DEVELOPMENT OF GROUND-SOURCE HEAT PUMP SYSTEM USING A FLOWING WELL

Gaurav Shrestha[1], Youhei Uchida[1], Satoru Kuronuma[2], Mutsumi Yamaya[2], Masahiko Katsuragi[2]

[1] Renewable Energy Research Center, Fukushima Renewable Energy Institute, AIST, 2-2-9 Machi-ikedai, Koriyama 963-0298, Japan

[2] Japan Groundwater Development Co. Ltd., Matsubara 777, Yamagata 990-2313, Japan

e-mail: shrestha-g@aist.go.jp

ABSTRACT

For the promotion of ground-source heat pump (GSHP) system in Japan, development of highly efficient system is essential. In this study, GSHP system was developed using a flowing well as a ground heat exchanger (GHE). Flowing well of 250mm diameter and 100m depth was constructed. Slit screens were set at intervals of 61.45 m - 83.45 m and 88.95 m - 99.95 m. 3 sets of 100m double U-tube with 34mm external diameter were installed and connected to 3 heat pumps of 10kW capacity. Performance of the system was evaluated for space-heating and space-cooling of an office building with room area of 126.7 sq. m. Average coefficient of performance (COP) was 4.5 for space-heating and 8.1 for space-cooling. Maximum heat exchange rate was 70.8 W/m for space-heating and 57.6 W/m for space-cooling. It can be said from these data that the system resulted in higher performance. Energy saving and cost reduction can be expected from this kind of system.

Keywords: ground-source heat pump system, flowing well, performance, Japan

1. INTRODUCTION

Ground-source heat pump (GSHP) system is an energy efficient and environment friendly technology that utilizes natural subsurface heat energy stored in the shallow depth for space-heating, space-cooling, snow-melting etc. Development of this system is gradually increasing in Japan (Ministry of Environment, 2015), however the pace is still slow due to higher initial cost caused by oversized design of ground heat exchangers (GHE).

In Japan, for closed loop GSHP system, vertical (GHE) is generally constructed by inserting single or double U-tube into the borehole drilled beforehand and the gap or void between U-tube and borehole’s wall is filled with silica sand as a grout. These kind of systems are typically used in Japan’s present context. Increasing the heat exchange efficiency of these systems can lead to energy saving and reduction in cost. This task is very important to promote the growth of GSHP system in Japan. Regional groundwater flow system affects subsurface thermal regime, caused by heat transfer through groundwater convection (Domenico and Schwartz, 1998). Therefore, in areas with abundant groundwater and its flow, higher performance of GSHP system can be expected with enhanced heat exchange rates.

Main objective of this study is to develop highly efficient GSHP system and evaluate its operating performance. In this study, GSHP system utilizing a flowing well as GHE (Fig. 1) was constructed in the premises of Japan Groundwater Development Co. Ltd. Study site is located at Aizu Bange Town (Fig. 2) which is situated at the central part of Aizu Basin. Flowing well is the well in which groundwater from aquifer (generally confined aquifer) naturally flows in upward direction and out of the well without pumping.

In Japan, large number of flowing wells are left abandoned without any active use of groundwater. The rationale of this study is that GSHP system similar to the one developed in this study can be introduced to these regions, so that the unused heat energy of groundwater can be effectively utilized for space-heating and space-cooling.

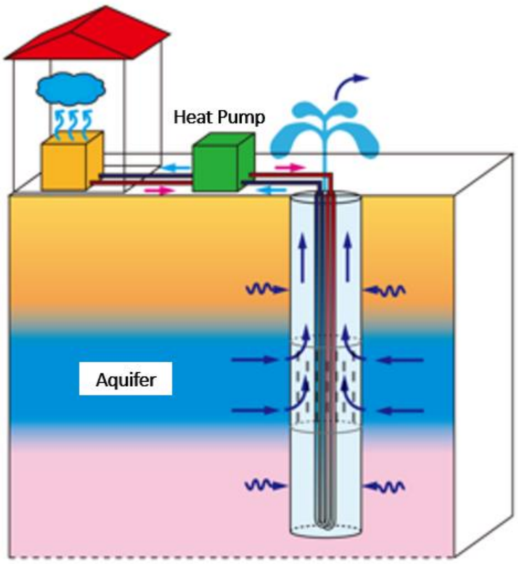

Fig. 1 Schematic diagram of GSHP system utilizing flowing well as GHE

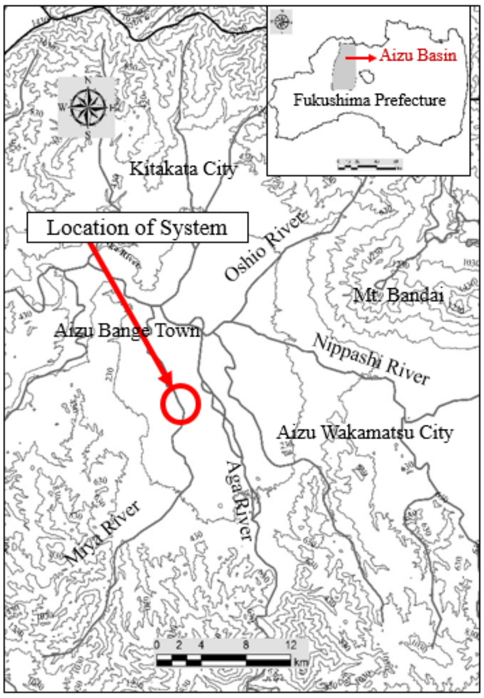

Fig. 2 System installation site and Aizu Basin

2. GSHP SYSTEM

Flowing well of 250mm diameter and 100m depth was drilled at study site. This well is taken as the heat source and heat sink. Slit screens were set at intervals of 61.45 m - 83.45 m and 88.95 m - 99.95 m. 3 sets of 100m double U-tube with 34mm external diameter were installed inside the flowing well and connected to 3 heat pumps of 10kW capacity. For demonstration, the system was used for space-cooling and space-heating of the 1 storey office building with room area of 126.7 sq. km. 6 fan coil units (FCU) were installed inside the office room. Groundwater flowing out from the well was regulated by an electric valve from the perspective of groundwater management preventing unnecessary wastage of groundwater. Fig. 3 shows the schematic diagram of installed GSHP system.

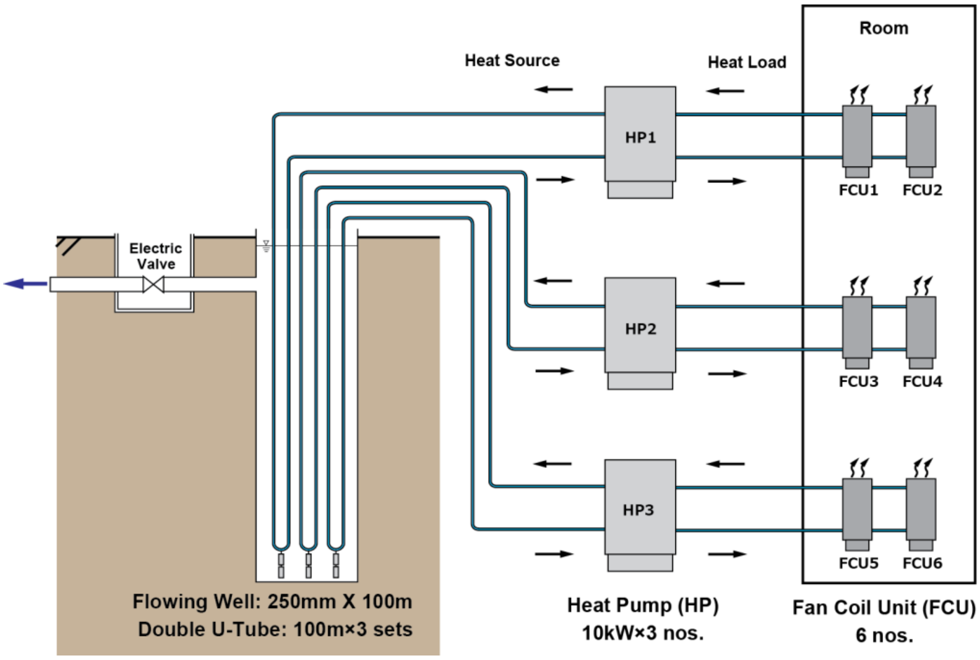

Fig. 3 Schematic diagram of installed GSHP system

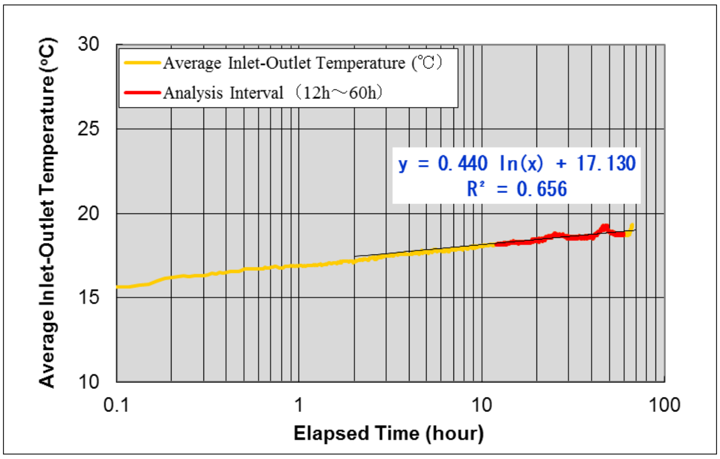

Fig. 4 Analysis result of TRT

3. THERMAL RESPONSE TEST

After inserting U-tube into the flowing well, thermal response test (TRT) was conducted to determine the thermal characteristic of GHE. TRT was done by applying a heat load of 4kW to the heat transfer medium (water), which was circulated in U-tube for 67 hours at the rate of 30.8 L/min (average). Temperature of the medium was continuously observed at the inlet and outlet of GHE. Average value of observed inlet and outlet temperatures were analyzed as shown in Fig. 4 to determine the effective thermal conductivity of geological layer at the site. The average effective thermal conductivity was found to be 7.98 W/mK, which is high compared to a common closed loop GHE that uses silica sand as a grout. This higher value of effective thermal conductivity is because of strong influence of groundwater convection (Domenico and Schwartz, 1998; Uchida et al., 2011).

4. REGULATION OF GROUNDWATER UP-FLOW

Groundwater up-flow and discharge from the flowing well during GSHP system's operation was regulated by an electric valve (Fig. 3), based on the well temperature at 50m depth. Usually, the electric valve remains closed. For space-heating operation, if operation is continued, well temperature decreases with time and thereafter COP also goes down. In order to maintain constant COP electric valve is regulated such that if the well temperature at 50m depth goes down to 10ºC, the valve gets opened and groundwater flow occurs within the well. Once the well temperature recovers to 12ºC, the valve closes automatically and this cycle continues. Similarly, for space-cooling operation, if the well temperature at 50m depth rises to 16ºC, the valve gets opened letting groundwater flow up the well. When the well temperature recovers to 14ºC, the valve gets closed.

5. OPERATION OF GSHP SYSTEM

The GSHP system was used for the space-heating and space-cooling of the office room with the area of 126.7 sq. km. Space-heating operation was started from 2014/10/28 to 2015/4/24 and space-cooling operation was conducted from 2015/5/26 to 2015/9/21. Fig. 5 and Fig. 6 show the operation results of the GSHP system. Average COP during space-heating operation was 4.5 and during space-cooling operation was 8.1. These values were taken as the daily average COP of 3 heat pumps. For space-heating, COP varied from 4 to 5.6 and for space-cooling, it ranged from 7.5 to 8.4. Regarding heat exchange rate, the maximum value was 70.8W/m for space-heating and 57.6 W/m for space-cooling. Specific results are shown in following sub-sections.

5.1 SPACE-HEATING OPERATION

During this operation, groundwater level dropped below 1m from ground surface for about 31 days from the month of December 2014 to March 2015. As groundwater was below the level of electric valve, the valve could not be opened to allow groundwater up-flow and the well temperature could not be recovered. Decrease in groundwater level in winter season is thought to be because of extensive groundwater pumping for snow-melting purpose in Aizu Basin.

Fig. 7 shows space-heating operation result on 2015/3/12. On this day, after 7 am groundwater dropped below -1m and electric valve remained closed inhibiting groundwater flow within the well. Average COP was found to be 4. As the operation continued, well temperature gradually decreased from 11ºC to about 8ºC at 20m depth, 11ºC to about 9ºC at 50m depth and 12ºC to about 10ºC at 80m depth. Consequently, COP also gradually decreased from 4.3 to 3.8 approximately.

Fig. 8 shows space-heating operation results on 2015/3/24 when groundwater level was above -1m. Electric valve was regulated such that it got opened when the well temperature at 50m depth decreased to 10ºC and closed when increased to 12ºC. On this day, electric valve was regulated for 6 times with about 100 minutes of groundwater up-flow. Average COP was 4.7 higher than the above case when the electric valve could not be regulated due to drop in groundwater level. By maintaining the well temperature between 10ºC to 12ºC, COP of the system remained around 5 and did not decrease with the operation time.

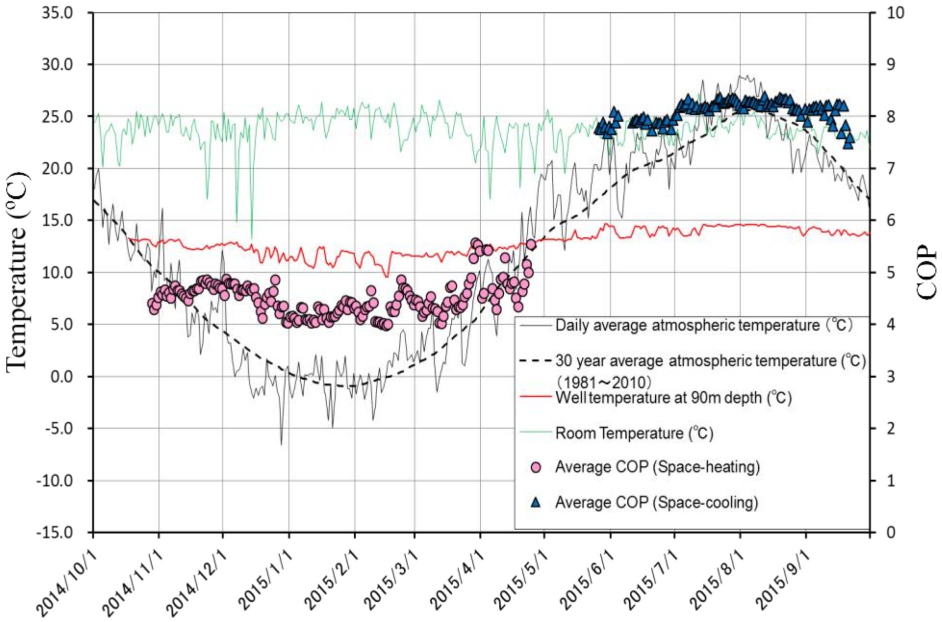

Fig. 5 COP of GSHP system

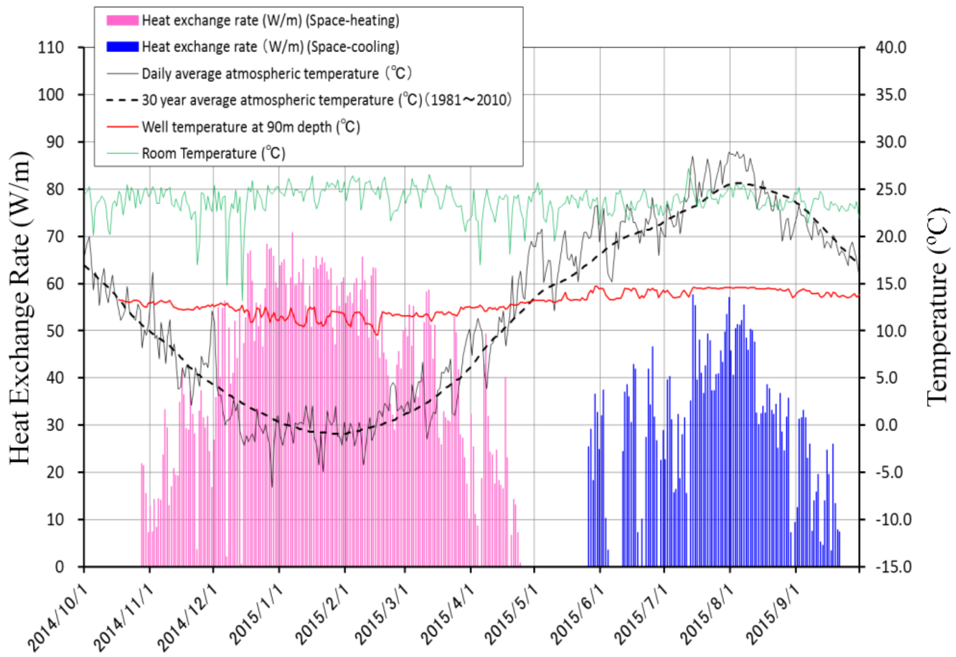

Fig. 6 Heat exchange rate of GSHP system

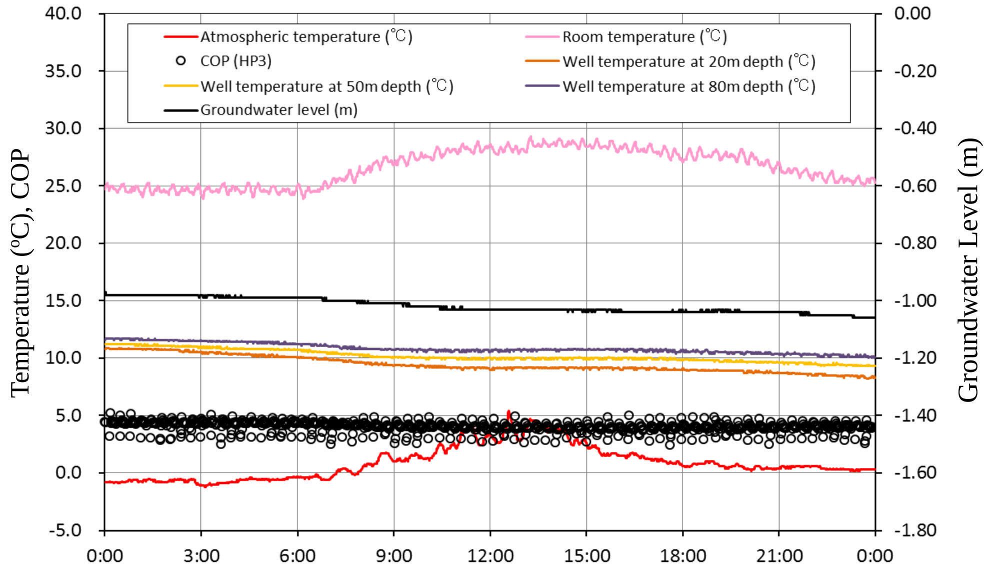

Fig. 7 Space-heating operation results on 2015/3/12

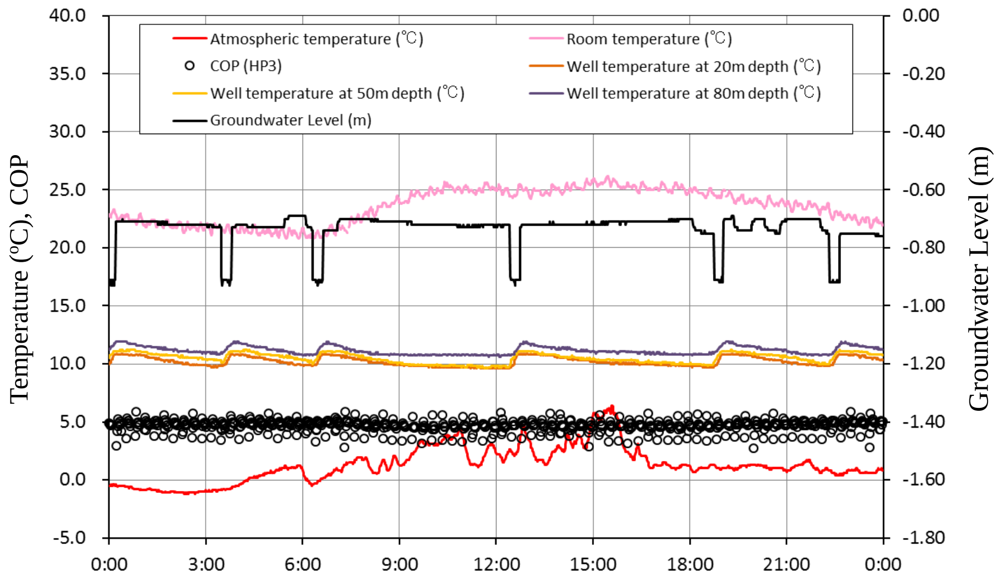

Fig. 8 Space-heating operation results on 2015/3/24

5.2 SPACE COOLING OPERATION

Fig. 9 shows the space-cooling operation results for 1 week from 2015/8/4 to 2015/8/10. COP ranged from 4.8 to 12 with the average value of 8.6. In fig. 10, operation results on 2015/8/5 is shown. On this day, electric valve was regulated for 8 times. Average COP on this day was also 8.6. By maintaining the well temperature between 14ºC to 16ºC, COP of the GSHP system did not decrease with the operation time.

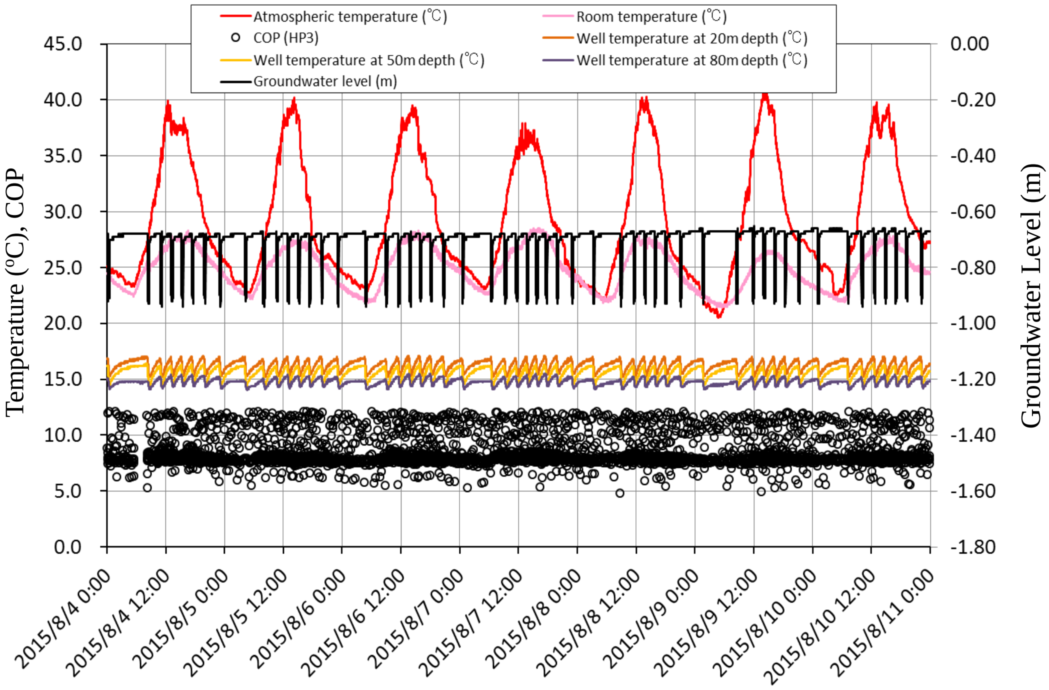

Fig. 9 Space-cooling operation results from 2015/8/4 to 2015/8/11

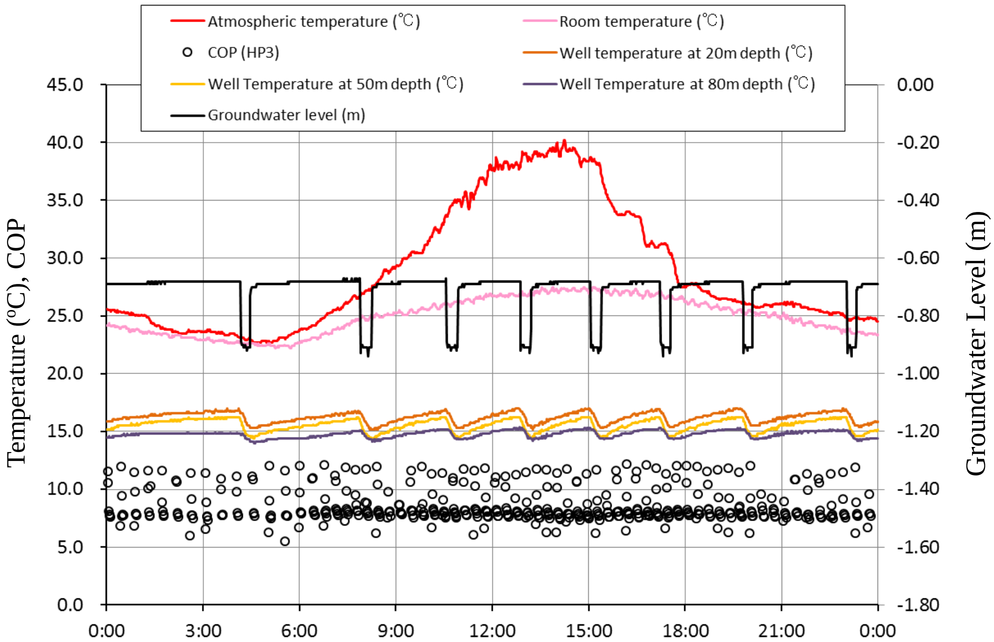

Fig. 10 Space-cooling operation results on 2015/8/5

From these operation results, it can be said that the GSHP system utilizing flowing well as GHE can demonstrate higher performance. This system's capability for space-heating and space-cooling operations is higher compared to the conventional closed loop GSHP system and air-source heat pump (air conditioning) system. This kind of high efficient system can be expected to lead to conservation of energy and reduction in cost, as well as it can assist in the promotion of GSHP system in Japan.

It was also determined that although by controlling the discharge of groundwater from the flowing well through automatic regulation of electric valve, higher COP of the GSHP system can be maintained. Therefore, higher system performance and conservation of groundwater at the same time can be achieved by this kind of operation pattern.

6. CONCLUSION

GSHP system was developed using a flowing well as GHE. Flowing well of 250 mm diameter and 100 m depth was drilled with slit screens at the intervals of 61.45 m - 83.45 m and 88.95 m - 99.95m. 3 sets of 100 m double U-tube with 34 mm external diameter were installed and connected to 3 heat pumps of 10 kW capacity respectively. Performance of the system was evaluated for space-heating and space-cooling of the 1 storey office building with the room area of 126.7 sq. m. Groundwater discharge from the flowing well was controlled by an electric valve to manage groundwater preventing its unnecessary usage.

Average COP of the system for space-heating was 4.5 and space-cooling was 8.1. Maximum heat exchange rate for space-heating was 70.8 W/m and 57.6 W/m for space-cooling. Performance of the system was higher compared to conventional closed loop GSHP system and air-source heat pump system. It is expected that this kind of system can contribute to conservation of energy and reduction in cost.

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