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A Numerical Study on System Performance of Groundwater Heat Pumps

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Abstract: Groundwater heat pumps have energy saving potential where the groundwater resources are sufficient. System Coefficients of Performance (COPs) are measurements of performance of groundwater heat pump systems. In this study, the head and power of submersible pumps, heat pump units, piping, and heat exchangers are expressed as polynomial equations, and these equations are solved numerically to determine the system performance. Regression analysis is used to find the coefficients of the polynomial equations from a catalog of performance data. The cooling and heating capacities of water-to-water heat pumps are determined using Energy Plus. Results show that system performance drops as the water level drops, and the lowest flow rates generally achieve the highest system performance. The system COPs are used to compare the system performance of various system configurations. The groundwater pumping level and temperature provide the greatest effects on the system performance of groundwater heat pumps along with the submersible pumps and heat exchangers. The effects of groundwater pumping levels, groundwater temperatures, and the heat transfer coefficient in heat exchanger on the system performance are given and compared. This analysis needs to be included in the design process of groundwater heat pump systems, possibly with analysis tools that include a wide range of performance data.

Keywords: groundwater heat pump; coefficient of performance; regression analysis; UA value; heat exchanger

1. Introduction

A large portion of energy use in buildings goes towards heating and cooling. Operating buildings contributes more to energy use and climate change than either transportation or industry, according to an estimate of global energy consumption [1]. On the other hand, buildings offer the largest global potential to reduce greenhouse gas consumption [2]. Geothermal heat pumps are the most environmentally friendly and efficient method for heating and cooling buildings, and thus could have the largest potential to mitigate greenhouse gas emissions.

Generally, ground heat source systems utilize the annually stable underground temperature. In particular, Groundwater Heat Pumps (GWHPs) directly use groundwater that has a huge amount of potential as a heat source. The Equitable Building—located in Portland (OR, USA)—initiated the use of groundwater as a heat source for heating and cooling in 1948; in recognition, the American Society of Mechanical Engineers recorded it as a National Mechanical Engineering Landmark. It is possibly the oldest geothermal heat pump and the oldest commercial heat pump.

In Korea, the use of renewable energy systems, including ground source heat pump systems, has been spreading widely in the building sector since it became mandatory in public buildings in

2004. Figure 1 shows applications of ground source heat pump systems in Korea [3,4]. According to a market analysis [5], the market for ground source heat pump systems in Korea may grow to 500 billion dollars. Although the market has been growing dramatically, most systems were closed loop system using a U tube pipe as a ground heat exchanger. GWHP systems are used in large-scale buildings, but it is difficult to say that the systems have spread widely.

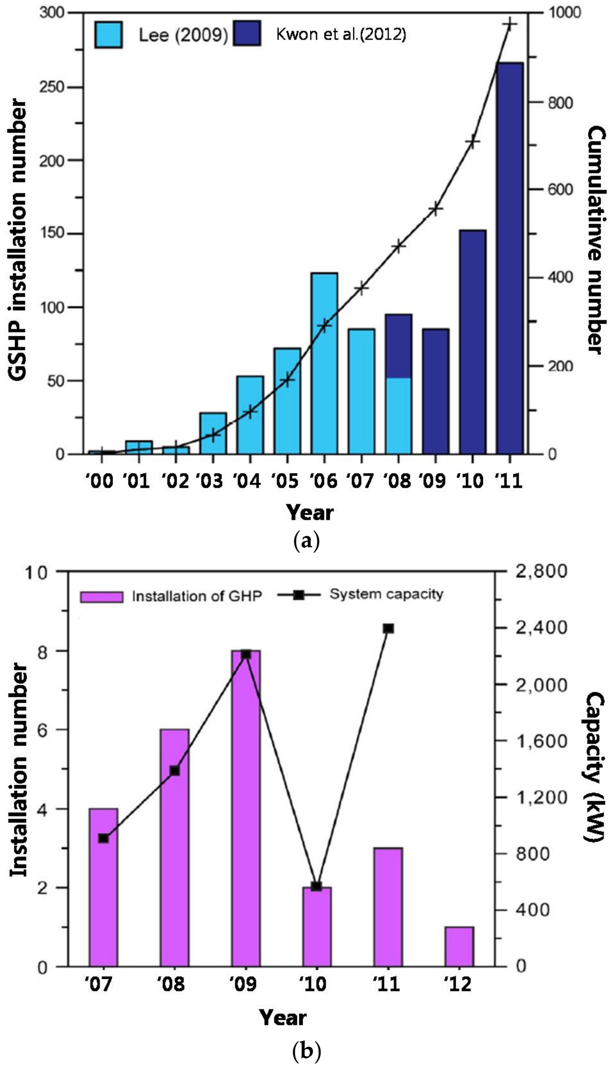

Figure 1. Current status of ground source heat pump system use in Korea. (**a**) Application of ground source heat pump systems; (**b**) Application of groundwater heat pump systems [3,4].

There are several barriers to the installation of a GWHP system, such as the limitations of groundwater condition, pumping power, and local regulations. In particular, most building designers did not recognize the system as a heating and cooling system, and did not understand the proper design methods. Although the Korean government has suggested design and installation guidelines for ground source heat pump systems [6], the explanations for GWHP systems are not sufficient.

Proper design of GWHP systems can realize both low installation and operation costs [7]. While ground-source heat pumps can be installed almost anywhere, GWHPs can be successfully constructed and operated only where an aquifer can sustainably provide groundwater to the heat pump units. Adequate site characterization and system design are essential for stable operation and efficiency. Several studies have been conducted on the design factors of GWHP systems. Nam and Ooka conducted a numerical simulation of ground heat and water transfer for GWHP systems compared with real-scale experiments [8]. The results confirmed that the groundwater flow and the well position are important for the optimum design of GWHP systems, and the electricity consumption of a pump must be reduced significantly to achieve a higher system coefficient of performance (COP). Zhou *et al.* also conducted numerical and experimental investigations of the thermal behavior in the well of a GWHP [9]. They compared the changes in the pumping temperature in different aquifer advection configurations and found that horizontal downstream cross-flow can improve the system efficiency in heating and cooling. ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) Research Report 1119 focused on the standing column well (SCW) design, and a design method for SCW systems was developed [10]. In that research, a simplified simulation tool for SCW systems was developed, and a parametric study for the design guidelines was conducted. Through the simulation tool, the groundwater temperature can be calculated for various conditions of the specific system and operation. Although the ground temperature or circulation temperature is important for calculating the performance of a heat pump, from the perspective of total system performance, the design and selection of the pumping system is also important.

Pumping systems and their operating conditions greatly influence GWHP system performance. Groundwater usually provides favorable operating conditions for heat pump units as compared to ground-source heat pumps, with higher COPs for heat pump units in GWHP systems. However, open-loop groundwater pumping power consumption increases rapidly as the groundwater level drops.

This theory is very simple and well known, but, in real system applications, it is difficult to quantitatively consider the relationship between the system performance and the groundwater conditions. Most system designers did not consider the COP of the total system, but only the lift of the pump for groundwater level and the friction factor. Of course, numerical simulations with ground heat and groundwater transfer models can support optimum designs, but they also have the limitation of practical calculation time. In order to develop a simple and practical design guide, it is necessary to utilize available performance data and individual component models.

In this study, the efficiencies of GWHP systems are analyzed based on the system heating and cooling COPs. The system COPs are calculated by employing polynomial models for heat pump units and pumps. The coefficients of the polynomial models are found by applying regression analysis to the manufacturers' catalog data. The effects of groundwater level and temperature, as well as heat exchanger UA (overall heat transfer coefficient) value (*i.e.*, the rate of heat transfer per temperature difference), on the system performance are analyzed. The analysis will be helpful in determining system performance during the design process of GWHP systems, possibly with analysis tools that include a wide range of heat pump units and pump performance data.

2. Groundwater Heat Pump (GWHP) System

GWHP systems may consume a smaller amount of energy in operating heat pump units than ground source heat pump (GSHP) systems because their heat pump units usually operate under more favorable operating conditions, *i.e.*, groundwater temperatures that remain stable throughout the year. However, in some instances, GWHP systems could consume more energy for pumping groundwater. The pumping energy consumption increases greatly as the groundwater level drops or the pumping flow rate increases.

The water table is maintained in wells and unconfined aquifers when no water is pumped from them. The static water level is the distance from the ground surface to the water level in the well. When water is pumped from a well, the water level in the well drops from the static water level. The water level in the well while pumping is called the pumping water level. The distance between the static water level and the pumping water level is called the drawdown [11,12]. The pumping water level is used in calculating the GWHP system performance.

GWHP systems are composed of one or more production water wells, heat pump units, submersible and circulation pumps, and heat exchangers. Their layouts can vary significantly with design intents and the number of production wells, heat exchangers, and other components. Some GWHP systems do not include heat exchangers between the heat pump units and the submersible pumps, allowing the groundwater to pass through the heat pump unit. This configuration is called a direct GWHP system, and is sometimes used in smaller capacity applications. Indirect GWHP systems, which include a heat exchanger between the groundwater submersible pump and the heat pump units, are often used in large commercial systems.

In this study, the indirect GWHP system is composed of one groundwater production well, one submersible pump, one water-to-water heat pump unit, one circulation pump, and one heat exchanger, as shown in Figure 2. Air handling units (AHUs) or fan coil units (FCUs) that are connected to the water-to-water heat pump unit are not included in calculating the system performance of the current GWHP system. The flow rates and inlet temperature to the AHUs are predefined and assumed to be unchanged. The system configuration is the same as that from the authors' preceding publication [13].

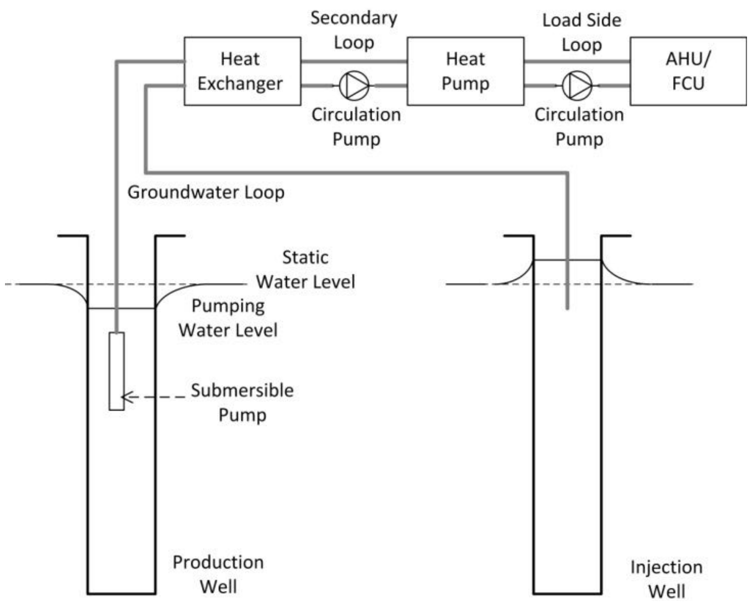

Figure 2. Groundwater heat pump system layout.

The submersible pump installed in the production well pumps the water, transfers it through the heat exchanger, and generally sends it to the injection well (unless there is another application). When the heat pump unit is in heating mode, the heat of the groundwater is transferred to the circulation water in the heat exchanger. The circulation fluid from the heat exchanger is sent to the heat pump unit by a circulation pump in the secondary loop. The heat of the circulation water is transferred to the refrigerant loop inside of the heat pump unit. The circulation water from the heat pump then returns to the heat exchanger in the secondary loop. The heat pump unit produces hot water with the capacity including the absorbed heat from the circulation water in the secondary loop and the electricity consumed by the compressor. The hot water produced by the heat pump units is sent to the AHUs or FCUs to heat the space, or for another process. In heating mode, the heat from the groundwater moves to the space or the process through the heat exchanger, heat pump unit, and the AHUs.

In cooling mode, the heat of the space or the process is transferred to the refrigerant loop inside of the heat pump unit via the AHUs and the circulation water in the load side loop. The circulation water in the secondary loop is chilled by the heat pump unit. Inside the heat exchanger, the heat travels from the circulation water to the groundwater, and the circulation water thus becomes cooler and the groundwater becomes hotter. The groundwater from the injection well is heated in the heat exchanger, and returns to the injection well (unless it is sent to another application).

3. Component Models

The GWHP system of this study is composed of one submersible pump installed in the groundwater production well, one water to water heat pump unit, one circulation pump, and one heat exchanger. In order to calculate the power consumption and the heating and cooling capacities of a GWHP system, the power consumption, head, and heating and cooling capacities of the components need to be modeled as functions of flow rate and temperature. When the flow rate varies in a GWHP system, the temperature distributions in the heat exchanger and heat pump unit vary. Accordingly, the heating and cooling capacities of the GWHP have different values.

3.1. Submersible Pump and Circulation Pump Model

Submersible pumps generally consist of multiple stages of identical impellers and housings installed in series with electric motors installed at the ends. The head and power consumption of submersible pumps are calculated by multiplying the number of stages n of the pump and the associated values for a single stage:

$$H_p = n \cdot h_p \tag{1}$$

$$W_p = n \cdot w_p \tag{2}$$

The head and power consumption for a single stage of a submersible pump are modeled in cubic polynomial equations in terms of flow rate V (in LPM (liters per minute)):

$$w_p = A_0 + A_1 V + A_2 V^2 + A_3 V^3 \tag{3}$$

$$W_p = B_0 + B_1 V + B_2 V^2 + B_3 V^3 \tag{4}$$

The eight coefficients in Equations (3) and (4) can be obtained through regression analysis from performance data typically provided in the manufacturer's catalog. For the single stage, h_p and w_p are the head (in m) and power consumption (in kW), respectively. The groundwater production well is assumed to be capable of providing the necessary flow rate to the heat exchanger or the heat pump unit, and it maintains the pumping water level throughout the operation. The circulation pumps in the secondary loops have similar characteristics as the submersible pumps. The same equation forms for the head and power consumption are used.

3.2. Heat Pump Model

When the circulation fluid of the secondary loop passes through the heat exchanger installed inside the heat pump unit to exchange heat with the refrigerant, head loss and temperature change occurs in the circulation fluid. The head loss in the secondary circulation loop of the heat pump unit H_{hp} is expressed in the following equation. The same equation is used for the head loss that occurs in the load side loop of the heat pump unit:

$$H_{hp} = C_{hp} \cdot V^2 \tag{5}$$

Temperature variations inside the heat exchanger and flow rate variations in the secondary loop cause the heat pump unit to produce different cooling and heating capacities—Q_c and Q_f (in kW), respectively—and consume different amounts of electricity—W_c and W_f (in kW), respectively:

$$\frac{Q_c}{Q_{c,ref}} = D_0 + D_1 \left(\frac{T_{S,in}}{T_{ref}}\right) + D_2 \left(\frac{T_{L,in}}{T_{ref}}\right) + D_3 \left(\frac{V_S}{V_{ref}}\right) + D_4 \left(\frac{V_L}{V_{ref}}\right) \tag{6}$$

$$\frac{Q_h}{Q_{c,ref}} = E_0 + E_1\left(\frac{T_{S,in}}{T_{ref}}\right) + E_2\left(\frac{T_{L,in}}{T_{ref}}\right) + E_3\left(\frac{V_S}{V_{ref}}\right) + E_4\left(\frac{V_L}{V_{ref}}\right) \tag{7}$$

$$\frac{W_c}{W_{c,ref}} = F_0 + F_1\left(\frac{T_{S,in}}{T_{ref}}\right) + F_2\left(\frac{T_{L,in}}{T_{ref}}\right) + F_3\left(\frac{V_S}{V_{ref}}\right) + F_4\left(\frac{V_L}{V_{ref}}\right) \tag{8}$$

$$\frac{W_h}{W_{h,ref}} = G_0 + G_1\left(\frac{T_{S,in}}{T_{ref}}\right) + G_2\left(\frac{T_{L,in}}{T_{ref}}\right) + G_3\left(\frac{V_S}{V_{ref}}\right) + G_4\left(\frac{V_L}{V_{ref}}\right) \tag{9}$$

Subscripts S and L indicate the secondary loop and the load side loop, and subscript ref is the reference value for the corresponding variable. The performance data of the water-to-water heat pump unit can be used to find the coefficients through regression analysis. The performance table includes the cooling and heating capacities and power consumption for source and load side water temperatures and flow rates [14].

3.3. Piping Model

Head loss occurs when the fluid passes inside the pipes and piping accessories. Pipe diameters, pipe lengths, and fluid properties influence the heat loss that occurs in the secondary and groundwater loops. The equation of the head losses expressed in terms of flow rate is as follows:

$$H_{piping} = C_{piping} \cdot V^2 \tag{10}$$

3.4. Heat Exchanger Model

Plate frame plate heat exchangers are normally used as heat exchangers installed between heat pump units and groundwater submersible pumps in indirect GWHP systems. The heat transfer occurs between the groundwater and the circulation fluid of a secondary loop inside the heat exchanger. When the flow rate of the groundwater or circulation fluid changes, the output temperatures vary in the following way:

$$H_{hx} = C_{hx} \cdot V^2 \tag{11}$$

$$Q_{hx} = \rho c_p \cdot \Delta T \cdot V \tag{12}$$

$$Q_{hx} = \mathrm{UA} \cdot \Delta T_{LM} \tag{13}$$

$$\Delta T_{LM} = \frac{\Delta T_1 - \Delta T_2}{\ln\left(\frac{\Delta T_1}{\Delta T_2}\right)} \tag{14}$$

Subscript hx indicates the heat exchanger, UA is a heat exchanger characteristic, and ΔT_{LM} is the logarithmic temperature difference of the heat exchanger as defined in Equations (13) and (14). U value is overall heat transfer coefficient, which considers the heat transfer coefficients of circulation fluid and the resistance of the pipe material.

4. GWHP System Configuration

The indirect GWHP system layout in this study is composed of one submersible pump installed inside the groundwater production well, one water to water heat pump unit, one circulation pump, and one heat exchanger.

A 4 inch diameter submersible pump SP 75S made by Grundfos (Bjerringbro, Denmark) was considered here [15]. All pump models from single stage through sixteen-stage are assumed to be available in this series of products. The eight coefficients of Equations (3) and (4) for the single stage are obtained from regression analysis of the performance data as shown in Table 1.

The McQuay GRW360 model (McQuary, Minneapolis, MN, USA) which uses R407a refrigerant and has a nominal capacity of 30 refrigeration tons is used for the water-to-water heat pump [16]. The twenty coefficients from Equations (6) to (9) are calculated from regression analysis of the manufacturer's data as shown in Table 2. The reference values used in Equations (6) to (9) and the head loss coefficients of Equation (5) are also given in Table 2. Figure 3 shows performance curves of the heat pump according to heat source temperature, which is based on the catalog data.

Table 1. Pump model coefficients for the single stage.

A_0	A_1	A_2	A_3
1.022×10	-1.351×10^{-2}	2.5313×10^{-5}	-1.1589×10^{-7}
B_0	B_1	B_2	B_3
2.07403×10^{-1}	8.9077×10^{-4}	3.467×10^{-6}	-9.95602×10^{-9}

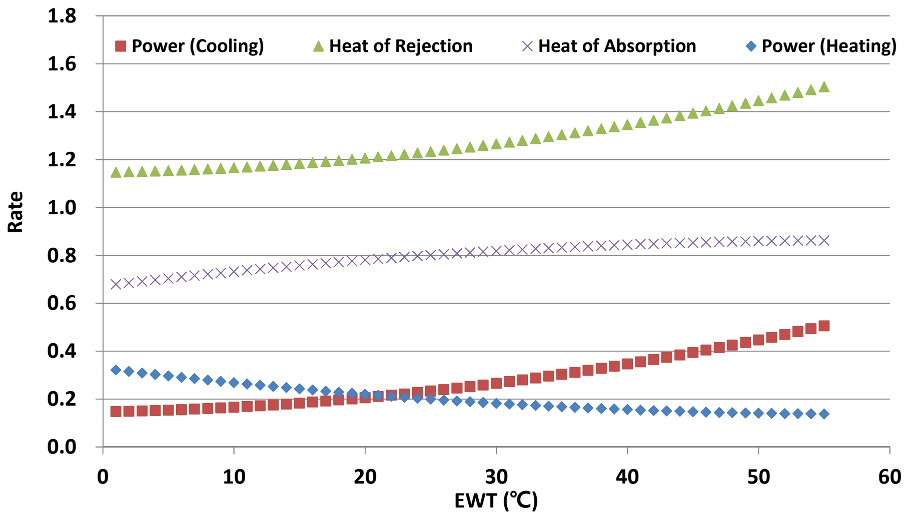

Figure 3. Performance curve of heat pump.

Table 2. Heat pump model coefficients.

D_0	D_1	D_2	D_3	D_4
-3.70415	-2.26533	6.75804	3.322×10^{-2}	7.447×10^{-2}
E_0	E_1	E_2	E_3	E_4
-6.28243	7.83147	-6.663×10^{-1}	9.162×10^{-2}	3.253×10^{-2}
F_0	F_1	F_2	F_3	F_4
-6.42	5.66874	1.32662	-1.106×10^{-1}	1.483×10^{-2}
G_0	G_1	G_2	G_3	G_4
-8.35467	9.0202×10^{-1}	7.81833	2.878×10^{-2}	6.669×10^{-2}
$Q_{c,ref}$	$Q_{h,ref}$	$W_{c,ref}$	$W_{h,ref}$	C_{hp}
70 kW	70 kW	15 kW	15 kW	5.08245×10^{-5}
T_{ref}	$T_{S,in}$	$T_{L,in}$	V_{ref}	V_S
273 K	288 K	313 K	284 LPM	250 LPM

The head loss that occurs in the piping of the groundwater loop is approximated by Equation (10), and the head loss coefficient in the piping H_{piping} is determined to be 3.25×10^{-5}. The submersible pumps installed in the wells supply the groundwater with the head to cover the system head of the groundwater loop, which includes the pumping water level and the head losses in the heat exchanger and piping. The system head equation is shown in Equation (15):

$$H_{SYS} = H_{GW} + H_{hp} + H_{hx} + H_{piping} \quad (15)$$

The head of the submersible pump and the system head vary as the groundwater flow rate varies. The residual head of the groundwater loop is defined as the difference between the groundwater loop system head and the submersible pump head. At the operating flow rate, the submersible pump head H_{p} matches the system head of the groundwater loop, meaning that the residual head becomes zero:

$$H_{res} = H_{SYS} - H_p \quad (16)$$

The Newton-Raphson method is used to find the operating flow rate. Iterations on the groundwater loop system head in terms of the groundwater flow rate are performed until the residual head vanishes. In the secondary loop, the chosen circulation pump is a Grundfos CR 15 single stage model (Manufacturer, Bjerringbro, Denmark). The operating circulation water flow rate of the circulation pump is 300 LPM with a head of 17.4 m. The power consumption of the pump is 1.17 kW, based on the performance data from the manufacturer's catalog.

5. Results

The performance of the GWHP system can be expressed in terms of system COPs, which are the ratios of the heating or cooling capacities to the corresponding electricity consumptions of the GWHP system. Meanwhile, the COPs of the heat pump units are the ratios of the heating and cooling capacities to the corresponding electricity consumption for only the heat pump unit, excluding the pumps. System COPs are always lower than heat pump unit COPs, since the denominators of the ratios always become larger with the additional pump power consumptions. In calculating the GWHP system performance, the power consumption of the AHUs or FCUs and the pump in the load side loop are not included. The performance and characteristics of the components in the load side loop varies greatly for various types of building uses and designs. To evaluate the system performance of the GWHP without the effects caused by load side designs, the load side loop is assumed unchanged in the analysis.

5.1. Groundwater Level

The pumping groundwater levels are assumed to be obtained from a series of pumping tests. Pumping tests are experimental tests for finding the aquifer transmissivity or the soil permeability. In the test, a well is pumped at a controlled rate, and water-level response (drawdown) is measured in one or more surrounding observation wells. The response data from pumping tests is used to estimate the hydraulic properties of aquifers and evaluate well performance. The drawdown is a function of various parameters including pumping flow rate, aquifer transmissivity, time since the start of pumping, and distance from the well [17]. However, the water levels in the well during pumping tests include the drawdown effects, which are thus not being treated separately in this study.

System COPs of GWHP systems are presented for three different constant pumping groundwater levels: 15, 25 and 35 m. At each groundwater level, groundwater flow rates for the selected submersible pumps are found, and performance results of the GWHP system are calculated for the flow rates. The submersible pumps of eleven different stages are considered at each groundwater level. Performance results include heat pump COP and GWHP system COP.

System heating and cooling COPs are shown in Figures 4 and 5 respectively. In Figure 4, as the groundwater level drops, the optimum flow rate for the GWHP heating system COP becomes more recognizable. In Figure 5, as the groundwater level drops, the slope of the curve in the low flow rate region becomes smaller in magnitude. However, in the high flow rate region, the system heating and cooling COPs drop rapidly as the flow rate increases.

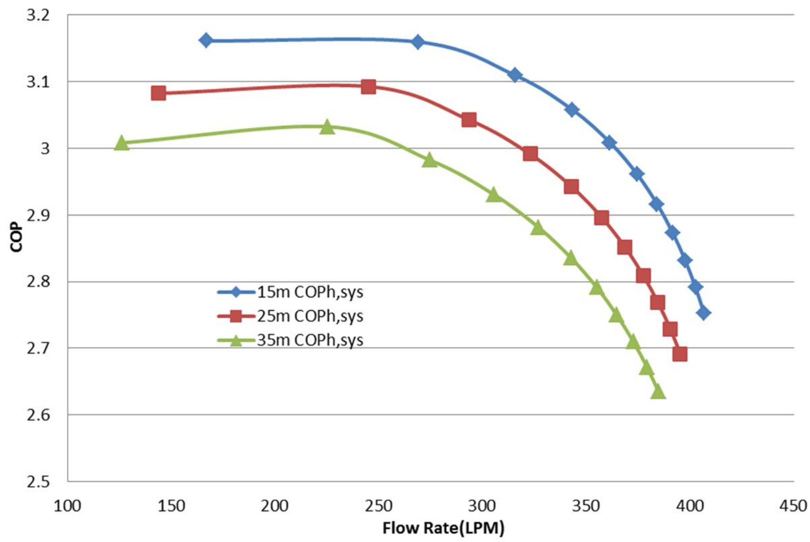

Figure 4. Heating system COP variation with the flow rate.

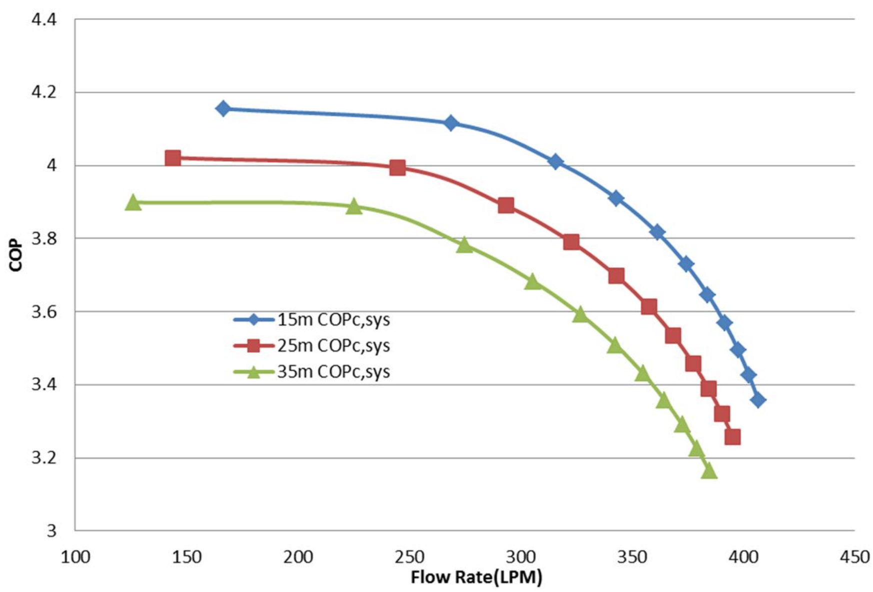

Figure 5. Cooling system COP variation with the flow rate.

The percentage of reduction of the COP of the GWHP system compared with that of the heat pump unit increases as the flow rate increases or the groundwater level drops. Figure 6 shows the system heating COP value variation with flow rates and groundwater levels. A 10%–15% reduction is shown for the 250 LPM groundwater flow rate. When the groundwater level is 35 m below the ground, the system heating COP shows the largest reduction (15%) as compared to the heat pump COP. At the higher flow rate of around 350 LPM, the system heating COP decreases by 15%–22% from the heat pump unit COP.

Figure 7 shows that the reduction percentage of system cooling COP as compared to the heat pump unit COP is larger than the reduction percentage of the system heating COP. A similar trend is found with the variation of flow rate and groundwater level. A 15%–22% reduction is observed for the 250 LPM groundwater flow rate. When the groundwater level is 15 m below the ground, the system heating COP shows the smallest reduction (15%) as compared to the heat pump COP. At the higher flow rate of around 350 LPM, the system heating COP shows a 22%–29% reduction from the heat pump unit COP.

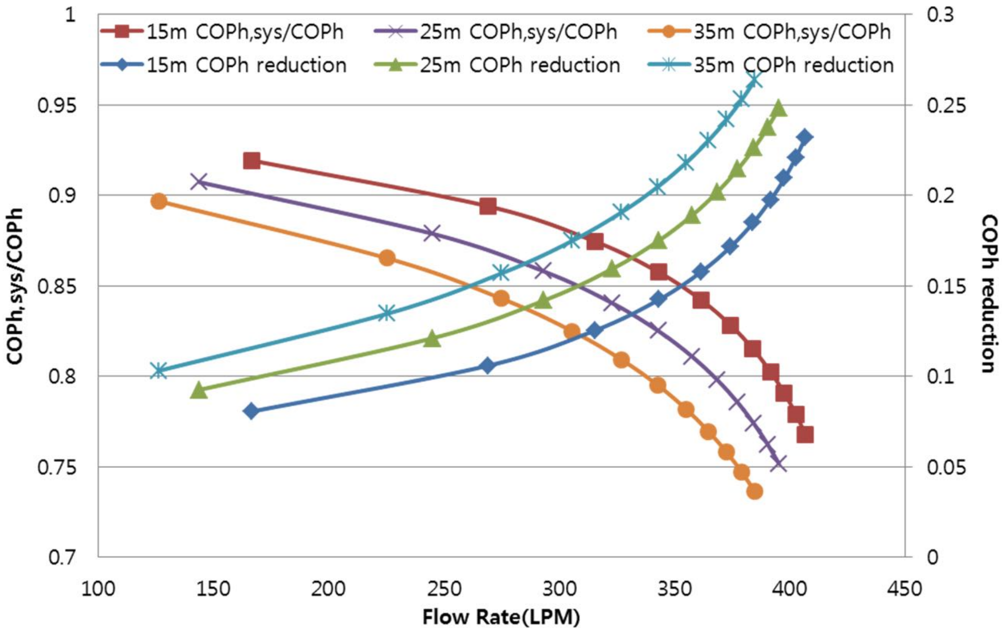

Figure 6. System heating COP reduction compared to heat pump unit COP.

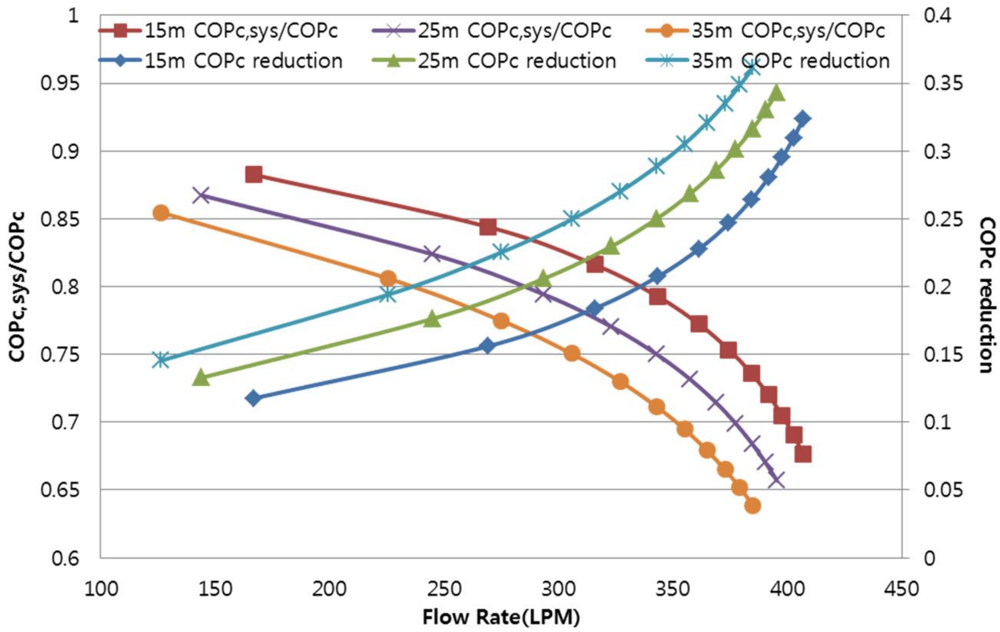

Figure 7. System cooling COP reduction compared to heat pump unit COP.

5.2. Groundwater Temperature

Groundwater temperature influences the system COPs of the GWHP system, as the heat pump capacities and COPs are dependent on the groundwater temperature. As the groundwater temperature increases, the heating COPs also increase, but the cooling COPs decrease. Conversely, as the groundwater temperature decreases, the heating COPs decrease, but the cooling COPs increase. While studying the effect of groundwater temperature on the system COPs of the GWHP, the groundwater level is set at a constant 25 m. The system COPs are calculated and shown in Figure 8 for groundwater temperatures of 12, 15 and 18 °C.

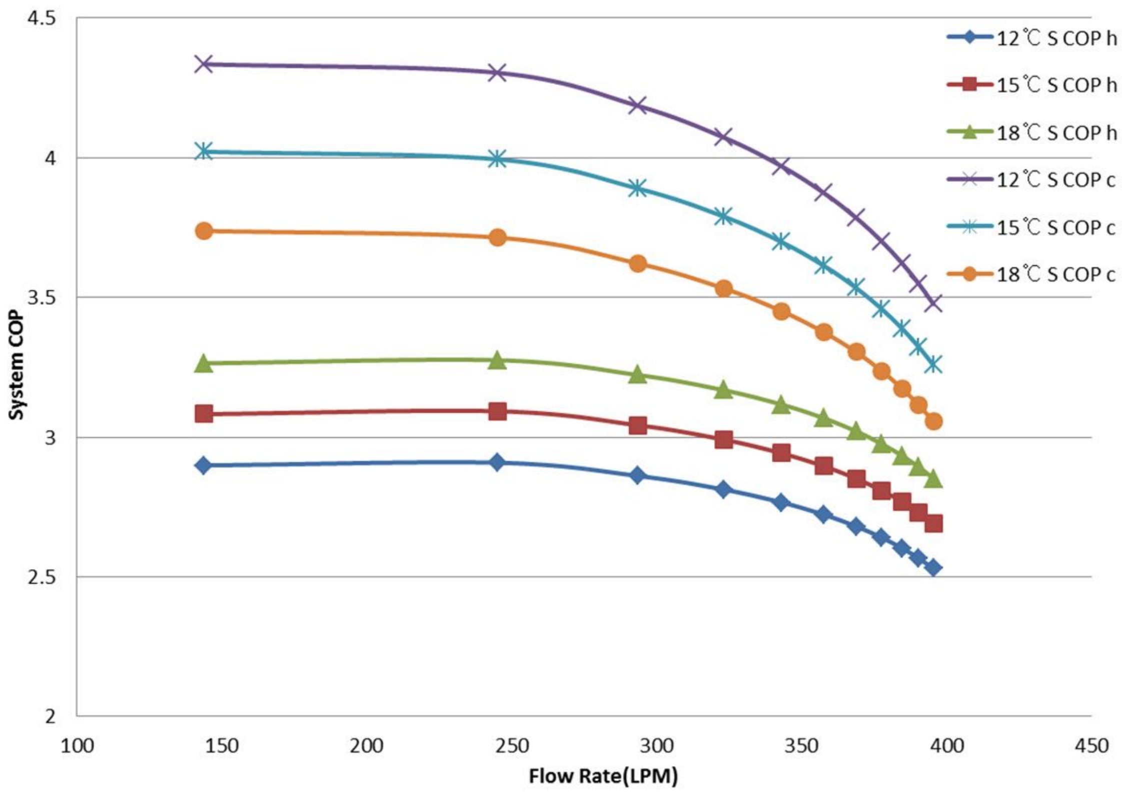

Figure 8. System Cooling and Heating COP variation to Groundwater Temperature.

The plot of the system cooling COPs for 12 °C groundwater shows the largest values; however, the system heating COPs show the smallest values. The system COPs for 18 °C groundwater show the opposite trend as compared to the case for 12 °C. The COPs for 15 °C groundwater lie between those for 12 and 18 °C. As the flow rate varies from 144.0 to 395.3 LPM, the system cooling COPs drop by approximately 19.0% (19.8% for 12 °C, 19.0% for 15 °C, and 18.3% for 18 °C), and the system heating COPs drop by approximately 12.7% (12.7% for 12 °C, 12.7% for 15 °C , and 12.6% for 18 °C).

At the flow rate of 245 LPM, the system heating COPs drop by 11.2% when compared with the COPs between 12 and 18 °C groundwater temperature, whereas the system cooling COPs drop by 13.7%. At a higher flow rate of 343 LPM, the system heating COPs drop by 11.2%, and the system cooling COPs drop by 13.1%

5.3. Heat Exchanger UA Value

Figure 9 shows the calculation results of system COP according to the change of heat exchanger UA values. The heat exchanger installed between the groundwater pump and the heat pump unit influences the system COP of the GWHP system. The temperature of the water circulated between the heat exchanger and the heat pump unit influence the capacity and power consumption of the heat pump unit.

The UA value of the heat exchanger determines the temperature differences between the hot and cold streams. In this study, a UA value of 12 W/K has been used for the previous results. A positive and negative variation by 25% from 12 W/K are considered, and three UA values of 9, 12 and 15 W/K are used to study its effect on the system COPs.

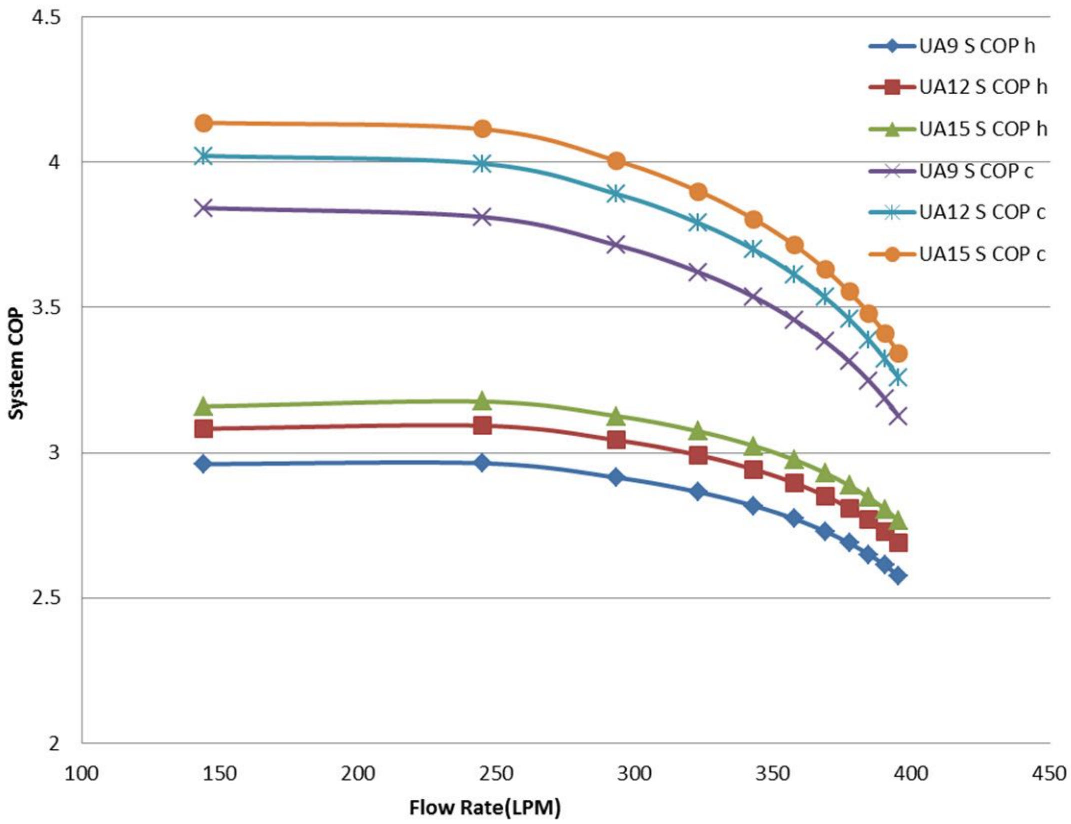

Figure 9. System cooling and heating COP variation to heat exchanger UA values.

When the UA value decreases from 12 to 9 W/K, the system heating COP drops by 4.2% and the system cooling COP drops by 4.6%. When the UA values increases from 12 to 15 W/K, the system heating COP rises by 2.7% and the system cooling COP rises by 3.0%. It is expected that the low UA values of the small heat exchanger may deteriorate the system COP values by a significant amount.

6. Conclusions

In this study, in order to develop an installation and operation guideline for a GWHP system, a numerical study was conducted using individual performance models and available system catalog data. The system COPs, as measures of performance for GWHP systems, were obtained by combining the component mathematical models. The system heating and cooling COPs were calculated for different groundwater levels, flow rates, groundwater temperatures, and UA values. The system COPs were almost unchanged or gradually changed in the low flow rate region as the flow rate increases. However, in the higher flow rate region, the system heating and cooling COPs decreased rapidly as the flow rate increased. The system heating COPs increased with warmer groundwater temperatures; similarly, the system cooling COPs increased with colder groundwater temperatures. Increasing the UA value of the heat exchanger universally improved the system heating and cooling COPs.

The system heating COPs were reduced 10%–15% at around 250 LPM and 15%–22% at around 350 LPM when compared to heat pump unit COPs. The system cooling COPs were reduced by a larger rate, 15%–22% at around 250 LPM, and 22%–29% at around 350 LPM. This result indicates that, if the flow rate is above 350 LPM at 30 refrigerant ton of heat pump, GWHP systems would be not proper due to low system COP.

At the flow rate of 245 LPM, the system heating COP dropped by 11.2% when 12 °C groundwater temperatures are compared to 18 °C, and the system cooling COP rose by 13.7%. At a higher flow rate of 343 LPM, the system heating COP dropped by 11.2%, and the system cooling COP rose by 13.1%.

When the groundwater temperature rose, the system heating COP of GWHP systems increased, and the system cooling COP decreased. These results show that the effect of groundwater temperature on system performance is as significant as the effect of groundwater level or flow rate. Generally, the groundwater temperature at shallow depths is determined by the annual regional air temperature, but it could be different according to the well depth. Therefore, well designers should decide the well depth considering the groundwater temperature and building load, such as deeper wells for heating dominant buildings.

The system heating COP dropped by 4.2% and the system cooling COP dropped by 4.6% when comparing UA value of 9 to 12 W/K. When the UA value of 15 W/K is compared to a 12 W/K one, the system heating COP rose by 2.7% and the system cooling COP rose by 3.0%. Selection of proper UA values of the heat exchanger may ensure proper system COP values.

GWHP system design engineers need to find the groundwater flow rates at which GWHP systems maintain high system COPs with a proper selection of heat exchanger. The GWHP systems need to be modeled with detailed information on components, such as submersible pumps, heat pump units, and heat exchangers. In order to accurately predict system performance, proper GWHP system models need to be used in conjunction with the building heating and cooling load variations.

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