The present study was conducted by employing the EnergyPlus model which has already been verified by a previous study (Hyun, I. T et al. 2014). In addition, the representative period for analysis was the winter season (December, January, and February). The day in which the temperature was the lowest in a year was designated as the representative day. The variables were pipe diameter and flow rate. The temperature pattern depending in the variables, and the electricity consumption resulting from applying the temperature pattern to a heat pump were verified to compare the electricity consumption with the energy consumption by the gas-boilers that are currently used.

Table 1. Simulation Cases (Hyun, I. T et al. 2014)

Case	Terminal unit at greenhouse	Heating/Cooling equipment	Heat source
1	Fan coil unit	Boiler/Centrifugal chiller	N.A.
2	Fan coil unit	Heat pump	Outdoor air
3	Fan coil unit	Heat pump	Sea water
4	Fan coil unit	Heat pump	River
5	Fan coil unit	Heat pump	Waste water from power plant
6	Fan coil unit	Heat pump	Geothermal (groundwater)

2. Overview of Simulation and Theoretical Background

2.2 Determination of Simulation Conditions

Within 100 ha horticulture facility modeled for this study, the detailed analysis was performed with a 1 ha glass greenhouse. The soil thermal conductivity (Kim, Y. H 2007) and the pipe material thermal conductivity (Choi, S. W 2012) on the basis of a previous study were applied, and the values are shown in Table 1. The detailed information for the heating and cooling set-points, hot water temperature entering fan coil unit (FCU), air infiltration rate are provided in the study by Lee et al (Lee, J. H et al. 2014).

Table 2. Simulation Conditions

Fixed Value	
Program	EnergyPlus v6.0
Modeling Size	100(m) × 100(m)
Model System	4Pipe Fan Coil System
Soil Thermal Conductivity (k)	2.50(W/m·K)
Cooling/Heating Setpoint(℃)	Day : 23℃ / Night : 11℃
Discharge Air Temperature of The FCU (℃)	16.0 ~ 24.3℃
Hot water temperature supplied to the FCU (℃)	Year-round 40℃
Date	2013, December, 15
Variable Value	

Average Pipe Air Velocity (kg/s)	3.67, 5.67, 7.67, 9.67, 11.67, 13.67, 15.67
Pipe Diameter	25A, 40A, 50A, 65A, 75A

2.3 System Modeling

The system model for the EnergyPlus simulation was set up with reference to a previous study (Hyun, I. T et al. 2014). The detailed information for the modeling of FCU, boiler and heat pumps are provided in the study by Lee et al (Lee, J. H et al. 2014).

3. Formula for Calculating Pipe Heat Loss

The formula for calculating pipe heat loss has already been mentioned in many previous studies (Lee, K. H and Strand. R. K 2006, Jacovides, C. P. and Mihalakakou, G 1995). Since a great number of mathematical formulae are required for the pipe heat loss through convention, only necessary formulae are shown in this article. To calculate the heat transfer between an underground pipe and surrounding soil, the thermal resistance of pipe inner surface, pipe outer surface, and the soil was calculated by using the following Equations (1), (2), and (3). In the Equations, r_1 denotes the inner radius of the pipe, r_2 the pipe thickness, and r_3 the distance between the pipe outer surface and the soil. A previous study set r_3 to be twice as great as r_1 (Jacovides, C. P. and Mihalakakou, G 1995).

$$R_C = \frac{1}{2\pi r_1 L h_c} \quad (1)$$

$$R_P = \frac{1}{2\pi L h_P} ln \frac{r_1+r_2}{r_1} \quad (2)$$

$$R_s = \frac{1}{2\pi L k_s} ln \frac{r_1+r_2+r_3}{r_1+r_2} \quad (3)$$

where,

R_c : Thermal resistance due to convection heat transfer between the air in the pipe and the pipe inner surface (℃/W)

R_P : Thermal resistance due to convection heat transfer between the pipe inner and outer surface (℃/W)

R_s : Thermal resistance due to convection heat transfer between the pipe outer surface (℃/W)

r_1 : Inner pipe radius (m)

r_2 : Pipe Thickness (m)

r_3 : Distance between the pipe outer surface and undisturbed soil (m)

L : Pipe length (m)

h_c : Convective heat transfer coefficient at the inner pipe surface (W/m℃)

k_s : Soil thermal conductivity (W/m℃)

k_p : Pipe thermal conductivity (W/m℃)

The overall thermal conductivity of the underground pipe is calculated by using the thermal resistance values calculated by using Equations (1), (2), and (3), as shown in Equations (4) and (5):

$$U_t = \frac{1}{R_t} \tag{4}$$

$$R_t = R_c + R_p + R_s \tag{5}$$

where,
U_t : Overall heat transfer coefficient of the whole earth tube system (W/m℃)
R_t : Total thermal resistance between pipe air and soil (℃/W)

Based the calculation procedure, the outlet temperature of heat source fluid eventually arriving at the heat pump is calculated by using Equations (6): (Lee, K. H and Strand. R. K 2006, Jacovides, C. P. and Mihalakakou, G 1995).

$$U_t dy[T_w(y) - T_{soil}] = -m_w C_w[dT_w(y)] \tag{6}$$

4. Simulation Analysis

4.1 Base Modeling

The load required by the simulation modeling results of the present study was 1,100 kW (Hyun, I. T et al. 2014). Therefore, it was assumed in the base model that ten 30 RT heat pumps are used, each able to bear 100 kW of load. The distance was set to be 5 km, the flow rate 5.67 kg/s, the pipe diameter 60 mm, and the pipe thickness 5.5 mm (Lee, J. H 2014). With respect to the soil temperature of the analyzed region, the data are not available. Therefore, the annual average temperature of 11.9℃ was assumed to the underground soil temperature. In a previous study conducted by employing the same model, it was assumed that the fluid outlet temperature was the actual heat source temperature reaching the source side of the heat pump for the analysis. The Base Model of the present study was compared with the previous study applying the assumption just mentioned, the energy consumption by the horticulture facility was about 5 to 10% higher or lower, depending on the heat sources. Therefore, it was presumed in the present study that various factors related with piping have a significant effect on the energy consumption of a large-scale horticulture facility, and thus the pipe diameter and the flow rate of the Base Model were selected as the variables to analyze the outlet temperature and the electricity consumption, respectively.

4.2 Analysis of Daily Average Outlet Temperature and Electricity Consumption According to Pipe Size

As described above, the pipe diameter, which is one of the variables of the present study, was calculated with reference to the catalogue data of 'S' company in Korea. The coldest day in 2013 on the basis of the meteorological data provided by EnergyPlus, which was December 15, was chosen as the representative day.
Table 3 shows the average outlet temperature on the representative day of the present study according to the pipe size. The average outlet temperature of the outer air and the soil was constant, regardless of the pipe diameter, but the temperature of the sea water, river water, and power plant waste heat water was dependent on the pipe diameter. As shown in Table 3, the temperature of the sea water and the river water was a little increased from 25A to 65A, but it was rather decreased at 75A. On the

contrary, the temperature of the power plant waste heat water was a little decreased from 25A to 65A, but it was rather increased at 75A. Such a tendency that the temperature variation pattern was consistent from 25A to 65A, but became opposite at 75A may be because of r_1, r_2, and r_3. Since the underground soil temperature was assumed to be constant in the present study, T_{soil}, the soil temperature, included in Equations (6) for the calculation of temperature, has a constant value despite the variation of the pipe diameter. Therefore, the final outlet temperature is dependent on e^A. Most of the values included in Equation (6) for the calculation of e^A are not varied by the change of the pipe diameter, but the overall pipe heat transfer coefficient U_t is greatly affected the change of the pipe diameter. According to Equation (6), the temperature is increased as U_t is decreased, while the temperature is decreased as U_t is increased. In the case of power plant waste heat water having a temperature higher than the soil temperature, as r_1, r_2, and r_3 were increased, U_t, which is the reciprocal value of the sum of R_c, R_P, and R_s, was increased. As U_t was decreased, the final effluent temperature was increased. As the pipe diameter was increased, r_1, r_2, and r_3 were also increased, while the sum of R_c, R_P, and R_s was decreased. As the sum of R_c, R_P, and R_s was decreased, the reciprocal value of the sum of individual resistance values, U_t, was increased, and $T_w(L)$ was thereby decreased. On the other hand, when the pipe diameter was 75A, the sum of R_c, R_P, and R_s, was increased, on the contrary to the previous pattern. As a result, U_t was decreased, and $T_w(L)$ was increased. On the contrary, in the cases of sea water and river water having a temperature lower than the soil temperature, the final outlet temperature was calculated by using Equation (6), which is contrary to the equation for the calculating of the outlet temperature of the power plant waste heat water having a temperature higher than the soil temperature, and thus the temperature variation was the opposite. Due to the page limit, effects of pipe diameter variation on the heat pump COP are not discussed in this paper. Instead, Table 4 show the day total consumption of electricity and gas for each heat source according to the pipe diameter. The electricity and gas consumption pattern was the same as that of the outlet temperature and COP described above. Although depending on the heat sources, the electricity consumption was about 65 to 75% lower than the energy consumption by general gas boilers. However, under the same distance condition, the difference caused by the pipe diameter was negligible, indicating that the pipe diameter does not have a significant effect.

Table 3. Average outlet temperature (℃) and boiler efficiency on the representative day for each heat source according to the pipe diameter

Pipe Standard	Air Source	Sea Water	River Water	Power Plant Waste Heat	Geothermal
25A	-6.3	8.0	11.2	14.7	11.9
40A	-6.3	8.2	11.3	14.6	11.9
50A	-6.3	8.2	11.3	14.5	11.9
65A	-6.3	8.4	11.3	14.4	11.9
75A	-6.3	8.2	11.3	14.5	11.9

Table 4. Accumulated electricity and gas consumption on the representative day for each heat source according to the pipe diameter (W/㎡)

Pipe Diameter	Boiler (Gas)	Air Source	Sea Water	River Water	Power Plant Waste Heat	Geothermal
25A	3063.4	790.8	594.0	554.6	515.6	546.9
40A	3063.4	790.8	591.0	554.1	517.4	546.9
50A	3063.4	790.8	590.4	554.0	517.8	546.9
65A	3063.4	790.8	588.8	553.8	518.8	546.9
75A	3063.4	790.8	590.4	554.0	517.8	546.9

4.3 Analysis of Daily Average Outlet Temperature and Electricity Consumption According to Pipe Diameter

In this section, the flow rate of the Base Model was varied to analyze seven cases where the flow rate was 3.67, 5.67 (Base Model), 7.67, 9.67, 11.67, 13.67, and 15.67 kg/s, each flow rate is different by 2 kg/s with reference to the Base Model flow rate 5.67 kg/s. Table 6 shows the day average heat pump outlet temperature according to the flow rate of each heat source, which was calculated by the heat transfer equation mentioned above. Since the air heat source was constant, regardless of the flow rate, the air heat source temperature was constant as -6.35℃ in all the cases. Overall, the outlet temperature of sea water and river water was decreased as the flow rate was increased, except in the cases of power plant waste heat water, geothermal heat, and air. It was because, as the flow rate was increased, the rate of the flow of sea water and river water heat sources, having a temperature lower than the underground soil temperature, toward the heat pump outlet was increased, and thus the sea water and the river water arrived at the outlet without gaining sufficient heat from the underground soil. On the other hand, as the flow rate was increased, the outlet temperature of power plant waste heat water, having a temperature higher than the underground soil temperature, was increased. Due to the page limit, effects of fluid flow rate variations on the heat pump COP are not discussed in this paper. Instead, Fig.1 show the daily accumulated electricity consumption for each heat source and the boiler gas consumption according to the flow rate. The electricity consumption was constant in the cases of geothermal heat and air, while the electricity consumption was increased by 10.83% and 1.92% in the case of sea water and river water, respectively, as the flow rate was increased from 3.67 kg/s to 15.67 kg/s. On the other hand, in the case of power plant waste heat water having a temperature higher than that of the underground soil, the electricity consumption was decreased by about 7.90%, as the flow rate was increased from 3.67 kg/s to 15.67 kg/s. This was the effect of the heat pump arrival temperature of fluid and the COP, as described above.

Table 5. Average outlet temperature of each heat source according to flow rate in the pipe (℃)

Average Pipe Air Velocity	Air Source	Sea Water	River Water	Power Plant Waste Heat	Geothermal
3.67	-6.3	9.9	11.6	13.3	11.9
5.67	-6.3	8.2	11.3	14.5	11.9

7.67	-6.3	7.0	11.1	15.4	11.9
9.67	-6.3	6.1	10.9	16.1	11.9
11.67	-6.3	5.4	10.8	16.6	11.9
13.67	-6.3	4.8	10.7	16.7	11.9
15.67	-6.3	4.4	10.6	17.3	11.9

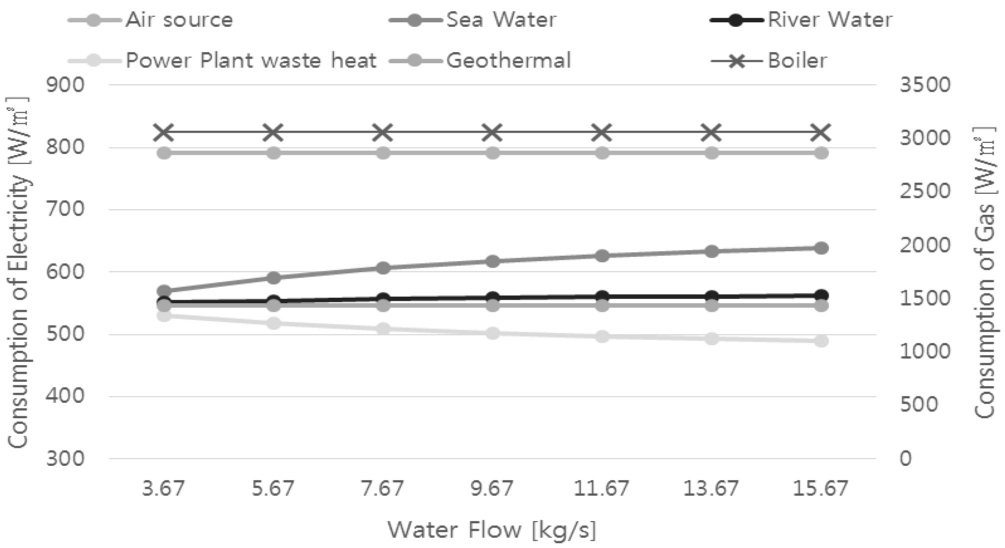

Figure 1. Daily average electricity and gas consumption per unit area according to the flow rate

5. CONCLUSION AND IMPLICATIONS

In the present study, the pipe diameter and the flow rate for energy supply in a large-scale horticulture facility were set as variables to compare the outlet temperature pattern and the electricity consumption. The following conclusions were made on the basis of the results:

(1) As the pipe diameter was increased from 25A to 65A, the fluid outlet temperature was a little increased in the cases of sea water and river water, while the outlet temperature was a little decreased in the case of power plant waste hot water.

(2) With respect to the average COP and electricity consumption for each heat source according to the pipe diameter, the difference in the pattern was negligible, indicating that the effect of the pipe diameter variation on the variation of the temperature, COP, and electricity consumption was insignificant.

(3) As the flow rate was increased, the outlet temperature was decreased in the cases of sea water and river water, while the outlet temperature was increased in the case of power plant waste heat water. This may be because the flow velocity from the inlet to the outlet was increased as the flow rate was increased, reducing the heat gain and loss due to the temperature difference between each heat source and the underground soil.

(4) The electricity consumption was increased by 10.83% and 1.92% in the case

of sea water and river water, respectively, as the fluid flow rate was increased from 3.67 kg/s to 15.67 kg/s. On the other hand, in the case of power plant waste heat water, the electricity consumption was decreased by about 7.90%.

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