 1: Building appearance**



Horizontal GHE: under basement foundation

**Figure 2: Cross-sectional view**



**Figure 3: Floor plan**

### 3 EQUIPMENT CONFIGURATION

#### 3.1 Ground Heat Exchangers

Figure 4 shows three kinds of GHEs installed in the building. Ten vertical double U-tube GHEs of 100m long are used as a main GHE. They were installed at intervals of 6 m and each of them was buried into the borehole (135 mm in diameter). The double U-tube, made of 27 mm inner diameter high density polyethylene pipe, was installed in borehole. In order to increase the heat exchange rate, highly thermal conductive sand was used as a backfill material. It was composed of low grade silicon carbide (0%~20%) and silica sand (80%~100%). Silicon carbide (SiC) is a nonmetal and it has high thermal conductivity and excellent corrosion resistance. In general, silicon carbide is used as a abrasives, but it is expensive because the standards of hardness and the quality are severely managed. In the manufacturing process of high standard products, low grade silicon carbide was generated and we got it at a low price. The silicon carbide and the silica sand can be evenly mixed only by stirring with a cement mixer because their density and diameter are close.

Horizontal GHEs are used just below basement foundation and they have 300 m high density polyethylene pipe (27 mm in inner diameter). Because it is possible to install the horizontal GHEs in the middle of underground foundation construction, the drilling work for the GHEs installation can be omitted. 10 vertical single U-tube GHEs of 10m long are tied to H steels of the earth retaining wall. A ground plan and sectional view of earth retaining wall are shown in Figure 5 and Figure 6. H steels were installed at intervals of 1.5 m and the one side of the web contacts with the basement wall. The guide steel pipes (100mm×100mm) were welded by both sides of flange and single U-tube, made of 27 mm inner diameter high density polyethylene pipe, was installed in them. In order to increase the heat exchange rate, highly thermal conductive sand was used as a backfill material. It was composed of 10% low grade silicon carbide and 90% silica sand.

#### 3.2 GSHP and HVAC System

Heat source systems utilized in the building consists of air-source heat pump chilling units and groundwater/ground-source hybrid heat pump chilling units. Figure7 shows a diagram of GSHP system. There's a well in the site, and we can use the water from it under

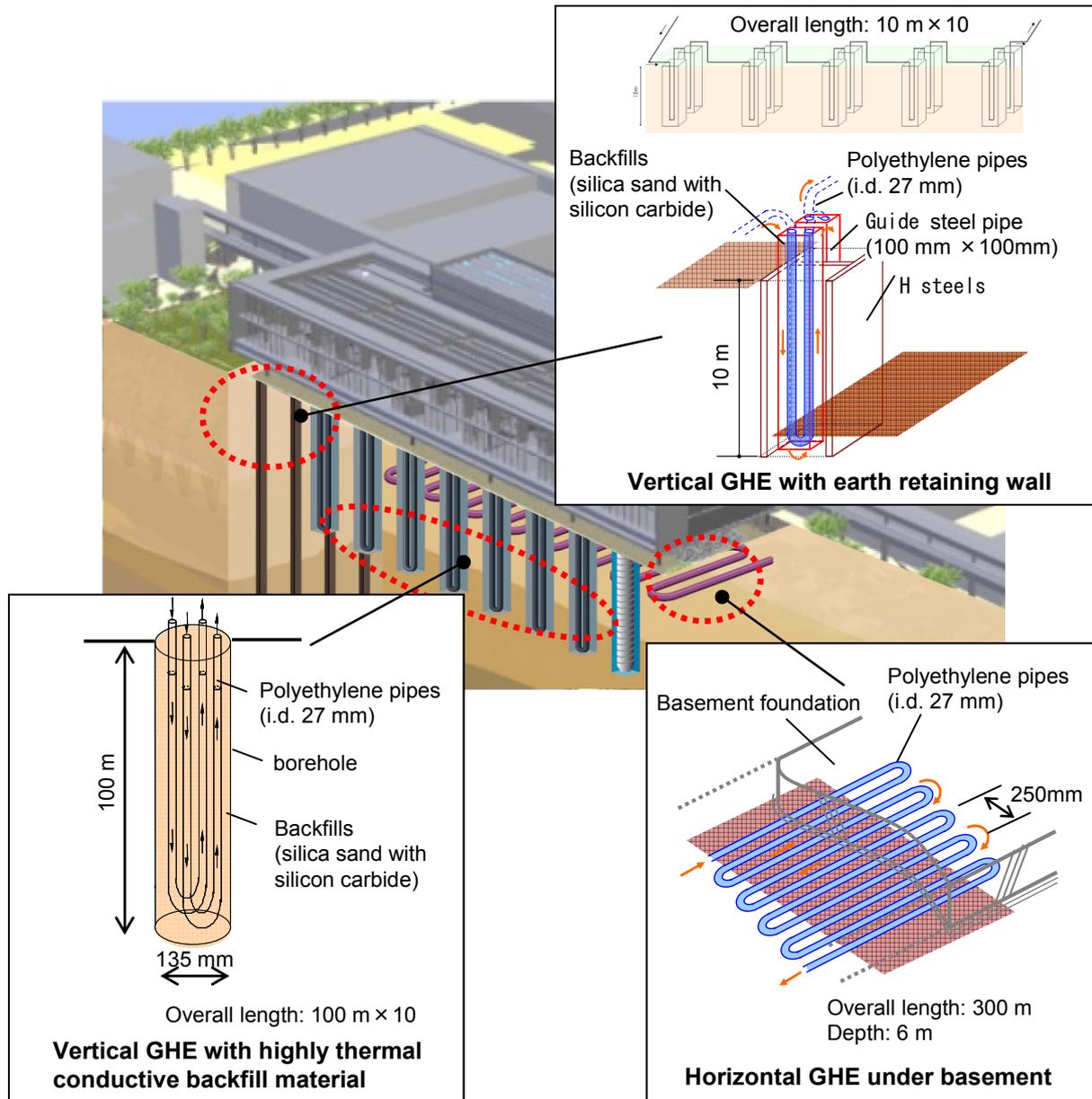


Figure 4: Ground heat exchangers installed in the building

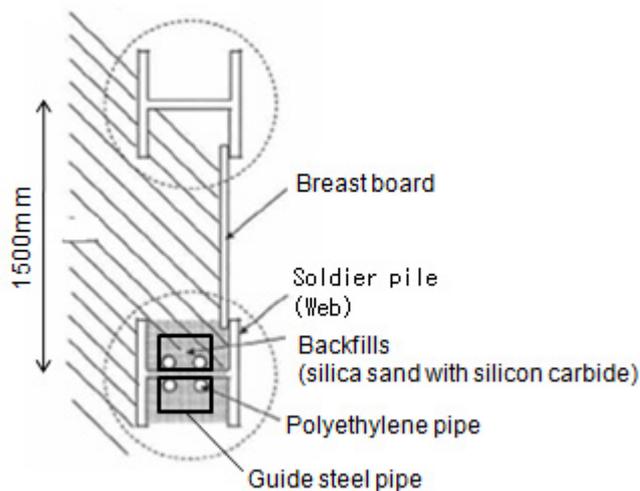


Figure 5: Ground plan of earth retaining wall

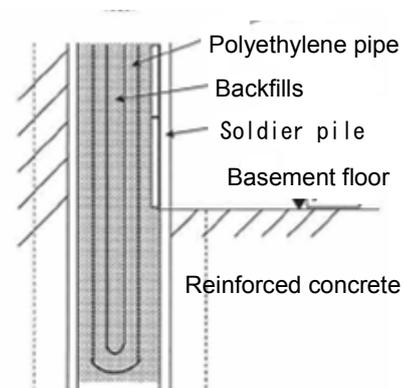


Figure 6: Sectional view of earth retaining wall

20 m<sup>3</sup>/day. GSHP chilling units are usually connected with GHE, but switch to well heat exchanger from 15:00 to 17:30. The well water that is used for a heat exchanger is reused for flushing toilets and watering biotope. As a heat source backup system, a cooling tower unit is prepared.

At daytime of winter, the flow rate in circulating loop of GHE is set at 230 L/min and 44°C warmed water supplied from GSHP to task panel for radiant heating. In order to reduce running costs, GSHP system is scheduled to operate at midnight in summer season when the electricity cost is cheap. At midnight of summer, the flow rate in the circulating loop of GHE is set at 396 L/min and 13°C cold water is scheduled to supply from GSHP to latent heat thermal storage tank and water thermal storage tank. At daytime of summer, 13°C cold water is scheduled to supply from water thermal storage tank to task panel for radiant cooling and it is scheduled to supply from latent heat thermal storage tank to desiccant air-conditioning system.

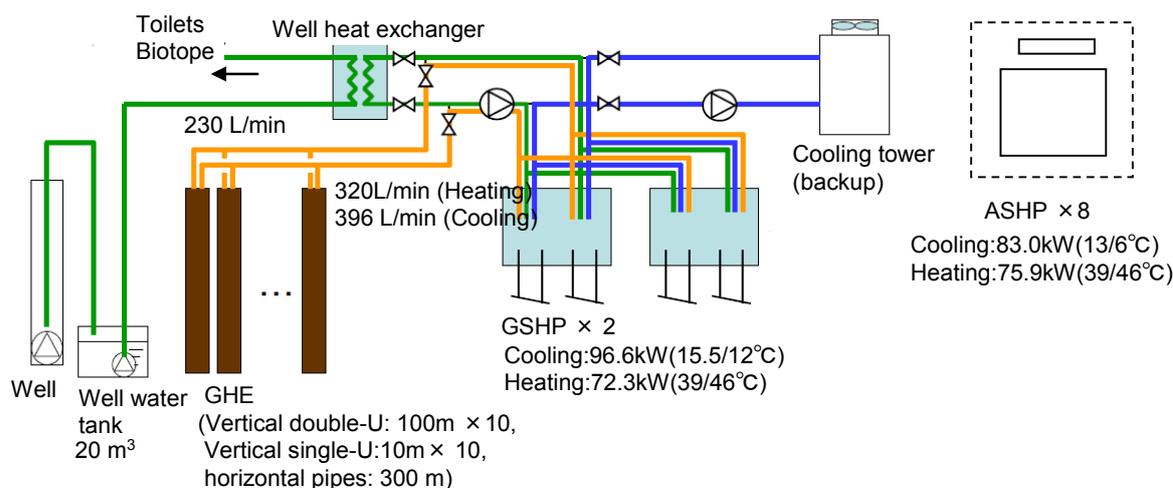


Figure 7: Diagram of GSHP system

## 4 HEATING RESULTS IN 2010

### 4.1 Underground temperature

Figure 8 shows the distribution of the observation wells. The temperature measurements of observation wells started from December 27, 2010. Underground temperature at measuring observation well-3 and outside air temperature are shown in Figure 9. Temperature, which is deeper than 10m below ground level (G.L.), was stable at around 16.5°C in winter. On the other hand, average outside air temperature was approximately 3.0°C in January, 2011. Underground temperature at measuring observation well-1 and U-tube surface temperature of GHE (U2) are shown on the left side of Figure 10. Daily average temperatures of U-tube surface (G.L. -12m and G.L. -33m) fell only 1.0°C and the temperatures of observation well-1 (G.L. -10m and G.L. -30m) fell only 0.2°C during 3 month. It is thought that the temperature change around the GHE was small because the heating load was less than the plan. Underground temperature at measuring observation well-4, well-5 and U-tube surface temperature of GHE with earth retaining wall are shown on the right side of Figure 10. Daily average temperature of U-tube surface (G.L. -4m) fell 2.2°C and the temperature of observation well-4 (G.L. -4m) fell 1.5°C during 3 month.

### 4.2 Thermal performances of GHEs

Table 1 shows the thermal performances of each GHE in winter season. These results are

well	Depth	Distance from GHE	Measurement point(depth)
O.W.-1	30m	0.5m(U2)	2.5,5,10,15,20,25,30m
O.W.-2	30m	1.0m(U2)	2.5,5,10,15,20,25,30m
O.W.-3	30m	7m(U10)	2.5,5,10,15,20,25,30m
O.W.-4	12m	0.5m(retaining wall)	1,2,4,6,8,10,12m
O.W.-5	12m	1.0m(retaining wall)	1,2,4,6,8,10,12m

Figure 8: Distribution of observation wells

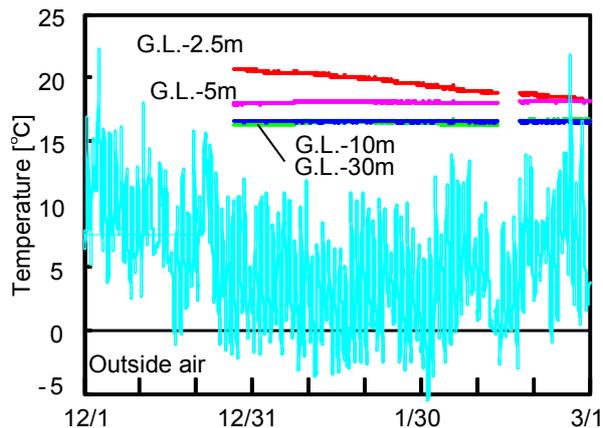


Figure 9: Underground and air temperature

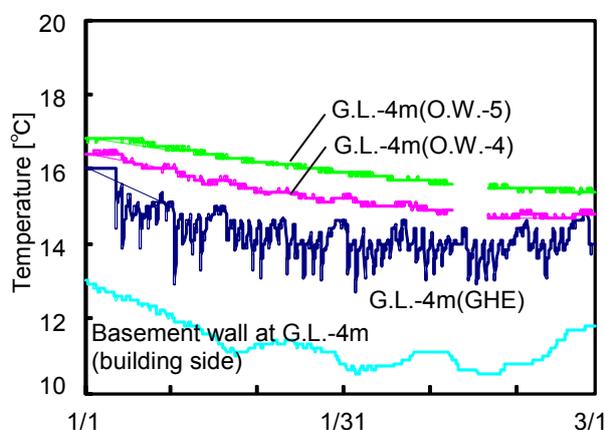
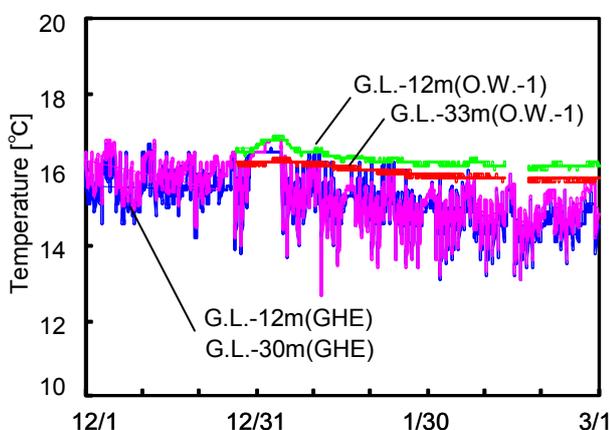


Figure 10: Temperatures around GHE (left: GHE (U2), right: GHE with earth retaining wall)

Table 1: GHE's performance of operation in daytime (Average daily value: Dec.2010~Jan. 2011)

	Type-1A	Type-1B	Type-2	Type-3
Inlet temperature of GHE[°C ]	13.86	13.93	13.93	13.85
Outlet temperature of GHE[°C ]	14.72	14.66	14.43	14.35
Outside air temperature [°C ]	6.71	6.71	6.71	6.71
Flow rate [L/min ]	21.4	21.3	9.0	11.0
Amount of heat extraction [MJ/d]	31.4	26.6	10.5	9.7
Depth of each GHE [m ]	100	100	6	10
Objective number of GHE [- ]	1	1	1	5
Overall pipe length [m ]	400	400	300	200
Heat extraction rate [W/(pipe)m ]	2.81	2.39	1.26	1.75

Type-1A: Vertical double U-tube GHE with special backfill (20%SiC and 80%silica sand)

Type-1B: Vertical double U-tube GHE with normal backfill (100%silica sand)

Type2: Horizontal GHE

Type3: Vertical single U-tube GHE with retaining wall

average values, which were operated in daytime (7:00~15:00). Each GHE wasn't used from 15:00 to 17:30 because well water was used as a heat source. Although each GHE was used from 17:30 to midnight, it doesn't include for evaluation during that time zone because heating load was very little. As a result of heating in winter season, heat source brine temperatures of all types were higher than outside air temperature. The heat extraction rate

of Type-1 was higher than that of the other types. The heat extraction rate of Type-1 with special backfill (Type-1A) was 18% higher than that of Type-1 with normal backfill (Type-1B). However, the heat extraction rate of each type was lower than expected value.

GSHP system should be used for not only radiant heating but also normal heating of workplace in the original plan. However, GSHP system will be used for only radiant heating, which is a small load, because the co-efficient of performance (COP) of GSHP installed in the building was quite lower than the COP of catalog value. We would be able to increase the heat extraction rate, if heating load will be increased.

#### 4.2.1 Vertical double U-tube GHE with highly conductive backfill

Heat source brine temperature (Type-1A) and outside air temperature are shown in Figure 11. These results are average values during operation in daytime (7:00~15:00). Average heat source brine temperature in winter season was 14.7°C and it was about 8.0°C higher than the outside air temperature. Figure 12 shows the amount of daily heat extraction and circulating brine flow rate (Type-1A, 1B). The flow rate is almost steady at 21~22 L/min in operation. Each average amount of heat extraction per day (Type-1A) was 26.4MJ/d in December, 34.5MJ/d in January, 33.4 MJ/d in February. On the other hands, each average amount of heat extraction per day (Type-1B) was 21.5MJ/d in December, 29.5MJ/d in January, 29.0 MJ/d in February.

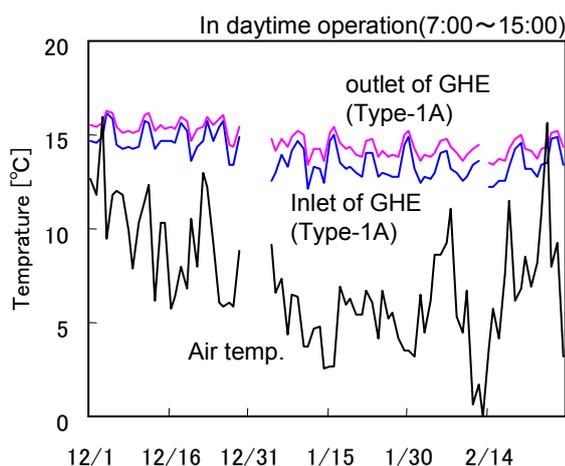


Figure 11: Brine and air temperature (GHE with special backfill: Type-1A)

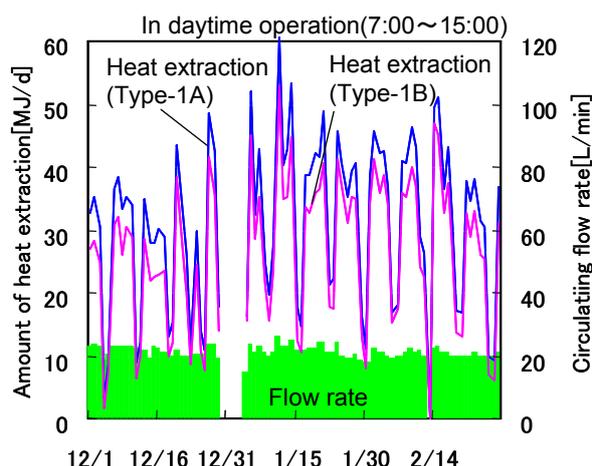


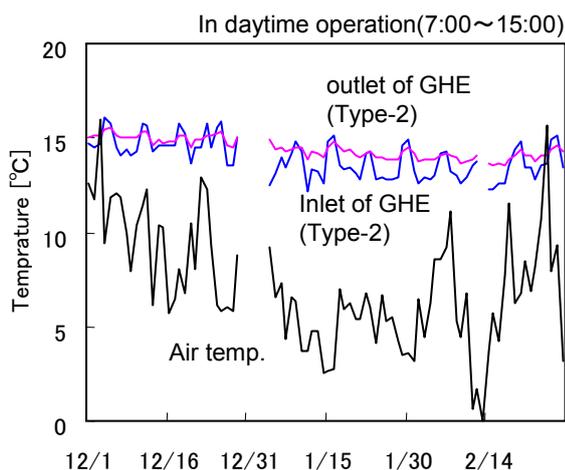
Figure 12: Amount of heat extraction and flow rate (GHE with special and normal backfill: Type-1A, B)

#### 4.2.2 Horizontal GHE under basement foundation

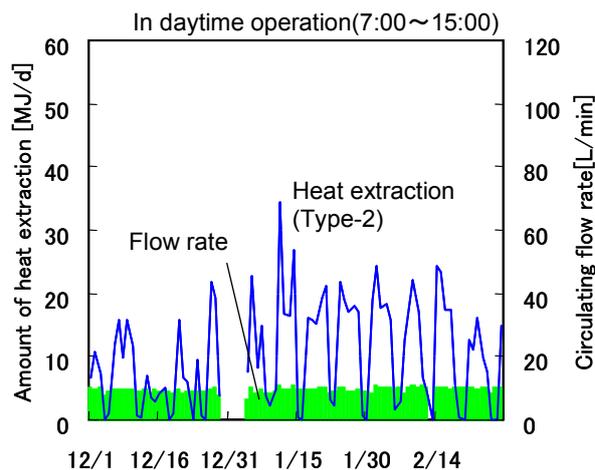
Heat source brine temperature (Type-2) and outside air temperature are shown in Figure 13. Average heat source brine temperature in winter season was 14.4°C and it was about 7.7°C higher than the outside air temperature. Figure 14 shows the amount of daily heat extraction and circulating brine flow rate (Type-2). The flow rate is steady at 9 L/min in operation. Each average amount of heat extraction per day (Type-2) was 6.9MJ/d in December, 13.0 MJ/d in January, 11.9 MJ/d in February.

#### 4.2.3 Vertical single U-tube GHE with earth retaining wall

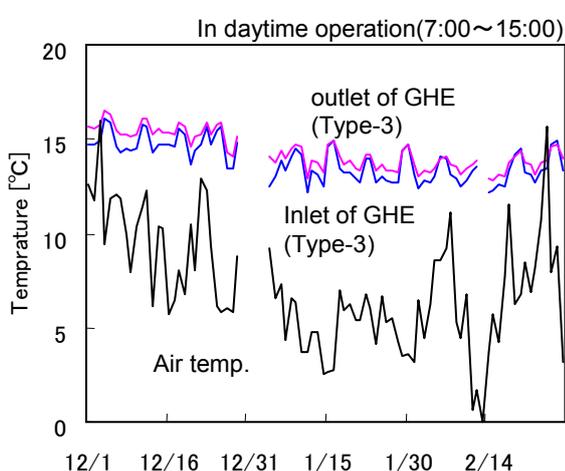
Heat source brine temperature (Type-2) and outside air temperature are shown in Figure 15. Average heat source brine temperature in winter season was 14.4°C and it was about 7.7°C higher than the outside air temperature. Figure 16 shows the amount of daily heat extraction and circulating brine flow rate (Type-3). The flow rate is steady at 11 L/min in



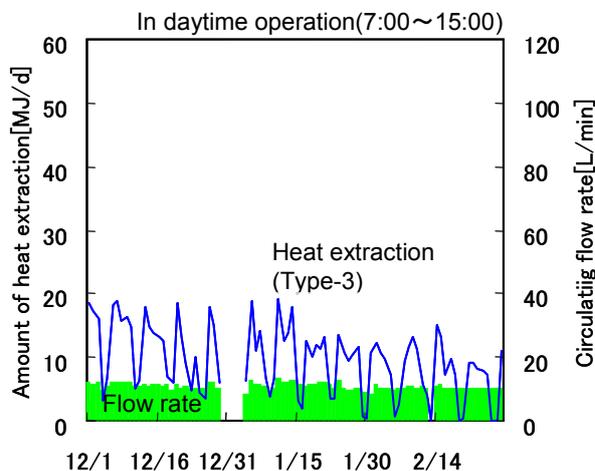
**Figure 13: Brine and air temperature (Horizontal GHE: Type-2)**



**Figure 14: Amount of heat extraction flow rate (Horizontal GHE: Type-2)**



**Figure 15: Brine and air temperature (GHE with earth retaining wall: Type-3)**



**Figure 16: Amount of heat extraction and flow rate (GHE with earth retaining wall: Type-3)**

operation. Each average amount of heat extraction per day (Type-2) was 11.8 MJ/d in December, 9.6 MJ/d in January, 7.5 MJ/d in February.

### 4.3 Heating load and COP of GSHP

Figure 17 shows heating load, water temperature for heating supply and water flow rate for heating supply. The temperature is an average daily value during daytime operation (7:00~15:00). The heating load and water flow rate for heating supply are total values during daytime operation (7:00~15:00). The heating water was supplied at 42~46°C for task panel. The water flow rate for heating supply is about 320 L/min. Radiant heating for workplace was operated almost every day and the heating load in daytime was about 300~500 MJ/d in weekday, 50~70 MJ/d in holiday.

Figure 18 shows the electric consumption for GSHP system, COP and SCOP. The electric energy for compressor of heat pump and the power of brine circulating pumps for the GHEs are included in the consumption for GSHP system. The average COP (= heating load/electric energy for only compressor of heat pump) was about 2.1. The average SCOP (= heating load/electric consumption for GSHP system) was about 1.7. Though the heat source brine temperature was much higher than the outside temperature during winter, the COP of

GSHP was quite lower than the standard performance which was shown in the catalog of heat pump machine. The improvement of this trouble is under consideration.

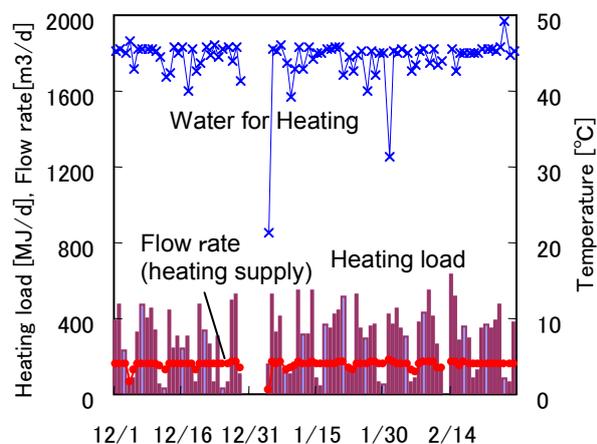


Figure 17: Heating load heating water flow rate

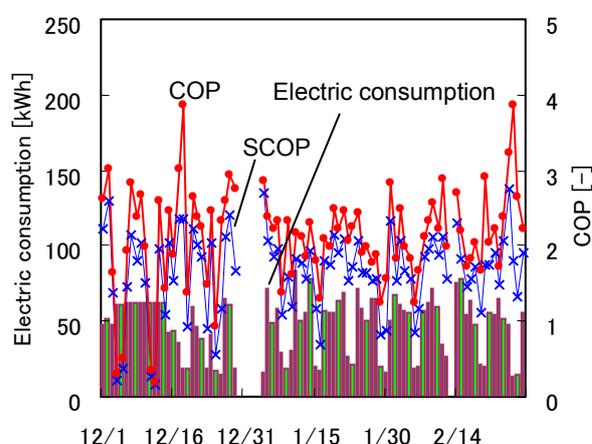


Figure 18 Electric consumption and COP

## 5 CONCLUSIONS

The authors have installed GSHP system in office building and three kinds of unique GHEs were used as heat exchanger; vertical double U-tube GHE with highly conductive backfill material, vertical single U-tube GHE which has been tied to H steels of the earth retaining wall, and horizontal GHE under the basement foundation. As a result of heating operation, the following results were obtained.

- 1) The outlet brine temperature of all GHE types was higher than outside air temperature.
- 2) When we compared the ratios of heat extraction performance of GHEs, vertical GHE using double U-tube was the highest of the three kinds of GHEs.
- 3) The heat extraction rate of vertical GHE with highly thermal conductive backfill is higher than that of vertical GHE with normal backfill.
- 4) Though the heat source brine temperature was much higher than the outside temperature during winter, the COP of GSHP was quite lower than the standard performance which was shown in the catalog of heat pump machine. The improvement of this trouble is under consideration.

## 6 REFERENCES

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