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Research Paper

Heat exchanger performance of ground source heat pump by water cooling method

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ABSTRACT

A ground source heat pump (GSHP) is one of the saving energy systems for air conditioning. However, the GSHP is not so popular in Japan because its initial cost is higher than an air source heat pump. This study describes the thermal performance of the GSHP using a water cooling method. An experimental apparatus consists of a commercialized water cooling heat pump, an underground heat exchanger, and existing wells. Heat from a refrigerant in an outdoor unit will be transferred to the circulating water, and finally, the heat will be transferred to an underground water by an underground heat exchanger. There is aquifer at over 6 m depth. This system uses the existing two wells. The depth of the wells are 40 and 30 m. The underground heat exchanger was inserted into the well having 40 m depth. A water pump was inserted into the well having 30 m depth. Water feeds to 38 m depth of the underground heat exchanger by the water pump. This pump is used to recover the temperature of underground by feeding water. In this study, a value of coefficient of performance (COP) of the proposed system was obtained. The value of COP of the cooling operation was 3.1~3.3 and that of the heating operation was 2.5~2.6.

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Key words: Ground source heat pump, coefficient of performance, water cooling indirect method.

INTRODUCTION

A ground source heat as renewable energy is useful to energy saving system. By an influence of geothermal energy and solar thermal energy, the temperature of an underground with 10 to 100 m depth is constant throughout the year. Therefore, the ground source heat can be used in an air conditioning, underfloor heating, and hot water heating. A heat pump is important as the one of application system which uses ground source heat. The conventional ground source heat pump uses a closed loop and a vertical borehole system. In general, a performance of the heat pump system is evaluated and discussed by coefficient of performance. The ground source heat pump system is one of the saving energy systems for air conditioning. It also reduces the emission of carbon dioxide and prevents heat island phenomenon. The ground source heat pump system is already popular (http://www.gshp.org.uk/index.html) in U.S., Europe, and China; however, it is yet to be known in Japan (Nagano, 2012; Ohashi et al., 2013). This is because the initial cost of the ground source heat pump is more expensive than the air source heat pump. The primary reason is that the cost of digging of borehole is high in Japan. The depth of borehole is typically 100 to 150 m. If the depth of borehole is shallow, the initial cost of the ground source heat pump system will be reduced. This study describes the experimental result obtained by the proposed ground source heat pump system using existing wells as the borehole (Endo et al., 2016). It also describes the initial cost of the proposed ground source heat pump system which is

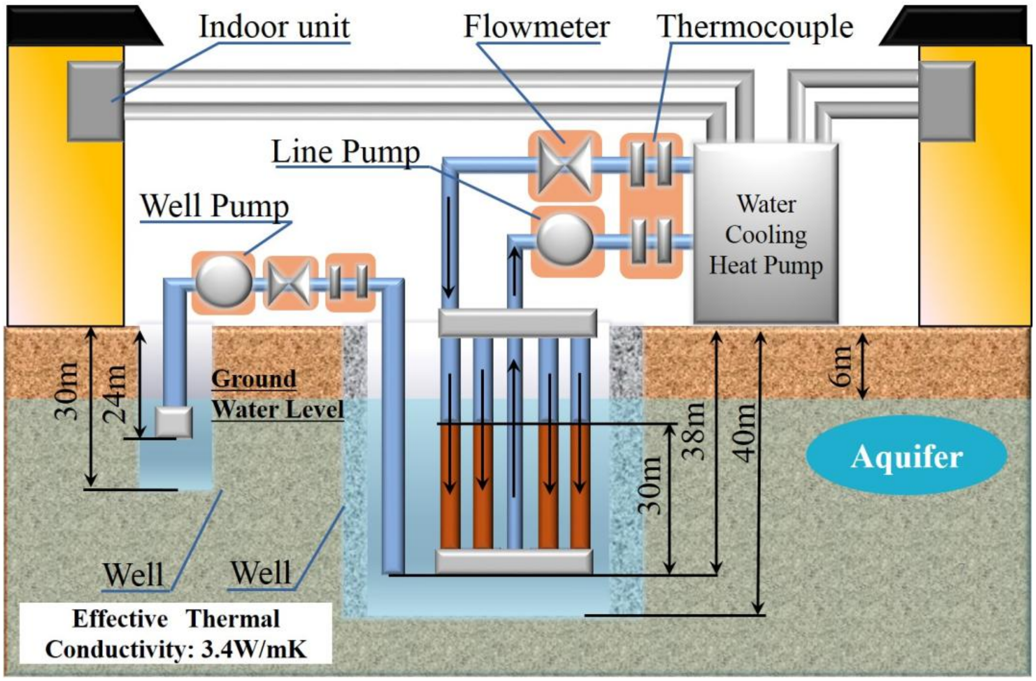


Figure 1: Schematic drawing of experimental apparatus.

lower than that of the conventional system.

EXPERIMENTAL APPARATUS

Figure 1 shows the schematic drawing of an experimental apparatus. The apparatus consists of a commercialized water cooling heat pump, an underground heat exchanger, and existing wells. An output power of the heat pump is 22.4 kW for the cooling operation and is 25kW for the heating operation. Heat from a refrigerant in an outdoor unit will be transferred to the circulating water, and finally, the heat will be transferred to an underground water by an underground heat exchanger. There is aquifer at over 6 m depth. The water is circulated by a line pump, and the flow rate is controlled by an inverter system.

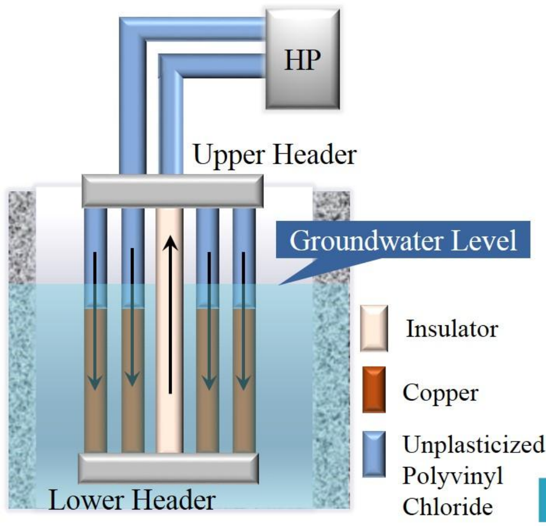
This system uses the existing two wells. The depth of the wells are 40 m and 30 m. A casing pipe, which a part of the surface was made like slit, was inserted into the well. The nominal diameter of casing pipe is 50A. The underground heat exchanger was inserted into the casing pipe having 40 m depth as shown in Figure 1. The space between the casing pipe and the borehole was filled with silica sand. A water pump was inserted into the well having 30 m depth. The power of the water pump was 0.25 kW. The water feeds to 38 m depth of the underground heat exchanger by the water pump. This pump was used to recover the temperature of underground by feeding water. The water pump operates when the temperature of borehole at 38 m point is lower than the set temperature. The air conditioning area was 20 and 24 m^2. The cooling and heating power of the indoor unit was 5.6 and 6.3 kW, respectively.

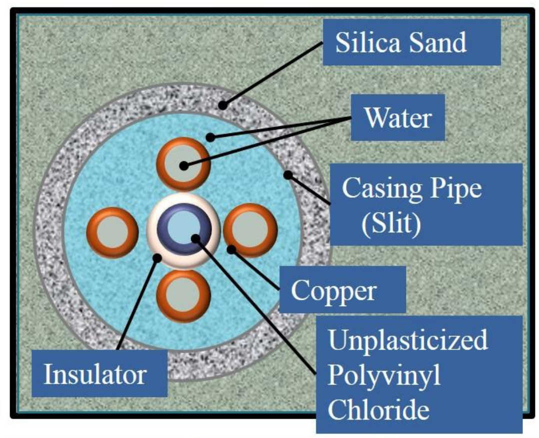
Figure 2 shows a sectional view of the underground heat exchanger. The heat exchanger consists of four copper pipes and one insulated copper pipe. The water flows from the top header to the bottom header through the four pipes. Thereafter, the water flows from the bottom header to the line pump through a single pipe. The four pipes were made of copper and unplasticized polyvinyl chloride. Also, the pipes were made of unplasticized polyvinyl chloride from the top header to the first 10 m depth. Then, the pipes were made of copper from 10 m to the bottom header. This is because there is no aquifer from the ground to 6 m depth. The length of the underground heat exchanger was 38 m. Thus, the effective length of heat exchange bacame 32 m. The inner diameter of copper and unplasticized polyvinyl chloride pipes was 21.6 and 41.6 mm, respectively. The centre copper pipe was wrapped by insulator in order to prevent heat loss.

PERFORMANCE OF GROUND SOURCE HEAT PUMP

Cooling operation

The coefficient of performance (COP) was obtained by Equation (1):





	Inner diameter	Outer diameter
Copper	21.6 mm	27.2 mm
U. Polyvinyl C.	41.6 mm	48.6 mm
Casing pipe	204.7 mm	216.3 m

Figure 2: Sectional view of underground heat exchanger.

Table 1: Experimental condition and result.

Items	Date		
	August 14,2015	August 23, 2015	August 19, 2015
Set temperature of the indoor units [°C]	20	27	27
Pouring ground water	Yes	Yes	No
Amount of pouring water[L]	1.3×10^4	8.3×10^3	0
Maximal heat gain[kW]	24.3	23.3	23.6
Average heat gain[kW]	21.2	15.7	16.8
COP	3.3	3.1	3.2

$$COP = \frac{Heat\ gain}{Power\ consumption} = \frac{\rho c q |t_{out} - t_{in}|}{W} \quad (1)$$

Here, ρ is the density of water, q is the flow rate of the line pump, c is the specific heat, t_{in} is the inlet temperature of the heat pump, t_{out} is the outlet temperature of the heat pump, and W is the electric power consumption of the compressor and the line pump. The value of the system COP was obtained by averaging the instantaneous value at every minute.

The heat pump was operated from 9:00 to 18:00 (9 h). Table 1 shows a set temperature of the indoor unit, condition of pouring ground water, and experimental results. Figures 3, 4 and 5 show the temperature of the borehole, the temperature of the inlet and outlet of the heat pump, the heat gain, and the electric power consumption. In the case of pouring ground water into the well, the value of COP on August 14 and August 23 was almost the same even if the set temperatures of the indoor units were different due to the temperature of the borehole recovered by pouring ground water. Temperature of the pouring water was 12~13°C. Then, the temperature of the borehole at 20 m depth and the outlet temperature of the heat pump increased to 27 and 35°C, respectively. The value of COP was not affected by changing the set temperature of the indoor unit. However, if the set temperature is changed to low temperature, the amount of pouring water will increase. Therefore, the value of the system COP will decrease if the amount of pouring water increases. The power consumption of the well pump is much smaller than that of

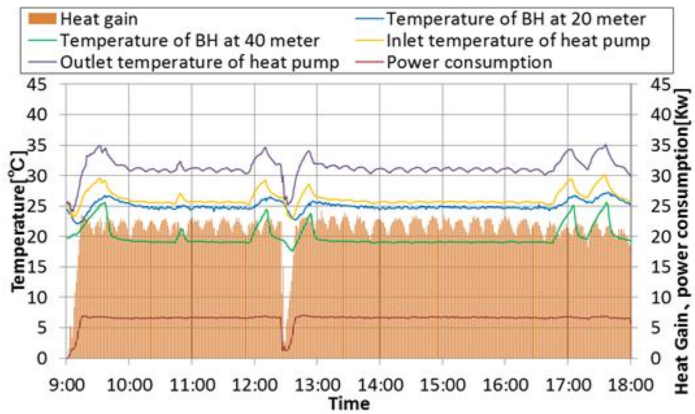


Figure 3: Temperature of borehole, temperature of inlet and outlet of heat pump, heat gain, and electric power consumption(August 14, 2015).

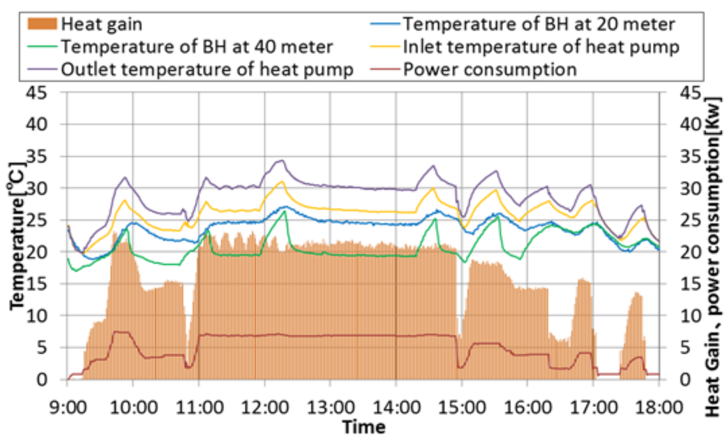


Figure 4: Temperature of borehole, temperature of inlet and outlet of heat pump, heat gain, and electric power consumption (August 19, 2015).

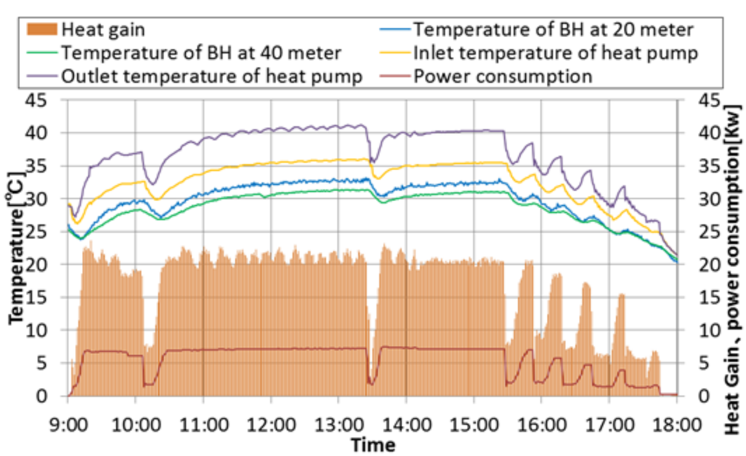


Figure 5: Temperature of borehole, temperature of inlet and outlet of heat pump, heat gain, and electric power consumption (August 23, 2015).

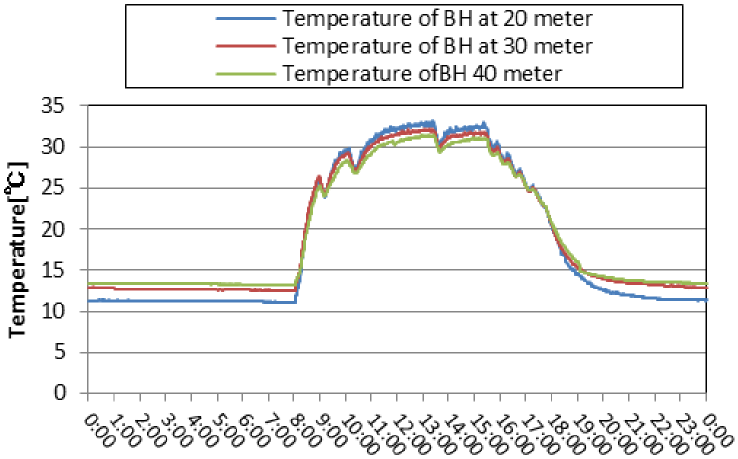


Figure 6: Temperature of borehole at 20, 30, and 40 m depth (August 19, 2015).

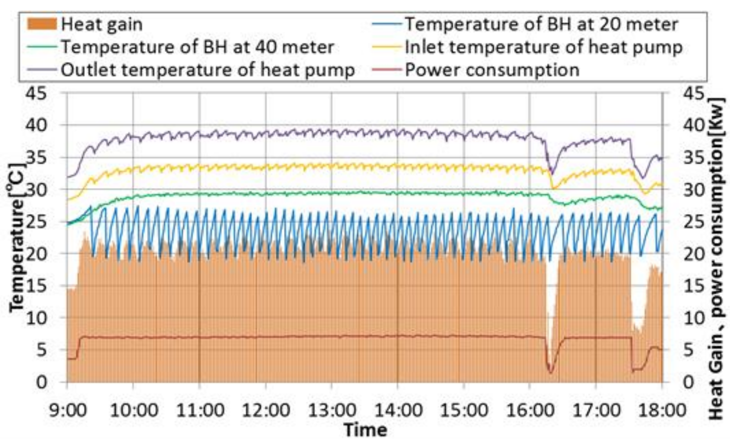


Figure 7: Results that injecting point of ground water was changed from 38 m to 20 m depth(July 13, 2015)

the compressor and the line pump. Thus, the power consumption of the well pump can be negligible to obtain the value of the system COP. If the ground water can be used to keep the borehole temperature, the length of borehole can also be shortened.

In the case of not pouring ground water into the well, the value of COP on August 19 was almost the same as on August 23. The temperature of the borehole at 20 m depth and the outlet temperature of the heat pump increased to 33 and 41°C.

Figure 6 shows the temperature change at the various depth of the borehole on August 14. The temperatures of the borehole at 20, 30 and 40 m depth were 11, 13 and 14°C, respectively before the heat pump was operated. After the heat pump stopped, the temperature of the borehole at 20, 30 and 40 m depth decreased. After 6 h, the temperature of the borehole decreased to 11, 13, and 13°C, respectively. The ground source heat pump can operate without pouring ground water into the borehole in the cooling mode.

The injecting point of the ground water was changed from 38 m to 20 m depth, the results are shown in Figure 7. The set temperature of the indoor units was 27°C and the value of COP was 3.2. The temperature of the borehole at 20 m depth fluctuated up and down several times. On the other hand, the temperature of the borehole at 40 m depth was stable. The inlet and outlet temperature of the heat pump barely changed. The heat was transferred actively at the shallow part of the underground heat exchanger in the cooling mode. The value of COP was not so affected by the

Table 2: Experimental condition and result.

Items	Date		
	December 12, 2014	February 5, 2015	December 22,2015
Set temperature of the indoor units [°C]	20	20	28
Pouring ground water	No	Yes	Yes
Amount of pouring water[L]	0	2.7×10^3	1.1×10^4
Maximal heat gain[kW]	13	14.8	14.4
Average heat gain[kW]	7.1	9.8	9.7
COP		2.6	2.5

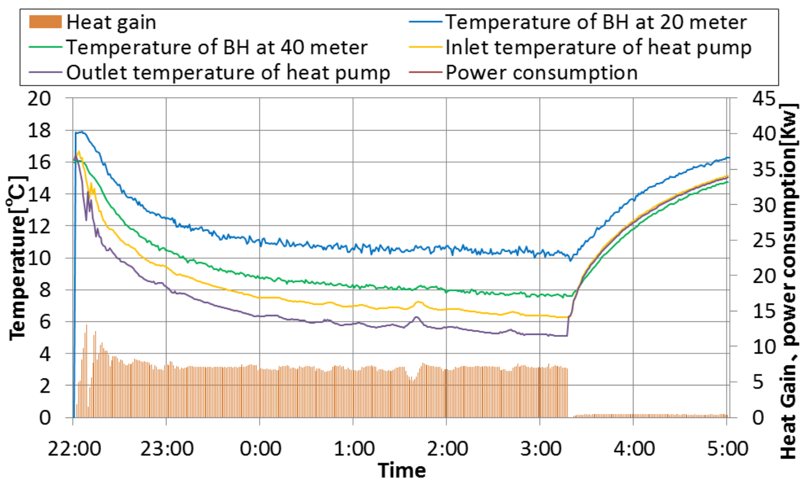


Figure 8: Temperature of borehole, temperature of inlet and outlet of heat pump, heat gain and electric power consumption(December 12, 2014).

injecting point of the ground water.

Heating operation

The heat pump was operated from 22:00 to 5:00 (7 h). Table 2 shows the set temperature of the indoor unit, condition of pouring ground water, and experimental results.

Figure 8, 9 and 10 show the temperature of the borehole, the temperature of the inlet and outlet of the heat pump, the heat gain and the electric power consumption. As shown in Figure 8, the operating time was about 5 h, 12 min. When the outlet temperature of the heat pump was lower than 5°C, the heat pump stopped to prevent the water in the heat exchanger from freezing. Thus, the ground source heat pump could not operate without pouring the ground water into the borehole. The value of COP on December 22 and February 5 were almost the same even if the set temperature of the indoor unit was different. The heat gain and the power consumption were also stable. The temperature of the pouring water was 17~18°C and thus, temperature of the borehole at 40 m depth was lower than that at 20 m depth.

The injecting point of the ground water was changed from 38 m to 20 m depth, the results are shown in Figure 11. The set temperature of the indoor units was 20°C and the value of COP was 2.7. The temperature of the borehole at 40 m depth fluctuated up and down several times. The temperature of the borehole at 20 m depth was stable. The inlet and outlet temperature of the heat pump barely changed. The heat was transferred actively at the deep part of the underground heat exchanger in the heating mode. The heat gain decreased with decreasing temperature of the borehole at 20 m depth. This is because the inlet and outlet temperature of the heat pump did not recover. When the water injecting point was 20 m depth of the borehole, the temperature of whole borehole cannot recover using the method of pouring ground water. Therefore, the heat pump could not exchange heat satisfyingly in this case.

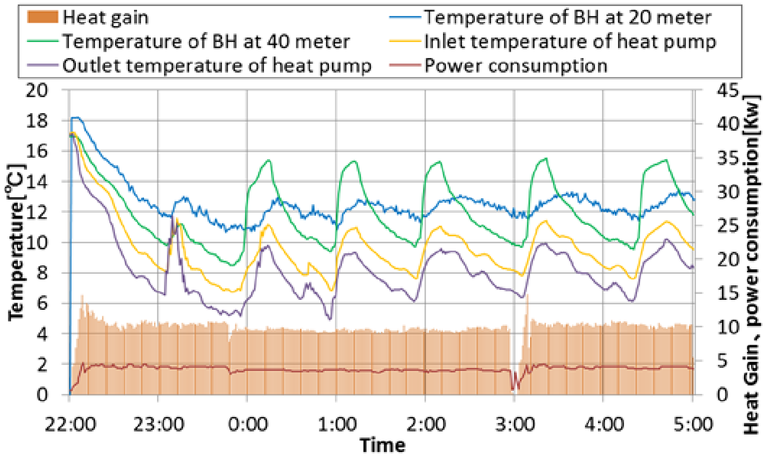


Figure 9: Temperature of borehole, temperature of inlet and outlet of heat pump, heat gain and electric power consumption(February 5, 2016).

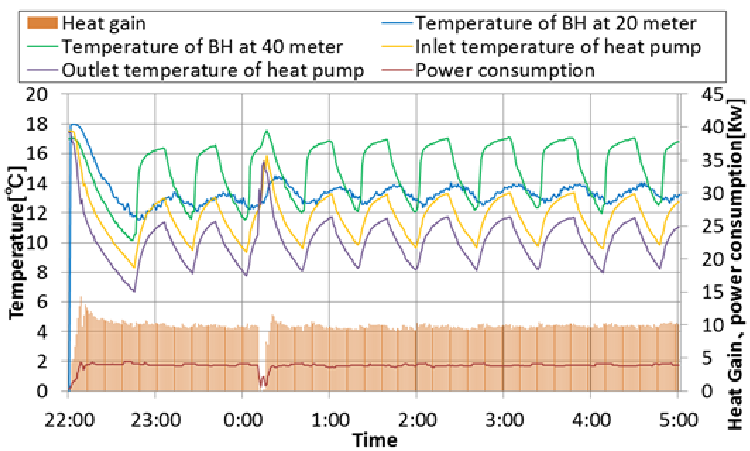


Figure 10: Temperature of borehole, temperature of inlet and outlet of heat pump, heat gain and electric power consumption(December 22, 2015).

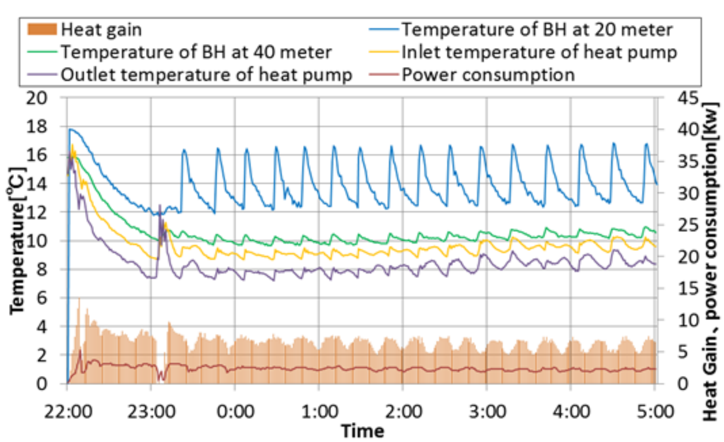


Figure 11: Results that injecting point of ground water was changed from 38 to 20 m depth (December 7, 2014).

From the results obtained in this experiment, it is possible to operate the ground source heat pump that use the water cooling method. However, when using the groundwater, consideration should be given to the drought of the groundwater and the ground subsidence. In addition to that, suppressing the power consumption of the well pump is greatly related to improvement of the value of system COP. Selection and control of the well pump will become important.

CONCLUSION

We conducted the experiment regarding heat exchanger performance of the ground source heat pump using the water cooling method. The experimental results can be summarized as follows.

1. The proposed ground source heat pump could operate without pouring ground water to the borehole in the cooling mode. The proposed ground source heat pump could not operate without pouring the ground water to the borehole in the heating mode.
2. The heat will transfer actively at the shallow part of the underground heat exchanger in the cooling mode. On the other hand, the heat will transfer actively at the deep part of the underground heat exchanger in the heating mode.
3. The average value of COP was 3.1~3.3 in the cooling mode and was 2.5~2.6 in the heating mode.
4. It is possible to operate the ground source heat pump that use the water cooling method. In addition to that, suppressing the power consumption of the well pump is greatly related to improvement of the value of system COP. However, when using the groundwater, consideration should be given to the drought of the groundwater and the ground subsidence. Selection and control of the well pump will become important.

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