

# Long-Term Heating Test Using the Semi-open Loop Ground Source Heat Pump System

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## ABSTRACT

In the Ground Source Heat Pump (GSHP) System, it is important to improve the heat exchange rate of ground heat exchangers (GHE) and reduce the initial cost. The Semi-open Loop GSHPs which is proposed in this study, improves the heat exchange capacity by pumping groundwater from one GHE into other one and to generating artificial groundwater flow. In this research, a Semi-open Loop GSHP system was installed in Akita City, Japan to carry out field tests and certify its efficiency.

This system comprises two ungrouted GHEs of 60 m depth with 5m distance. The pumping and injection of groundwater is done using a water pump connected to pipes to the depth of 15 m of the GHEs. The heating room is approximately 90 m<sup>2</sup> and heated by 3 fan coil units which are connected to a 10 kW heat pump. The pumping and injection rate of groundwater was set as 0 (base case), 5 and 15 L/min and heating tests were performed for 7 days at each condition.

The heating test in the base case with a pumping rate of 15 L/min showed that the COP (Coefficient of Performance) and SCOP (System COP) were improved by 8.3% and 3.5%, respectively. In addition, in the same case, average outlet water temperature of GHE was 5.5 °C higher than the base case. From these results, the Semi-open Loop GSHP system is expected to improve operational performance and reduce the initial cost.

## 1. INTRODUCTION

In recent years, the installations of GSHP system are expanding mainly in North American, Europe and China. In 2015, the number of installed units increased by 51% comparing to 2010 (Lund and Boyd, 2015). In Japan, the installation of GSHP system including open-loop and closed-loop system was increased since 2010 and the total number of facilities was 2,230 in end of 2015 (MOE, 2016). GSHP system has a low environmental impact and high energy saving effects. However, because of its high initial cost, it has lower cost advantage compared to conventional heating and cooling systems (e.g. air source heat pump, boiler using fossil energy, etc.). Thus, it is important to reduce the initial cost by increasing the heat exchange capacity of GHEs for further dissemination of the GSHP system.

In general, the heat exchange capacity of grouted borehole GHEs is dominated by the thermal conductivity of the soil and grouting material. On the other hand, in ungrouted GHEs, effective thermal conductivity will be higher than grouted GHEs due to the heat advection caused by groundwater flow.

Fujii et al. (2005) modeled a 3D single well finite element simulator and validated it using the results of thermal response test (TRT). In the results of 5 days tests under different groundwater velocities, showed that heat exchange rates were increased in Pecret number of larger than 0.1 (due to groundwater flows). Wang et al. (2009) conducted a thermal performance experiment of a BHE under groundwater flow, and estimated the characteristics of groundwater flow using a simplified theoretical model. They reported that; due to the strong groundwater advection effect, the heat injection and heat extraction of the BHE were enhanced on average by 9.8% and 12.9%, respectively, compared with the case without the groundwater flow. Huber and Arslan (2015) performed laboratory, field tests and numerical extrapolation to investigate the increment of the effective thermal conductivity of water saturated sediments in dependence of the groundwater flow velocity. They reported that there is an exponential correlation between the increase of the effective thermal conductivity of water-saturated sands and the groundwater flow velocity, and for water-saturated strongly aquiferous (0.6 m/d - 1.0 m/d) sand, an increase of the effective thermal conductivity up to 100% can be expected.

From these researches, the improvement of heat exchange capacity was clarified due to the presence of the underground water flow. However, the heat advection effect is very small in absence or very low groundwater flow. Therefore, our research investigated the improvement of the heat exchange capacity by using the Semi-open Loop GSHP system in cooling and heating tests. This system includes two ungrouted GHEs that are intended to improve the heat exchange capacity by generating the artificial groundwater flow by pumping groundwater from one of GHE to another one. In previous research, sensitivity analysis and numerical simulation were carried out for heating tests in an installed system in Akita University, Japan. In the heating tests, improvement of COP remind constant at approximately 5% due to the influence of groundwater flow in the test site. However, in numerical study, COP and SCOP could be improved by 40% and 20%, respectively, in the absence of groundwater flow (Farabi et al. 2017). Furthermore, sensitivity study and economic analysis were carried out for this system during the cooling test. In the cooling test, COP was improved by maximum of 8%; however, by numerical study, COP and SCOP in the absence groundwater flow could be estimated to be improved by 101% and 62 %, respectively. Also, when

operating the Semi-open GSHP System for 20 years, indications are that the reduction the costs can be expected by 22 to 36% compared with the conventional GSHP system (Farabi et al. 2018).

In this paper, we will report the results of the field tests of this site in Akita University, which is different from the previous report into the versatility of the Semi-open Loop GSHP system in the different geological structure and groundwater level.

## 2. OVERVIEW OF SEMI-OPEN LOOP SYSTEM

The Semi-open loop GSHP system was constructed in Akita University campus, Japan that was placed 260 m away in a southwest direction from the previous site. The two ungrouted vertical GHEs with depth of 60 m, were drilled at interval of 5 m and the double U-tube inserted to each GHE. Figure 1 and Figure 2 show the geological column of site and the casing of each GHE, respectively. The formation from surface to -50 m is an alluvial deposit of the Quaternary System, consisting of sand, silt and gravel, while the formation below -50 m is mudstone of the Tertiary System. Since the aquifer was estimated to be a depth of around -48m from the surface, the screen pipe was installed between -43.5 m and -49.4 m, and a steel casing pipe was installed in the other parts.

The schematic of the Semi-open loop system and its main components are shown in Figure 3 and Table 1, respectively. The tubes from each GHE were parallel connected to the heat pump and the heat pump heated the test room using 3 FCUs (fan coil unit) with a total output of approximately 30 kW. For pumping and injection of groundwater, polyethylene tubes were inserted into each GHE at the depth of -15 m and connected to a pump installed on the ground. Table 2 shows a list of measured data. The data from each sensor was recorded by data acquisition system on a memory card. And also, water level sensors which are battery supplied, were installed into each GHE to observe the variation of groundwater level for a long time.

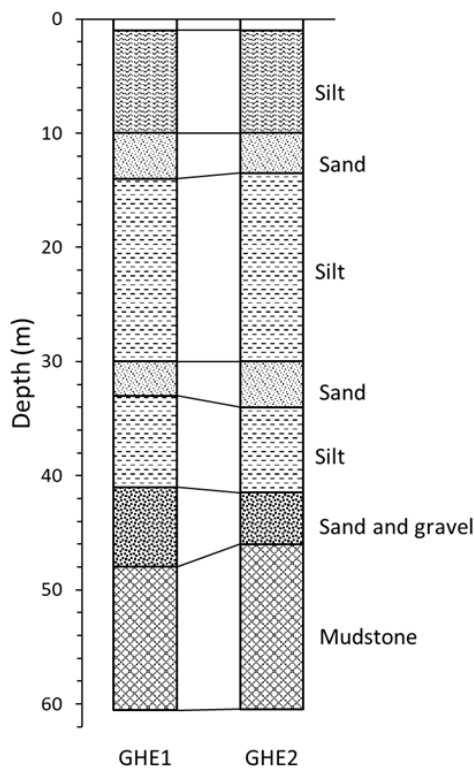


Figure 1: Geological column of test site.

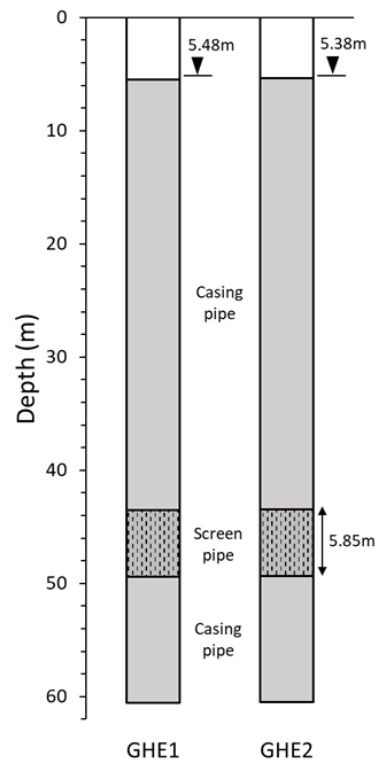


Figure 2: Casing program of the GHEs.

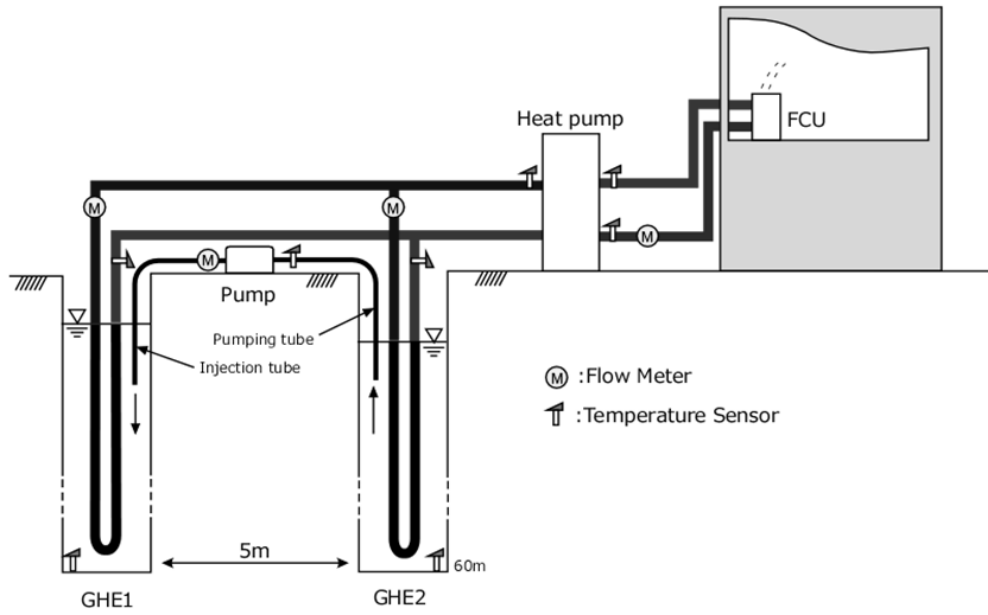


Figure 3: Schematic of the Semi-open Loop GSHP system.

Table 2: Main components of Semi-open Loop GSHP System.

Equipment	Manufacture	Model	Note
Heat pump	SUNPOT	GSHP-1001	10 kW output
Fan coil units	MITSUBISHI	LV-1200WFE-C2 LV-400WFE-C2 x2	30 kW total heating capacity
Pump, and inj. pump	EBARA	20HPA5.12S	125 W output
Data acquisition system	YOKOGAWA	MW100	
Flow meters	KEYENCE	FD-MH50A	
Power meters	M-SYSTEM	LTWTN	
Temperature sensors	CHINO	R040-31	Pt100

Table 2: List of measured data.

<b>Temperature</b>	Heat pump primary outlet GHE1 and GHE2 outlet Heat pump secondary outlet and inlet Pumping and injection water Bottom of GHE1 and GHE2
<b>Flow rate</b>	GHE1 and GHE2 Heat pump secondary
<b>Power consumption</b>	Heat pump Pumping and injection pump

### 3. RESULTS OF THERMAL RESPONSE TEST

After installing the Semi-open Loop GSHP system, thermal response tests (TRTs) were carried out to obtain the performance of the GHEs. The conditions of the TRTs are shown in Table 3. The equipment used for these TRTs was built of Akita University, with a maximum heat load of 6 kW. It has an automatic heat load control function to avoid the variation of heat load of GHE due to the variation of power-supply voltage (Kosukegawa et al., 2015).

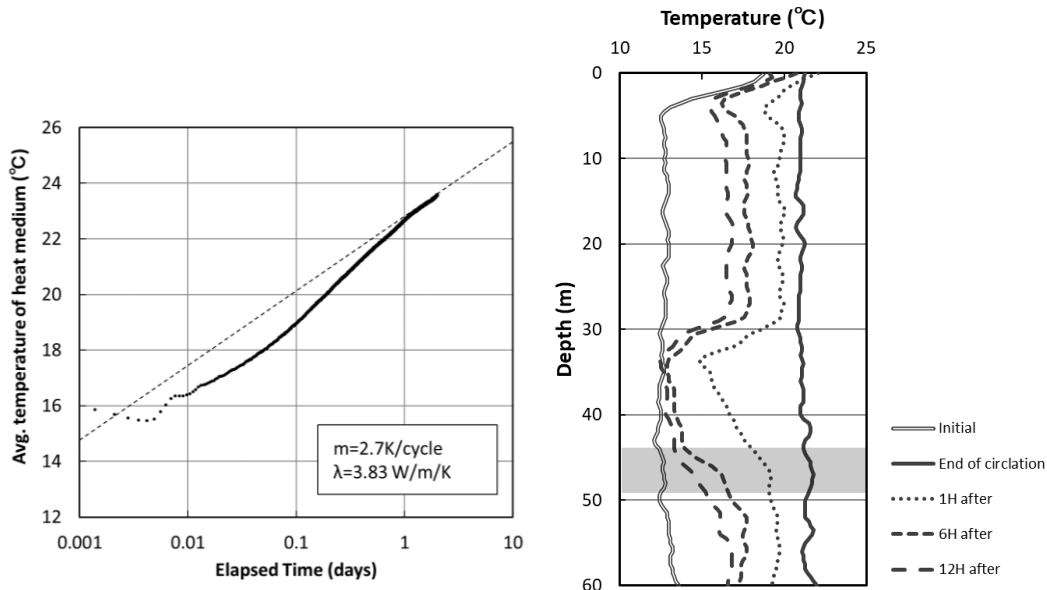
**Table 3: Conditions of the TRTs.**

Test Name	Well	Heat Load	Flow Rate	Pumping Rate	Test Period
TRT1-3	GHE1	3 kW	20 L/min	-	48 Hours
TRT2-3	GHE2	3 kW	20 L/min	-	48 Hours
TRT1-6	GHE1	6 kW	20 L/min	-	72 Hours
TRT1-6P	GHE1	6 kW	20 L/min	10 L/min	72 Hours

#### 3.1 Normal TRT

At first, normal TRTs were carried out for each GHE using a 3 kW heat load and for a 48 hours test period (test name of TRT1-3 and TRT2-3). Also, the recovery of soil temperature from the end of the heating period was measured using an optical fiber temperature sensor, which was inserted into the return pipe of the U-tube.

Figure 4 and Figure 5 show an analytical result of the TRT and measured vertical temperatures of GHE1 and GHE2, respectively. From these results, the thermal conductivity of each GHEs were estimated of 3.83 and 5.64 W/m/K, which are higher than the thermal conductivity without groundwater flow (generally, 1.2-1.5 W/m/K). Furthermore, in the vertical temperature transition, fast temperature recovery in a wide range was confirmed from a screen pipe section (shaded part in the figure) to the upper part. It is considered that the cross flow occurred between the upper and lower aquifer between the casing pipe and the soil.



**Figure 4: Analysis result of the TRT and measured vertical temperature (GHE1).**

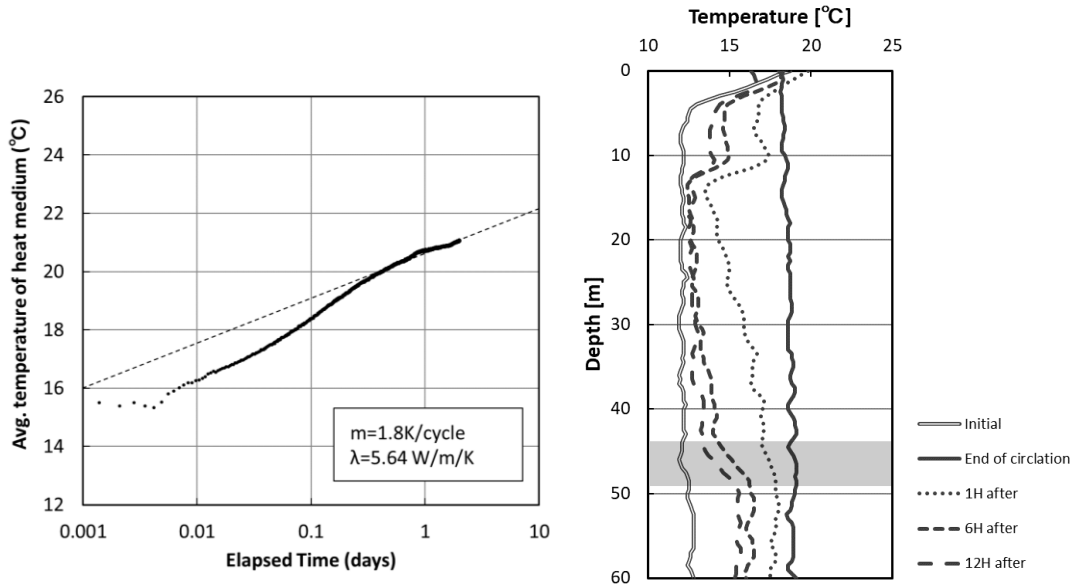


Figure 5: Analysis result of the TRT and measured vertical temperature (GHE2).

### 3.2 TRT with pumping groundwater

Afterward, TRTs with pumping groundwater presence were carried out for GHE1 using a heat load of 6 kW, pumping rate of 10 L/min and a test period of 72 hours (test name of TRT1-6 and TRT1-6P). The equation for calculating COP (equation 1) was derived from the performance curve of the heat pump SUNPOT GSHP-1001.

$$COP_C = -0.23 \times T_{out} + 14.02 \tag{1}$$

In this equation,  $T_{out}$  is the output temperature of GHE. Comparison of the average heat medium temperature and calculated COP in the case of pumping and without pumping are shown in Figure 6 and Figure 7, respectively. In Figure 7, average heat medium temperature, without pumping, is continuously increased, on the other hand, temperature increase was suppressed of around 20 °C with pumping. In comparison this data by an average value of 24 hours to 72 hours, increases of the average heat medium temperature was able to suppress at 10.3 °C. Similarly, in comparison of calculated COP using data from outlet temperature of GHE, COP was increased from 7.3 to 9.2 by pumping groundwater, resulting in a 26% improvement.

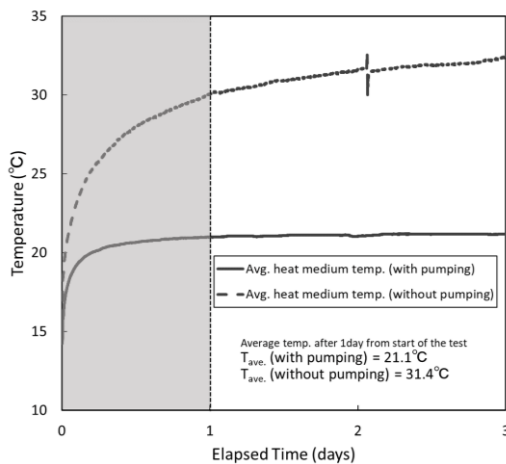


Figure 6: Comparison of average heat medium temperature.

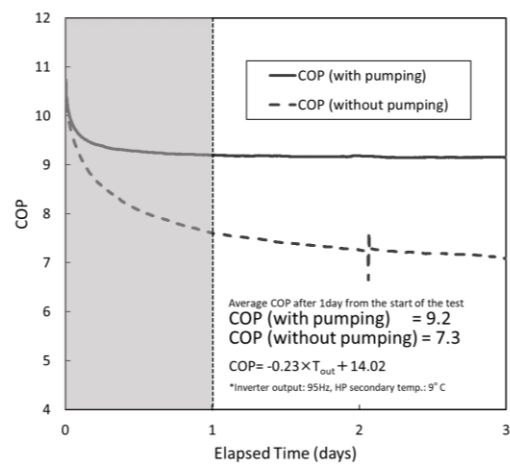


Figure 7: Comparison of calculated COP.

**4. LONG TERM HEATING TEST**

Table 4 shows the condition of a long term heating test. In order to give a larger heat load to GHEs, secondary outlet water temperature of the heat pump was set to 50 °C (maximum temperature) and the output of FCU fan speed was set to maximum. Also, in order to equalize the temperature of the test room, air was circulated by fans that were installed on the ceiling of the test room. Pumping and injection rate was set to 0, 5 and 15 L/min, and the test period was continued for 7 days for each pumping and injection rate. The pumping and injection rate was controlled by the output of pump using an inverter unit, however, in test of Run-5, the flow control valve was used in combination with an inverter unit because it was not possible to control when only using an inverter unit.

**Figure 4: Conditions of each heating test.**

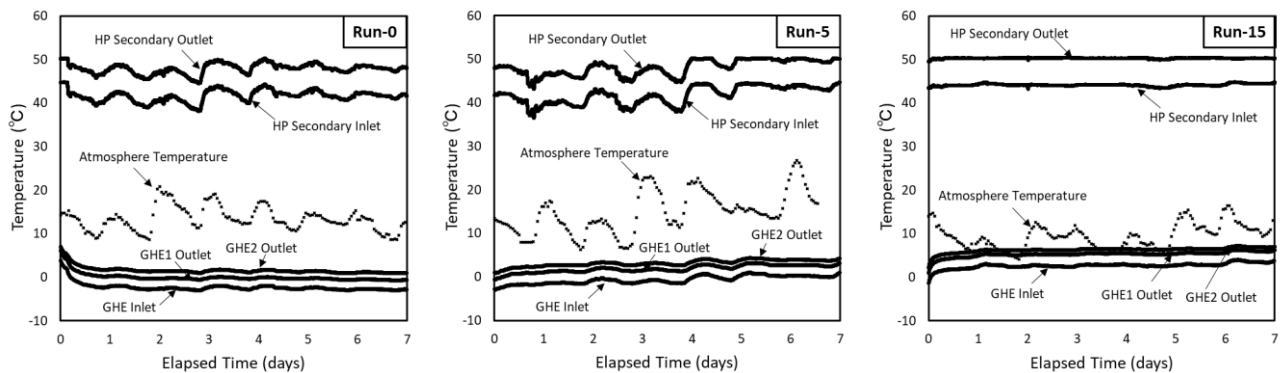
Test Name	Duration	Pump. And Inj. Rate	HP secondary outlet temperature	FCU fan speed
Run-0 (base case)	Apr.18 2018 - Apr.25 2018	0 L/min	50	maximum
Run-5	Apr.25 2018 - May.2 2018	5 L/min		
Run-15	Apr.11 2018 - Apr.18 2018	15 L/min		

**4.1 Influence of the nearby pumping well**

Heating operation was started from Jan.10 2018. However, the test by pumping and injecting of groundwater was began from Apr.11 2018. The reason for this is because groundwater level decreased to -10 m or less due to an influence of nearby pumping wells and we could not pump the groundwater. Two pumping wells exist in sites of 80 m and 112 m away in the northwest of the test site and supply 400 L/min groundwater to snow melting system when the outside temperature is -1 °C or less or during snowfall. The pump for pumping groundwater used in this system cannot pump groundwater with a water level below -8 m physically. Improvement of SCOP can be expected when using a ground pump because power consumption is lower than the submersible pump; however, when the Semi-open GSHP system is installed in the soil of lower groundwater level, investigation into the introduction of a submersible pump is necessary.

**4.2 The effect of heat exchange capacity by pumping and injection groundwater**

Figure 8 shows the temperature data of each test conditions. From these results, in the test of Run-15, stable operation was achieved despite the low outside temperature because the outlet temperature of the secondary side of the heat pump was stable at almost 50 °C and also GHE outlet temperature was maintained higher than in the another case.



**Figure 8: Temperature data of each test conditions.**

Next, comparison of COP and SCOP of each tests are shown in Figure 9. As mentioned above, in the test of Run-5, since power consumption of the pump increased because the flow rate that was controlled using the inverter and valve, power consumption of the pump was simply set to 1/3 of in test of Run-15. Comparing these results, COP increased by 8.3% in the test of Run-15, however SCOP increased by only 3.5%. The reason of this was that high apparent thermal conductivity was acknowledged from the TRT results and the large daily outside temperature fluctuation during the test period.

Figure 10 shows the transition of GHE outlet temperature in each test case. The average of the GHE outlet temperature after the second day from the beginning increased due to the pumping and injection rate increment and was 5.6 °C higher than the base case in the test Run-15. Also, as a result of comparing the calculated COP using these average GHE outlet temperatures and the equation that derived from the performance curve of the heat pump SUNPOT GSHP-1001 (Equation 2), COP was improve by 14% in the case of 15 L/min pumping and injection. From the result of this calculation, COP can be expected to improve due to the operating condition of the Semi-open Loop GSHP system.

$$COP_H = 0.0917 \times T_{out} + 3.2065 \tag{2}$$

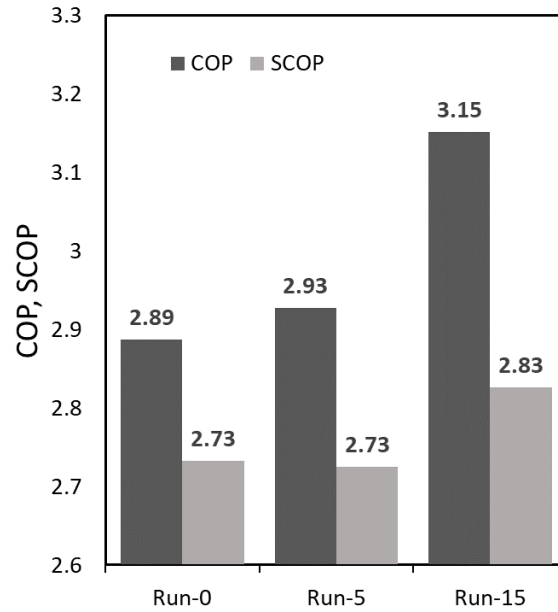
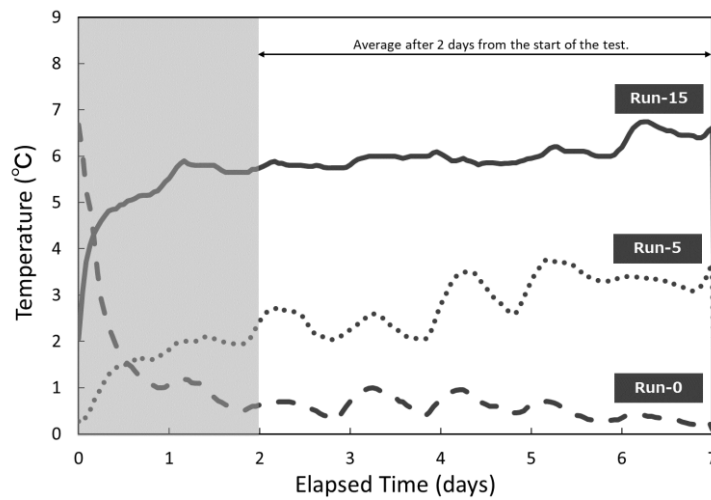


Figure 9: Comparison of COP and SCOP of each tests.



	Average Temp.	Average COP
Run-0	0.5	3.25
Run-5	2.9	3.47
Run-15	6.1	3.77

Figure 10: Transition of GHE outlet temperature.

From the results of long term heating test, the heat exchange capacity was improved by artificial groundwater flow caused by pumping and injection of the groundwater. However, the effect of improving the heat exchange capacity was low because there is a high groundwater flow in this test site. Significant improvement of heat exchange capacity can be expected by installing Semi-open GSHP system where there is no advection effect and very low groundwater flow.

## 6. CONCLUSION

In this paper, we carried out the field tests to verify the versatility of Semi-open loop GSHP system in different geological structures and groundwater levels than the previous report by Farabi et al. (2017, 2018).

Although COP increased by 8.3% in the case of 15 L/min (pumping and injection in long term heating test), SCOP increased only 3.5%. However, stable operation was achieved despite the outside temperature being lower than other cases during the test period because the secondary outlet temperature of a heat pump was almost stabilized as 50 °C and the outlet temperature of GHE was 5 °C higher than in base case. Also, a ground pump used in this system could not pump groundwater because the groundwater level was decreased due to the existence of other pumping wells for snow melting purposes. Therefore, when installed in a soil with low groundwater level, it is necessary to consider selecting a submersible pump.

The effect of the improvement in heat exchange capacity in this study was small because of fast groundwater existing in this area. However, it can be expected that the installation costs can be reduced and SCOP will significantly be improved by installing this system in very slow groundwater flow areas.

## ACKNOWLEDGEMENTS

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