

Article

Development of a Variable Water Flow Rate Control Method for the Circulation Pump in a Geothermal Heat Pump System

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Abstract: This study assessed a variable flow rate control method for a circulation pump based on the geothermal water temperature difference in a geothermal heat pump system. As interest in energy conservation and efficient use is increasing around the world, the development and use of renewable energy is increasing and various related studies are currently underway. Among the renewable energy systems, the interest in geothermal energy system is high because of its efficient year-round operation. Geothermal heat pump system installations have increased in number, but the systems operate inefficiently. Generally in Korea, geothermal heat pump system operates under partial load conditions, but the circulation pump operates at constant speed and supplies a constant flow rate. Therefore, this study examined the operation of the current problems of a geothermal heat pump system. A variable flow rate control method of the circulation pump is proposed to improve the efficiency of the geothermal heat pump system and save energy during the cooling operation. As a result, the total energy consumption was reduced by 57,017 kW compared to the existing flow rate control method and the energy consumption of the circulation pump system was reduced by 35,209 kW.

Keywords: renewable energy; geothermal heat pump system; COP (Coefficient of Performance); variable water flow rate control; circulation pump

1. Introduction

With the increasing interest in energy conservation and the efficient use of energy around the world, the need for the development and use of new and renewable energy sources has increased rapidly, and related research and applications have been actively conducted. Among the new and renewable energy sources, systems using geothermal sources are attracting considerable attention. This is because while there is a lack of continuity of heat sources for systems using other heat sources, a stable supply of heat and efficient operation throughout the year are possible if geothermal energy is used as a heat source. Although geothermal energy shows excellent efficiency as a heat source for cooling and heating, geothermal heat pump systems have mainly been installed in public buildings, and systems with low capacity have mostly been installed because of the high initial investment costs and difficulty in construction. On the other hand, since regulations on new and renewable energy installation institutions for public buildings were implemented in Korea in 2004, installations in non-public buildings and public institutions have also increased.

While the installation of geothermal heat pump systems is increasing, the systems are not being operated efficiently. This results in a waste of energy due to the inefficient utilization after the

installation of systems with more than the necessary capacity in conformity with the standards set forth in the relevant laws and regulations regarding the mandatory supply and installation. The geothermal heat pump system is generally responsible for a number of indoor units and is operated mostly under partial load conditions. On the other hand, most of the geothermal circulation pumps in geothermal heat pump systems are operated at a constant rate and a constant flow rate is supplied continuously, regardless of the load. As a result, the performance of the geothermal heat pump system is decreased. This paper proposes a variable water flow rate control method for a geothermal circulation pump to improve the efficiency of the geothermal heat pump system.

As the interest in geothermal heat pump systems has increased, various studies have been conducted on these systems [1–8]. Moreover, there have been several studies related to the cooling and heating performance evaluation of geothermal heat pump systems. Sohn [9] and Kwon [10] assumed that a geothermal heat pump system was installed in an actual commercial office building instead of a conventional heating and cooling system, and analyzed the cooling and heating performance of the geothermal system according to the time of the year through a simulation. They compared the actual energy consumption of the existing system and the estimated energy consumption of the geothermal system [9]. Nam conducted a system performance analysis through dynamic energy simulation of the heat pump system using solar and geothermal energy [10]. Hwang et al. [11] and Ozgener [12,13] conducted research to verify the feasibility of a hybrid system and the performance of the system through the experimental performance evaluation of the actual system.

In addition, various studies have been conducted to improve the performance of geothermal heat pump systems. Studies of the efficiency and optimal design of the geothermal heat exchanger, including studies by Park [14] and Lee [15], are being conducted. Park measured the changes in the ground temperature according to the burial depth for a geothermal heat pump system actually installed in a residential building, and analyzed the performance of the heat exchanger and cooling performance of the heat pump according to the ground temperature variation [14]. Lee derived the optimal design method through an analysis of the design load and the actual usage data of the geothermal system with the main focus on electricity consumption and heating and cooling energy consumption of the building studied [15].

Many studies have been conducted on the performance improvement of the heat pump system through integrated design with other heat source systems and complex operation in relation to the cause of the decrease in the efficiency of the geothermal heat pump system. In a study by Girard, a performance analysis was conducted by simulating a hybrid operation geothermal heat pump system and a general geothermal heat pump system to improve the performance of the hybrid operation of solar and geothermal heat pump systems [16]. The problems of the operation of a geothermal source heat pump system were derived through an investigation of the building where the system was installed, a complex operation method with an absorption chiller-heater was then proposed to increase the share ratio of the geothermal heat pump system, and the method was evaluated through a simulation [17]. Jung proposed an operation method of adding the coefficient of the performance to the operation points, which makes it possible to maximize the equipment efficiency of the geothermal heat pump system and take into account the equipment performance. Jung also suggested an operation method to maximize the use of the geothermal heat pump system through an integrated design with an existing heat source and improve energy efficiency, and conducted an evaluation of the method through a simulation [18].

Although many studies on efficient design methods of an underground heat exchanger are being conducted, there has been a lack of research on the variable flow rate control of geothermal water and the operations utilizing it. Jung analyzed the pump energy consumption of a geothermal heat pump system according to the changes in the geothermal water flow rate of the geothermal heat pump system and the COP (Coefficient of Performance) of the heat pump unit [19]. Song reported a variable flow rate control method of the geothermal circulation pump using the source side temperature difference of the geothermal heat pump and validated the application of the method through an empirical

study [20]. This study demonstrated the performance of the variable flow rate control method through a replacement of the circulation pump during the heating operation and verified the effectiveness for COP improvement of the geothermal heat pump system. On the other hand, the energy-saving effect and cooling performance have not been evaluated.

Therefore, this paper suggests a variable water flow rate control method of a geothermal circulation pump to improve the efficiency and energy savings of the geothermal heat pump system during the cooling operation. For this purpose, the proposed variable water flow rate control method was applied to the target building using the TRNSYS (Transient System Simulation Tool) program, and comparative analysis with the existing operation method was performed. The analyses of the indoor thermal environment, energy consumption of the geothermal circulation pump, and energy consumption of the geothermal heat pump system was then performed.

2. Theoretical Analysis

2.1. Building Information

The target building is a mixed-use building consisting of cultural and meeting facilities, business facilities, retail facilities, and neighborhood living facilities located in Daegu, Korea. Figure 1 shows the exterior of the building and Table 1 provides basic information of the building. The total floor area was 49,667 m² and the air conditioned area was 33,744 m². It consists of two basement floors and nine above ground floors.



Figure 1. Exterior of the building.

Table 1. Building information.

Classification	Contents
Location	Daegu, Korea
Building purpose	Mixed-use building (cultural and meeting facilities, business facilities, sales facilities)
Structure	Reinforced concrete
Building stories	The second basement/the ninth floor
Total floor area	49,667 m ²

For the development and evaluation of a variable flow rate control algorithm for the efficient operation of a geothermal heat pump system, a target building with an actual geothermal heat pump system was selected and the operation status was investigated. The geothermal heat pump system, ice storage system, and condensing boiler were being used as the heat source system of the target building. The geothermal heat pump system had a total capacity of 320 RT and seven units were operated. A total of 8 geothermal circulation pumps, including one spare pump, were used. Tables 2 and 3 show the basic information of the geothermal heat pump and a summary of the circulation pump features, respectively.

Table 2. Geothermal heat pump system information.

Classification	GH-1	
Quantity	7	
Capacity (USRT)	Cooling 48.3	Heating 44.4
Entering source temperature (°C)	25	5
Supplied temperature (°C)	12	40
Flow Rate (LPM)	600	600

Table 3. Circulation pump information.

Classification	GP-1
Quantity	8
Power (kW)	7.5
Head (M)	35
Flow Rate (LPM)	700

The geothermal heat pump was separated from other heat source systems and used for air-condition some parts of the building. The heat source water produced was supplied to AHU (Air Handling Unit) and FCU (Fan Coil Unit) to air-condition each area for which the geothermal heat pump is used. The geothermal heat pump system meets the heating and cooling loads of the cultural and meeting facilities on the first basement and the business facilities on the third and fourth floors, which account for approximately 26% of the total heating and cooling loads, and they are responsible for three air conditioners.

The geothermal heat pump system is controlled by the operating number control based on the cold and hot water supply temperatures. The hot and cold water produced by the geothermal heat pump system is returned after heat exchange in the air conditioner coil. The operating number control of the geothermal heat pump system is performed using the temperature difference of the hot and cold water between the inlet and outlet. The geothermal circulation pump is operated to supply a set flow rate continuously regardless of the load. In this operation method, even if the load is lowered, the system operates continuously to maintain the set temperature. In addition, the geothermal circulation pump supplies a constant flow rate even under partial load conditions, so a certain amount of power of the pump is consumed continuously and an energy waste problem arises.

2.2. Theoretical Analysis of the Relationship between Water Flow Rate and COP

The geothermal heat pump system COP is affected by the consumption power of the geothermal circulation pump and the power of the compressor. The following equation and p - h diagram were used to check the variable water flow rate control of the circulation pump in the geothermal heat pump system to reduce the energy consumption and improve the system performance. When a heat exchange is performed in a geothermal heat pump, the average temperature difference can be obtained, as shown in Equation (1), and the quantity of heat using the total heat transfer coefficient is given by Equation (2):

$$\Delta t_m = F \Delta t_{m,cf} \quad (1)$$

$$q = UA \Delta t_m \quad (2)$$

Ignoring any heat transfer between the exchanger and its surroundings and the changes in potential and kinetic energy, and assuming that the specific heat is constant, Equations (3) and (4) can then be obtained by applying a total energy balance of the hot and cold fluids:

$$q = \dot{m}_h(h_{h,i} - h_{h,o}) = \dot{m}_c(h_{c,i} - h_{c,o}) \quad (3)$$

$$q = \dot{m}_h c_{p,h}(t_{h,i} - t_{h,o}) = \dot{m}_c c_{p,c}(t_{c,i} - t_{c,o}) \quad (4)$$

Equations (5) and (6) were obtained by applying an energy balance to each micro element in a heat exchanger, where heat exchange occurs only between the high temperature fluid and the low temperature fluid because the surrounding is insulated:

$$qp = -\dot{m}_h c_{p,h} dt_h = -C_h dt_h \quad (5)$$

$$qp = \dot{m}_c c_{p,c} dt_c = C_c dt_c \quad (6)$$

By integrating these equations over the heat exchanger, the total energy balance can be obtained using Equations (4), and the heat transfer through surface area dA can also be expressed as Equation (7):

$$dq = U \Delta t dA \quad (7)$$

Equation (8) can be obtained by substituting Equations (4) and (5) into the derivative of Δt :

$$d(\Delta t) = -dq \left(\frac{1}{C_h} + \frac{1}{C_c} \right) \quad (8)$$

Equation (9) can be obtained by substituting dq in Equation (7) and integrating the heat exchanger as a whole. Equation (10) can be derived by substituting C_h and C_c in Equation (4):

$$\ln \left(\frac{\Delta t_2}{\Delta t_1} \right) = -UA \left(\frac{1}{C_h} + \frac{1}{C_c} \right) \quad (9)$$

$$\ln \left(\frac{\Delta t_2}{\Delta t_1} \right) = -UA \left(\frac{t_{h,i} - t_{h,o}}{q} + \frac{t_{c,i} - t_{c,o}}{q} \right) = -\frac{UA}{q} [(t_{h,i} - t_{h,o}) - (t_{c,i} - t_{c,o})] \quad (10)$$

In a parallel-flow heat exchanger, the heat transfer rate can be expressed as Equation (13) using Equations (11) and (12):

$$\Delta t_1 = t_{h,i} - t_{c,i} \quad (11)$$

$$\Delta t_2 = t_{h,o} - t_{c,o} \quad (12)$$

$$q = UA \frac{\Delta t_2 - \Delta t_1}{\ln(\Delta t_2 / \Delta t_1)} \quad (13)$$

Comparing Equations (2) and (13), the appropriate mean temperature difference is the logarithmic mean temperature difference. Therefore, the heat flow rate and mean temperature difference can be calculated using Equations (14) and (15):

$$q = UA \Delta t_{lm} \quad (14)$$

$$\Delta t_{lm} = \frac{\Delta t_2 - \Delta t_1}{\ln(\Delta t_2 / \Delta t_1)} = \frac{\Delta t_1 - \Delta t_2}{\ln(\Delta t_1 / \Delta t_2)} \quad (15)$$

Through this relationship, the flow rate of geothermal water can be obtained, as shown in Equation (16):

$$\dot{m}_{source} = \frac{\dot{m}_{refrigerant} \Delta h}{C_{p,source} \Delta t_{source}} \quad (16)$$

Figure 2 presents the p - h diagram with varying flow rates at the same indoor load in the target building. The system COP can be obtained using the values at each point of the heat pump cycle shown in Figure 2, as shown in Equation (17): [21]

$$cop_{sys} = \frac{Q}{w_c + w_p + w_f} \quad (17)$$

The geothermal heat pump system COP was 3.3 when the flow rate of the circulation pump was 25 LPM (flow Rate₁), and geothermal heat pump system COP was 5.4 when flow rate of circulation pump was 15 LPM (flow Rate₂). This shows that with decreasing flow rate, the pressure decreases, the power consumption of the compressors decreases and the system COP increases. This means that the variable water flow rate control of the geothermal heat pump system reduces the energy consumption of the compressors and improves the system COP.

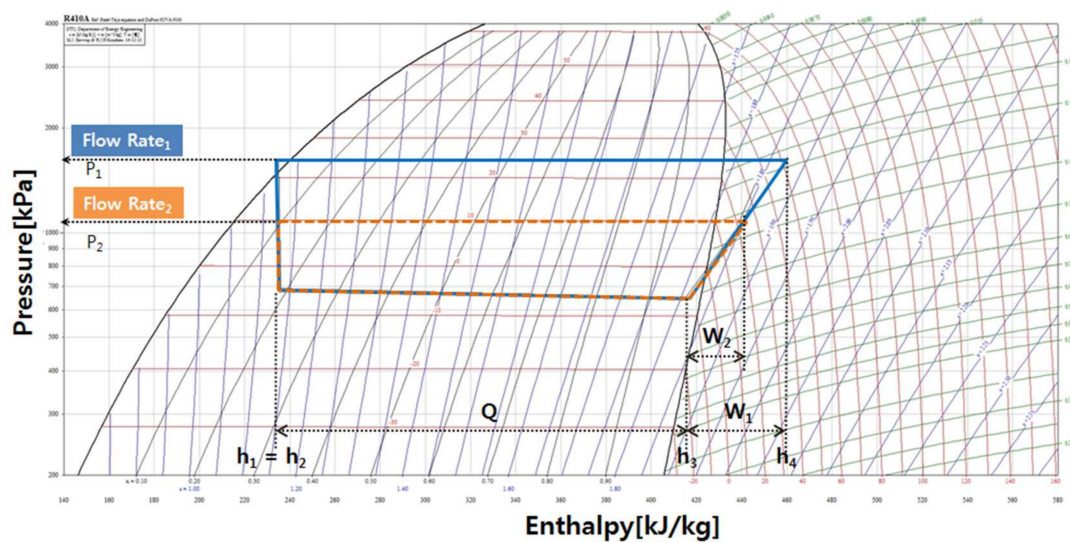


Figure 2. Relationship of flow rate and p - h Chart.

3. Development of the Variable Water Flow Rate Control Method of a Circulation Pump

3.1. Constant Water Flow Rate Control of a Circulation Pump

In general, when a heat pump, which is responsible for only a part of the load of the entire building, is operated, the efficiency of the entire system is reduced when a constant-speed pump is used. A constant water flow rate control method was the existing operation method of the target building and this method was to supply a constant water flow rate. According to the set cold and hot water temperatures, the system is operated if the upper limit of the set temperature is reached, and the operation of the heat pump is stopped if the temperatures of the cold and hot water outlets reach the set lower limit. Figure 3 shows the existing constant water flow rate control algorithm.

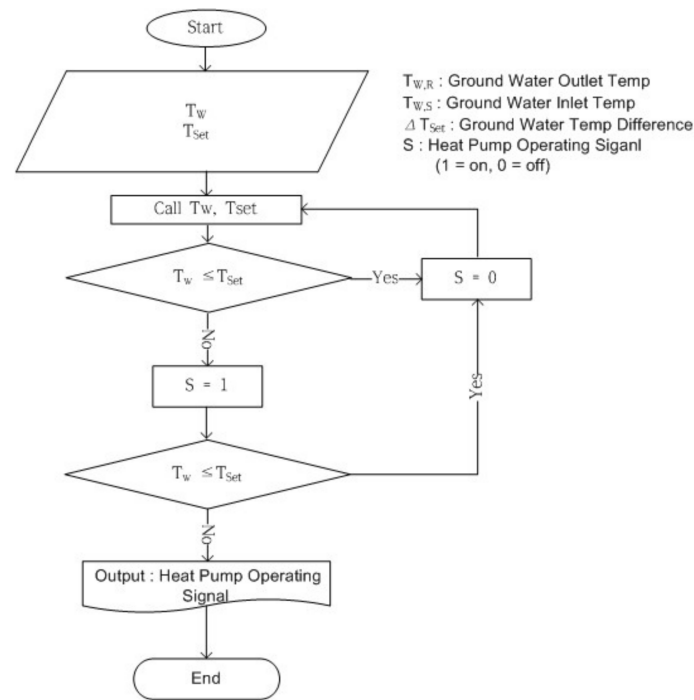


Figure 3. Existing constant water flow rate control algorithm.

The flow rate of geothermal water and the heat transfer coefficient using the inlet-outlet temperature difference can be calculated using Equation (18). The geothermal water flow rate can be calculated using Equation (19), and the COP of the geothermal heat pump system can be determined using Equation (17). In constant flow rate control, the flow rate is provided regularly and the difference in temperature varies according to the load:

$$q = m_{\text{source}} c_{p,\text{source}} (t_{\text{source},i} - t_{\text{source},o}) \quad (18)$$

$$m_{\text{constant}} = \frac{q}{c_{p,\text{source}} \Delta t_1} \quad (19)$$

3.2. Reset Water Flow Rate for Max COP

Load calculations from constant flow rate control and variable flow rate control can be expressed as Equation (20); therefore, the flow rates from variable control may be written as Equation (21):

$$m_{\text{constant}} \Delta t_1 = m_{\text{variable}} \Delta t_2 \quad (20)$$

$$m_{\text{variable}} = m_{\text{constant}} \frac{\Delta t_1}{\Delta t_2} \quad (21)$$

Equation (21) was used to calculate the flow rate to a variable water flow control to improve the system efficiency and reduce energy. If the flow rate is controlled using the temperature difference that can lead to the maximum COP of the total system of the geothermal heat pump, it can operate the system with less energy and achieve high efficiency. The relationship between the COP and the variations in load conditions were analyzed to determine the flow rates, indicating the maximum COP. Figure 4 presents the analysis results.

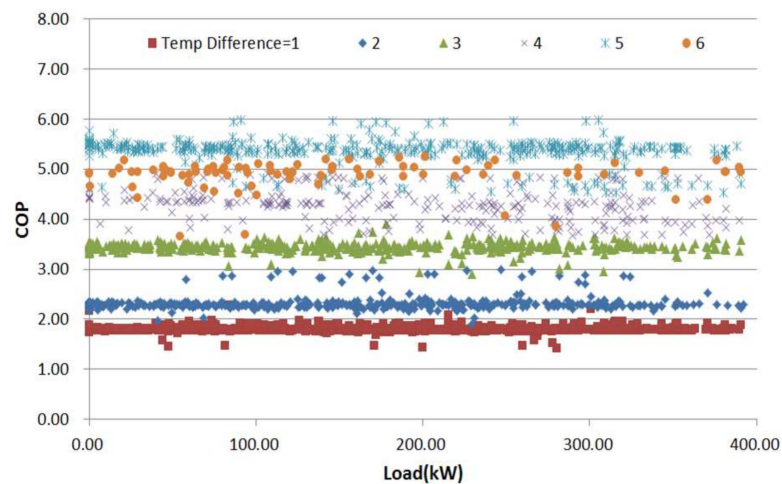


Figure 4. Relationship of temperature difference and geothermal heat pump system COP according to the load.

Figure 5 presents the results of COP analysis according to the temperature difference and flow rate. At a lower flow rate and higher temperature difference, the COP showed an improvement of the COP; the highest COP was observed when the flow rate was 13 LPM and the difference in temperature was approximately 5 °C. If the flow rate decreases since then it is likely that the COP shows a decrease. The COP improvement effects of the geothermal heat pump systems can be verified by controlling the variable flow rate between the designed maximum flow rates and the smallest flow rate to the maximum COP.

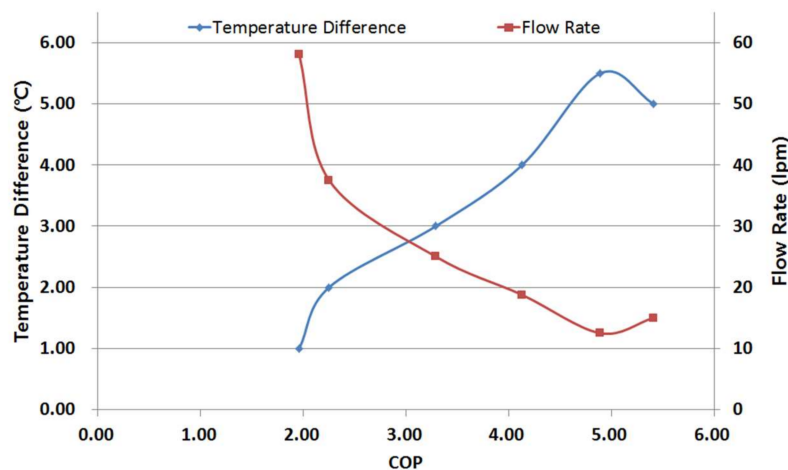


Figure 5. Relationship of the flow rate and COP, and temperature difference.

As shown in Figure 6, the energy consumption of the geothermal heat pump decreases with increasing flow rate, but the COP is decreased as the energy consumption of the geothermal circulation pump increases considerably. Therefore, the maximum efficiency is achieved by variable flow rate control method of controlling the flow rate so that a geothermal water temperature difference of 5 °C can be maintained. Therefore, this paper proposes a variable flow rate control method by maintaining a geothermal water temperature difference of 5 °C.

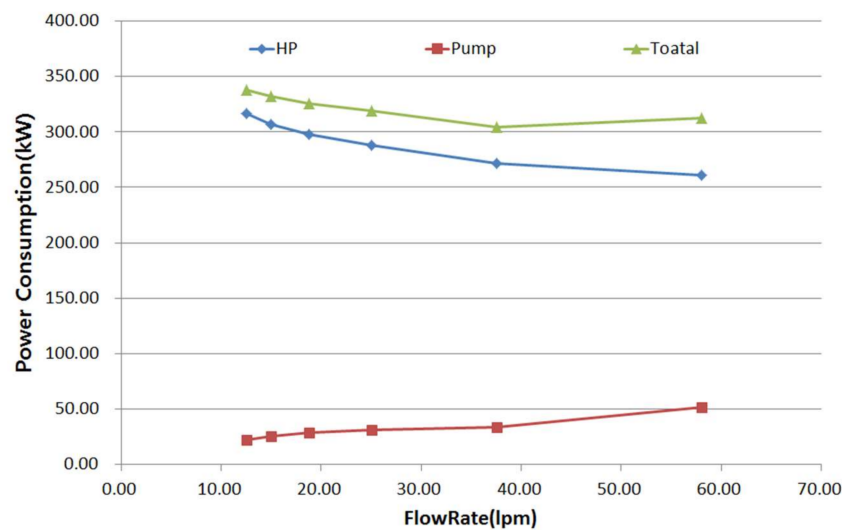


Figure 6. Relationship of the geothermal water flow rate and power consumption.

3.3. Proposed Variable Water Flow Rate Control Method

As shown in Figure 7, after calculating the temperature difference between the inlet and outlet by measuring the geothermal water temperature of the inlet and outlet of the geothermal heat pump, the calculated temperature difference was compared with the set temperature difference, and the system was controlled proportionally to reach the set temperature difference. Several cases are considered:

- ① If the temperature difference between the inlet and outlet of the heat pump is within the range of the set temperature difference

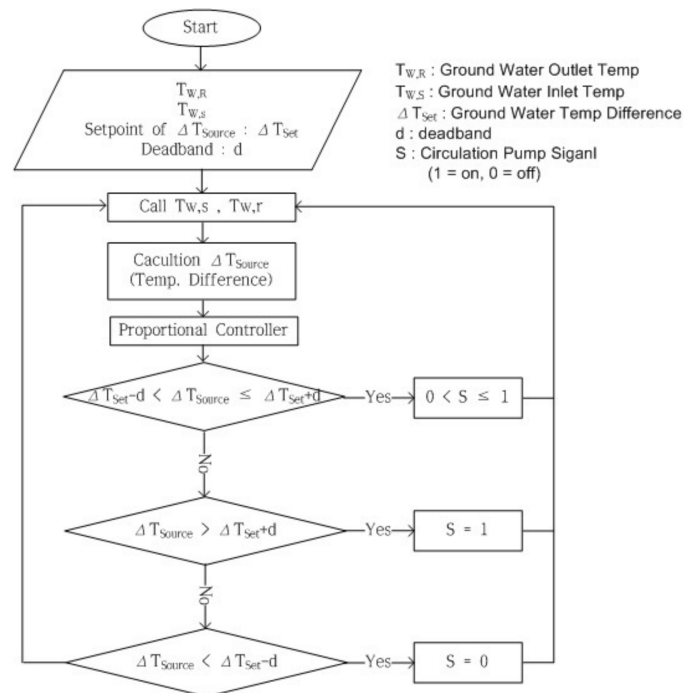


Figure 7. Proposed variable water flow rate control algorithm.

If the temperature difference between the inlet and outlet of the heat pump is within the range of the set temperature difference ($T_{\text{set}} - d < \Delta T_{\text{source}} \leq T_{\text{set}} + d$), the supply flow rate of the pump is determined proportionally by the signal value of the proportional control ($0 < \text{Singal} \leq 1$).

- ② If the temperature difference is larger than the set temperature difference ($\Delta T_{\text{source}} > T_{\text{set}} + d$)

If the temperature difference is larger than the set temperature difference ($\Delta T_{\text{source}} > T_{\text{set}} + d$), 100% of the design flow rate of the circulation pump is provided.

- ③ If it is smaller than the set temperature difference

If it is smaller than the set temperature difference ($T_{\text{set}} - d > \Delta T_{\text{source}}$), the operation of the circulation pump is stopped.

4. Modeling Dynamic Simulation

Transient Systems Simulations (TRNSYS) is a detailed building energy analysis program. The program was written for long-term cost reduction verification through a dynamic simulation of the solar thermal system developed by researchers at the University of Wisconsin in 1975, and is currently being used as the energy simulation and building energy analysis program involving HVAC (Heating, Ventilation, Air Conditioning) equipment, cogeneration system, and control system, including new and renewable energy in Europe and other countries around the world [22–24].

TRNSYS is a program suitable for detailed analysis of the systems that change over time. When the TRNSYS program is used, the user performs the simulation by connecting the components to each other. Components are being developed around the world and can be added after coding using the FORTRAN language. In this respect, TRNSYS has an advantage in that it is convenient when the user selects the system. The modeling of the target building was conducted using the Google Sketch Up program, as shown in Figure 8.

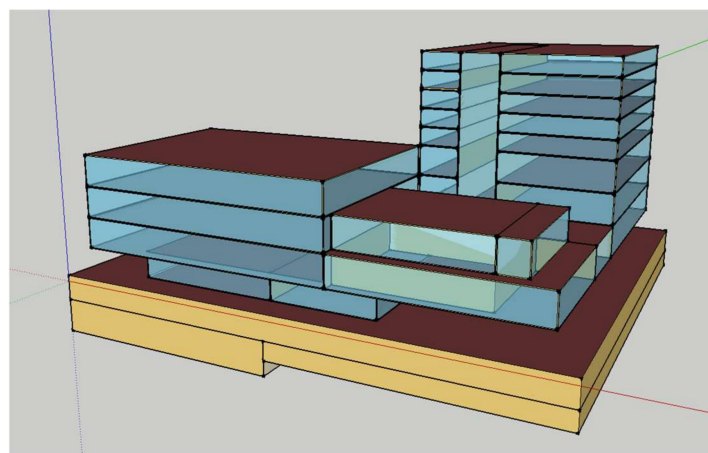


Figure 8. Building modeling using the Google Sketch Up program.

Table 4 lists the indoor load, temperature, and humidity conditions of the representative room used in the simulation. The following was performed to implement the geothermal heat pump system: the Type 927 water to water heat pump was used for the geothermal heat pump; the vertical heat exchanger Type 557a was used for the geothermal heat exchanger; and Type 3b was used for the geothermal circulation pump and cold water supply pump.

Table 4. Indoor condition and Indoor load.

Room	Summer		Winter	
	Temperature (°C)	Humidity (%)	Temperature (°C)	Humidity (%)
Exhibition	24	50 ± 5	20	40 ± 5
Office	24	50 ± 5	22	40 ± 5
Library	24	40 ± 5	20	40 ± 5
Meeting room	24	50 ± 5	20	40 ± 5
Indoor load				
	Person load		Seated, Light work, 150 W	
	Lighting load		13 W/m ²	
	Device load		16 W/m ²	

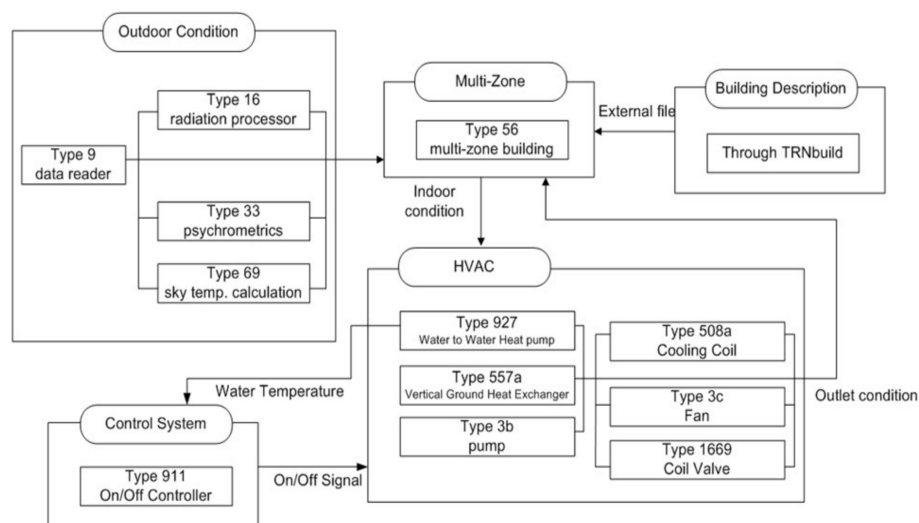
The existing operation method of the geothermal heat pump system of the target building is a constant water flow rate control based on the cold and hot water supply temperatures. This was selected as CASE 1, and the method reflecting the variable water flow rate control method of geothermal water circulation to improve the efficiency of the geothermal heat pump system was selected as CASE 2. Table 5 summarizes the simulation CASE.

Table 5. Summary of CASE.

CASE	Control Method
CASE 1	Existing Constant Water Flow Rate Control Method
CASE 2	Proposed Variable Water Flow Rate Control Method

(1) Existing constant water flow rate control method (CASE 1)

Figure 9 shows the simulation flow diagram of the operating number control according to the set temperature, which is the existing operation method of the target building. The water-to-water type heat pump Type 927 was used for the heat pump and the vertical heat exchanger Type 557a was used for the underground heat exchanger. Type 3b was used for the underground circulation pump and cold water supply pump. To control the set temperature of each geothermal heat pump, the set temperature of the heat pump was used as the controller input value and the on/off controller Type 911 was used.

**Figure 9.** Simulation flow chart of the constant water flow rate control method (CASE 1).

(2) Proposed variable water flow rate control method (CASE 2)

For the variable water flow rate control method, the geothermal water temperature difference between the inlet and outlet was changed to the control point. The proportional controller Type 1669 was used to control the flow rate based on the circulation pump temperature difference. The equations were used to calculate the temperature difference and reflect the indoor temperature. The circulation pump was implemented using the variable speed pump Type 110 to analyze geothermal water flow rate control and changes in the pump energy consumption depending on the change in flow rate. Figure 10 shows the variable water flow rate control method.

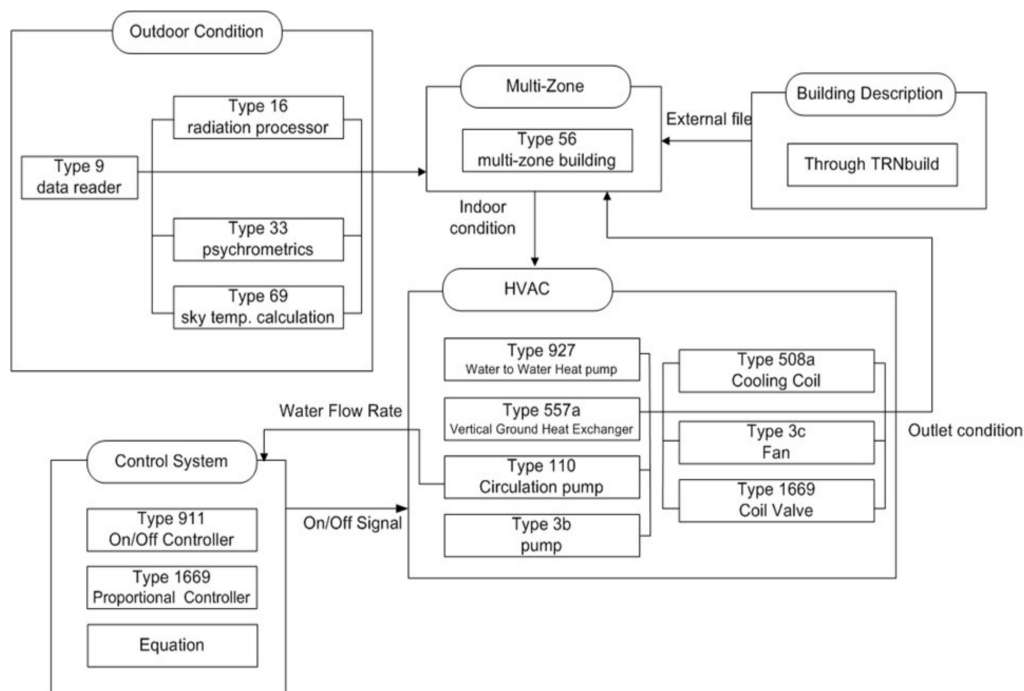


Figure 10. Simulation flow chart of the variable water flow rate control method (CASE 2).

5. Results and Discussion

The conventional flow rate control method of the geothermal heat pump system of the target building provides a continuous supply at a constant flow rate regardless of the load by installing a constant speed pump. This method was selected as CASE 1. To improve the efficiency of the geothermal heat pump system, the variable geothermal water flow rate control method was applied, and it was selected as CASE 2. Table 6 presents a summary of the simulation CASE.

Table 6. Summary of CASE.

CASE	Control Method
CASE 1	Existing Flow Rate Control Method by Constant Flow Rate
CASE 2	Proposed Flow Rate Control Method by Variable Flow Rate

(1) Indoor Thermal Environment

The indoor thermal environment when the geothermal water flow rate control of the geothermal heat pump system was applied was analyzed. Figures 11 and 12 show the changes in the indoor temperature according to the CASE. The room temperature was set to 24 °C (± 0.5 °C), which the

temperature was maintained within the set temperature variation in CASE 1, which was the existing method, and CASE 2, where geothermal water flow rate control was applied.

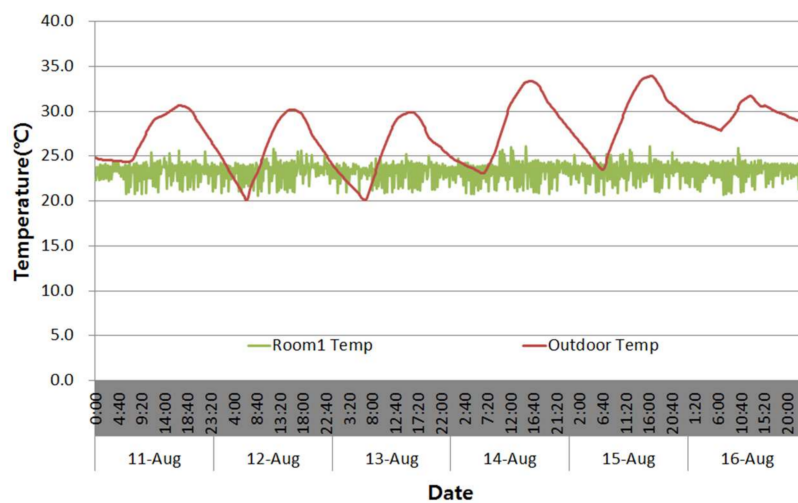


Figure 11. Room temperature (CASE 1).

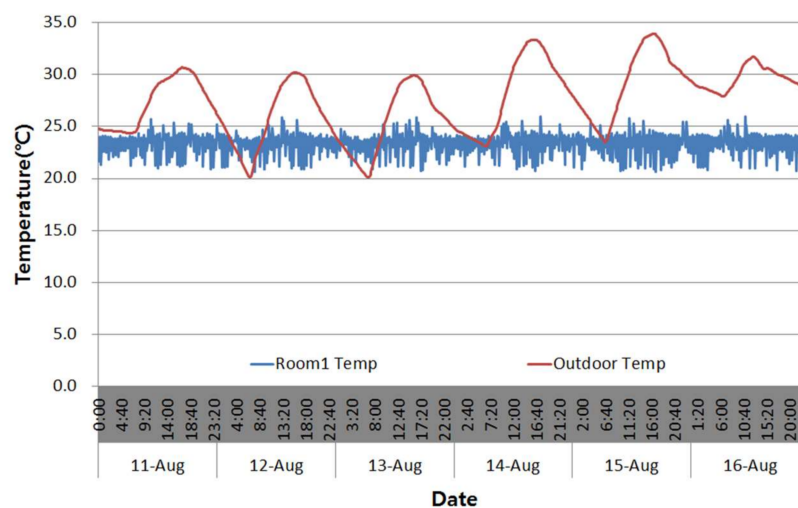


Figure 12. Room temperature (CASE 2).

(2) Geothermal Side Temperature

To analyze the geothermal water temperatures of the inlet and outlet of the geothermal heat pump, Figures 13 and 14 present the changes in the geothermal water temperatures of the inlet and outlet. In CASE 1, the average temperature difference was approximately 1.7 °C. In CASE 2, because the flow rate was controlled by adjusting the geothermal water temperature difference so that it would be 5 °C (± 0.5 °C), an average of approximately 4.3 °C was relatively stable.

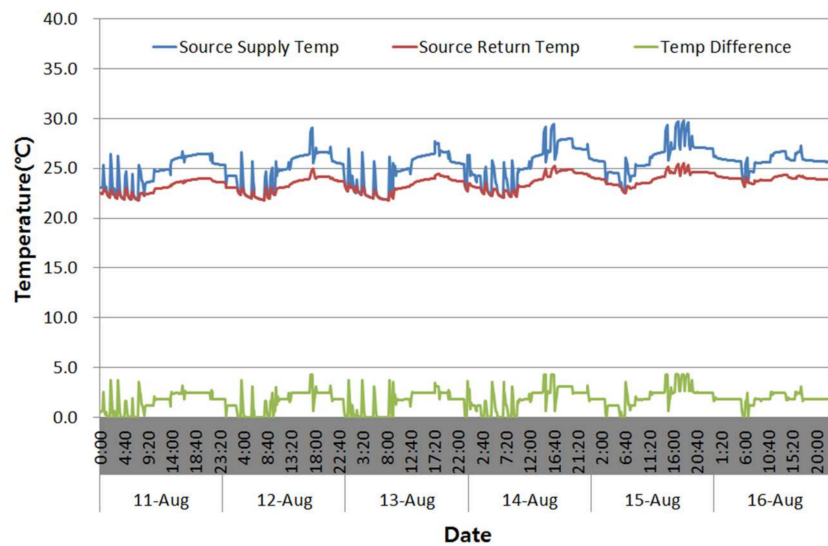


Figure 13. Geothermal water temperature (CASE 1).

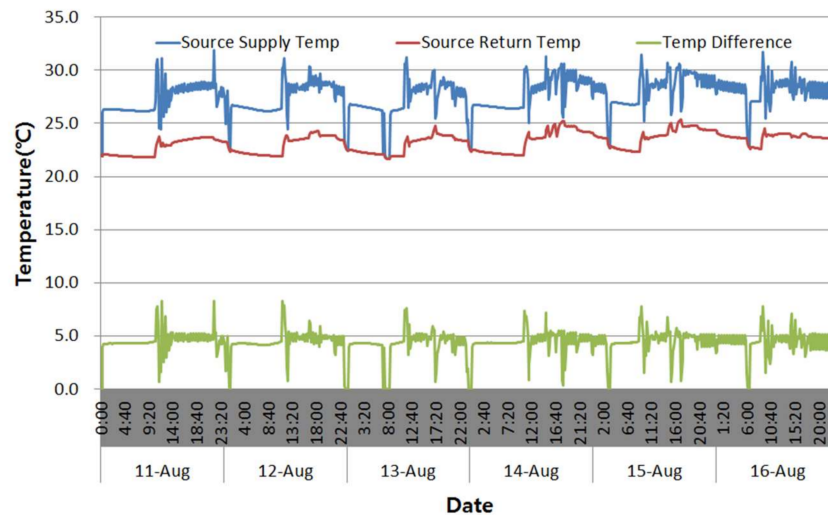


Figure 14. Geothermal water temperature (CASE 2).

(3) Water Flow rate and Energy Consumption

Figure 15 shows the geothermal water flow rate for each case. The flow rate in the variable flow rate control method is approximately 70% lower than the constant water flow rate method. Figure 16 shows the heat pump and circulation pump energy consumption for each case to analyze the energy consumption when applying the geothermal water flow rate control method of the geothermal heat pump. The total energy consumption was 182,936 kW for CASE 1, in which the constant flow rate control method of the target building was used, and 125,919 kW for CASE 2, in which the geothermal circulation water flow control method was applied. The energy consumption of CASE 2 was 32% lower than CASE 1, and the energy consumption of the circulation pump is approximately 70% lower. Table 7 lists detailed energy consumption values of the heat pump and circulation pump for each case.

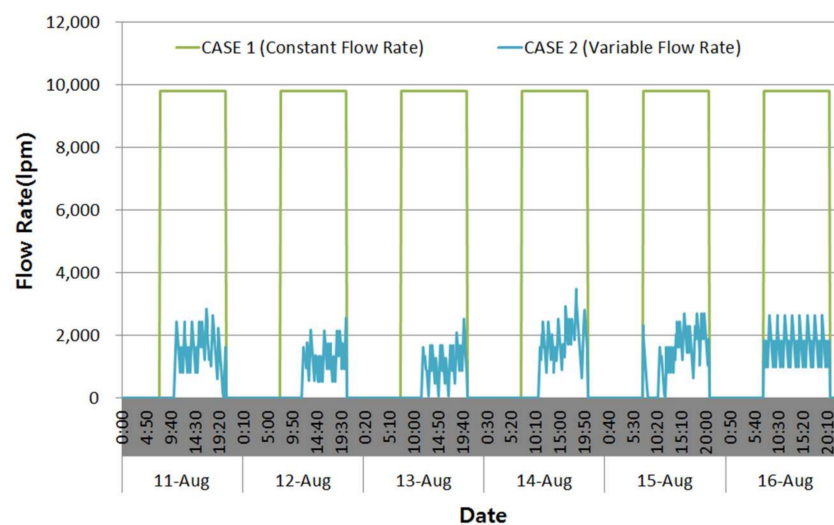


Figure 15. Water flow rate.

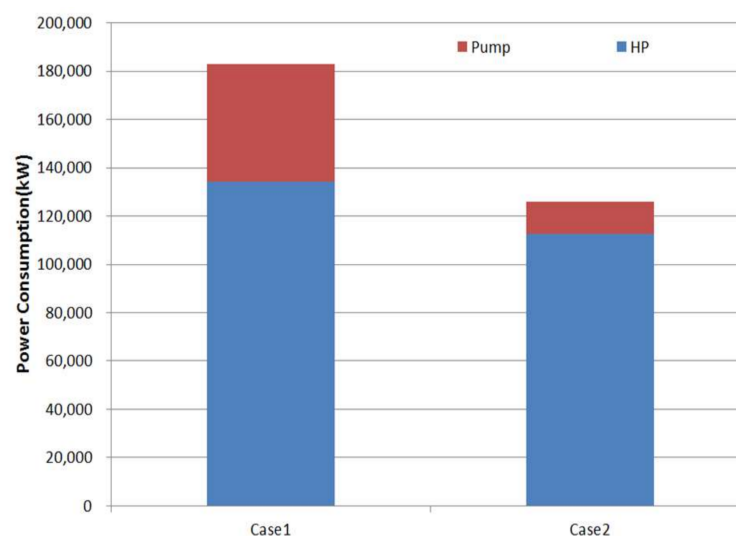


Figure 16. Heat pump and circulation pump power consumption.

Table 7. Heat pump and circulation pump power consumption (kW).

CASE	Heat Pump	Circulation Pump	Total
CASE 1	134,336	48,600	182,936
CASE 2	112,528	13,391	125,919

6. Conclusions

This study examined the operation of the current problems of geothermal heat pump system and proposed a variable water flow rate control method of the circulation pump to improve the efficiency of the geothermal heat pump system and save energy during cooling operations. The proposed operation method was compared with the existing operation method using a simulation. The results of this study can be summarized as follows:

- (1) After selecting the target building where the geothermal heat pump system was installed, the operation method of the heat pump system was investigated. The geothermal heat pump system of the target building was operated by on-off control according to the set temperature

to adjust the load side return water temperature so that it can match the set temperature, and a constant flow rate was supplied continuously due to the constant speed pump of the geothermal circulation pump. If this operation method is used, the return water temperature of geothermal water circulation is adjusted, irrespective of the load. Therefore, unnecessary energy is consumed due to the continuous operation of the circulation pump. A variable flow rate control method of geothermal water circulation was proposed to solve this problem.

- (2) To control the geothermal water flow rate to reduce the energy consumption and improve the efficiency of the geothermal heat pump, this paper suggested a flow rate control method of the circulation pump by geothermal water temperature difference. An analysis of the COP according to the geothermal water temperature difference and an analysis of energy consumption of the heat pump and circulation pump according to the flow rate showed that the energy consumption was lowest and the efficiency was highest when the temperature difference was 5 °C.
- (3) A variable flow rate control method of the heat pump system was proposed and the proposed variable flow rate control method was evaluated by a comparison with the existing constant flow rate control method of the target building. As a result, the total energy consumption was reduced by 57,017 kW compared to the existing flow rate control method and the energy consumption of the circulation pump system was reduced by 35,209 kW, which corresponds to an approximately 70% reduction.

In this study, the flow rate control method was applied and evaluated through simulations. Therefore, there is still a need to evaluate the effect when it is applied to actual buildings. In addition, because the flow control method was applied and evaluated only in summer, it will be necessary to apply the operation method in winter. In other words, future studies should apply the proposed flow rate control method to actual buildings and apply and evaluate it in winter to enable efficient control of the geothermal heat pump system.

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Nomenclature

Δt_m	Mean temperature difference, °C
F	modification factor
q	Heat transfer rate, kW
U	Heat transfer coefficient
A	Area, m ²
$\dot{m}_h$	Flow rate of a high temperature fluid, kg/s
$h_{h,i}$	Inlet enthalpy of a high temperature fluid, kJ/kg
$h_{h,o}$	Outlet enthalpy of a high temperature fluid, kJ/kg
$\dot{m}_c$	Flow rate of a low temperature fluid, kg/s
$h_{c,i}$	Inlet enthalpy of a low temperature fluid, kJ/kg
$h_{c,o}$	Outlet enthalpy of a low temperature fluid, kJ/kg
$c_{p,h}$	Specific heat under constant pressure of a high temperature fluid, kJ/kgK
$t_{h,i}$	Inlet temperature of a high temperature fluid, °C
$t_{h,o}$	Outlet temperature of a high temperature fluid, °C
$c_{p,c}$	Specific heat under constant pressure of a low temperature fluid, kJ/kgK
$t_{c,i}$	Inlet temperature of a low temperature fluid, °C
$t_{c,o}$	Outlet temperature of a low temperature fluid, °C
C_h	Heat capacity ratio of a high temperature fluid
C_c	Heat capacity ratio of a low temperature fluid

Δt_{lm}	Logarithmic mean temperature difference, °C
$\dot{m}_{source}$	Geothermal water flow rate, kg/s
$\dot{m}_{refrigerant}$	Refrigerant flow rate, kg/s
Δh	Enthalpy difference of the condenser, kJ/kg
$C_{p,source}$	Specific heat of geothermal water
$c_{p,source}$	Specific heat under a constant pressure, kJ/kgK
	Geothermal water temperature difference, °C
$t_{source,i}$	Geothermal water inlet temperature, °C
$t_{source,o}$	Geothermal water outlet temperature, °C
$T_{w,r}$	Geothermal water outlet temperature, °C
$T_{w,s}$	Geothermal water inlet temperature, °C
T_{set}	Geothermal water set temperature difference, °C
S	Circulation pump signal
COP_{sys}	Geothermal heat pump system coefficient of the performance
W_C	Power consumption in a compressor of heat pump, kW
W_P	Power consumption in the circulation pump of a heat pump, kW
W_f	Power Consumption in fan, kW

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