Incheon region which is available in EnergyPlus. In the previous study, the efficiency and gas consumption of a boiler used in a glass greenhouse of about 1 ha were compared with the coefficient of performance (COP) and electricity consumption of the heat pumps using different heat source (Hyun, I. T. et al. 2014). Table 1 shows the heat sources in each case. An economic assessment was performed with reference to Table 1 to compare the cost of electricity consumption against gas consumption for conventional gas boiler. The gas and electricity cost was calculated using the current gas price and electricity price. The initial investment cost for each facility was calculated with reference to previous studies. On the basis of the results, a LCC analysis was finally performed to calculate the initial investment payback period in order to propose a heating system for saving horticulture facility heating energy.

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	Waste water from power plant
4	Fan coil unit	Heat pump	Sea water
5	Fan coil unit	Heat pump	River
6	Fan coil unit	Heat pump	Geothermal (groundwater)

2. Energy Consumption Analysis

2.1 Boiler Efficiency and Performance Coefficient of Heat Pump for Each Heat Source

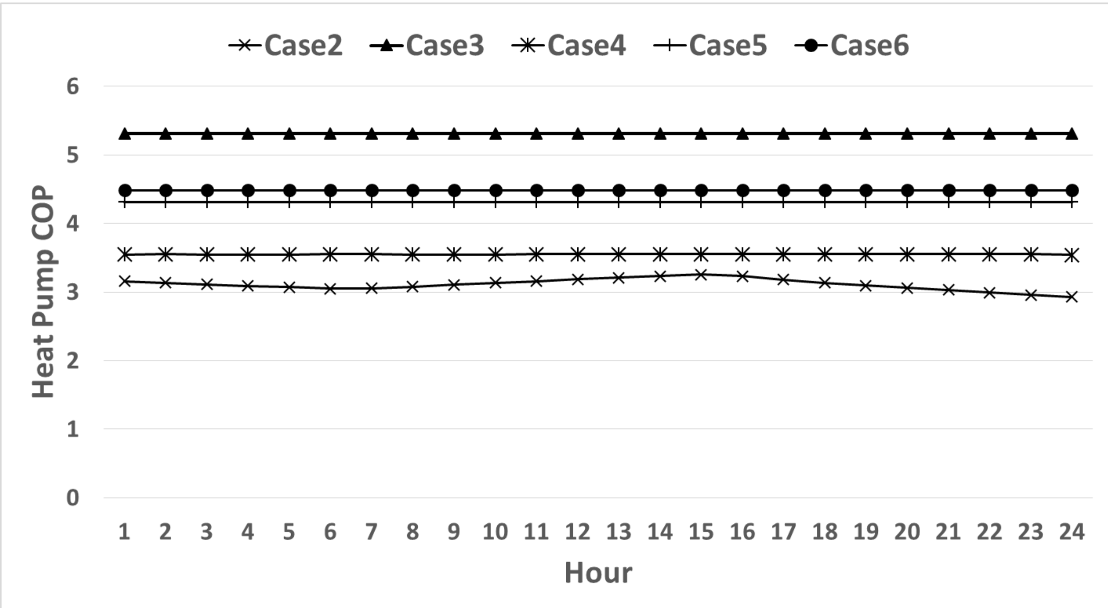

Figure 1. Heat pump COP variations (Hyun, I. T. et al. 2014)

Fig. 1 shows the COP of the heat pump for each heat source. Cases 2, 3, 4, 5, and 6 shown in Fig. 1 are mentioned in Table 1 above. Case 1 represents the reference model, and the performance of Case 1 is represented by boiler efficiency. In other five Cases, the performance was represented by the COP of heat pumps. The efficiency of Case 1, the Base Model, was maintained mostly at about 80% for 24 hours with a fluctuation of about 0.4%. In Cases 2 to 5 where a heat pump was used, COP was the highest for the heat pump using power plant waste heat whose temperature was high and the energy loss was the least. The COP was the lowest for the heat pump using air heat. This showed that the performance of a heat pump was greatly affected by the temperature of the used heat source. Therefore, it was presumed that the electricity consumption may be lower when a heat pump using higher temperature heat source is applied, since the energy loss by the compressor of the heat pump is less.

2.2 Energy Consumption by Boiler and Heat Pump for Each Heat Source

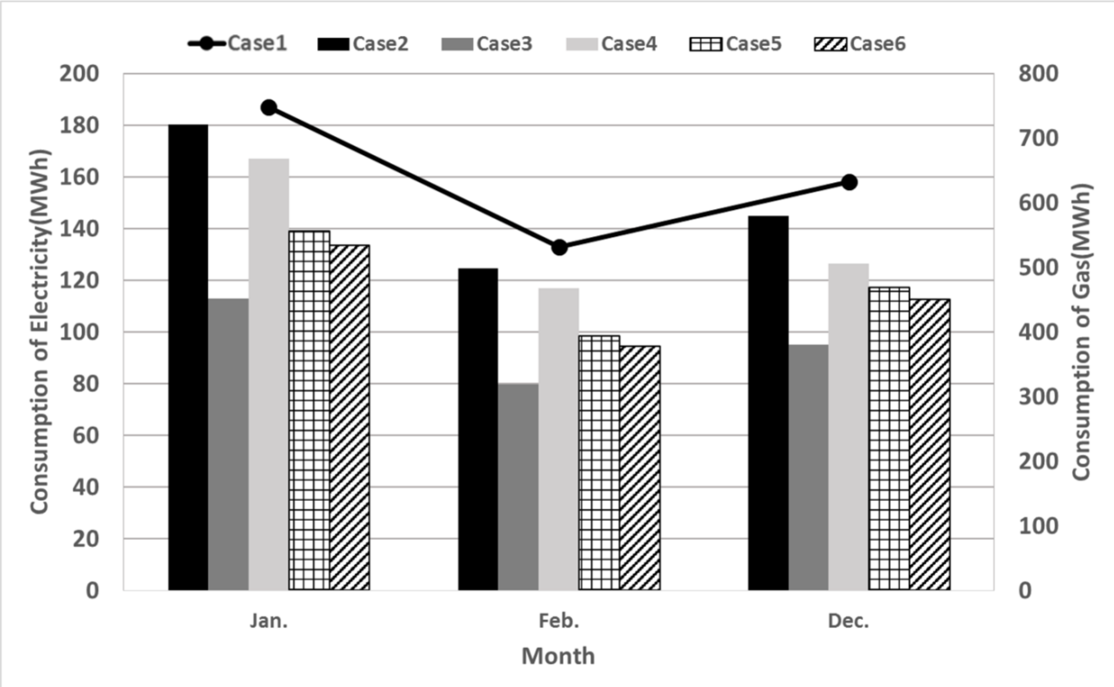

Figure 2. Monthly total consumptions for boiler gas and heat pump electricity (Hyun, I. T. et al. 2014)

Fig. 2 shows the gas consumption of boiler (case1) and the electricity consumption by the heat pumps for each heat source (case2-6) in winter. The consumption was the lowest in February and the highest in January in all the Cases. Beside the fact that the number of day in February is 28 which is lesser than that of other months, the air temperature in February was higher than in December and January. Therefore, the energy consumption was lower in February. In addition, in Cases 2 to 6, the electricity consumption was the lowest with the heat pump using power plant waste heat for which COP was the highest. The heat pump using air heat for which COP was the lowest showed the highest electricity consumption, since the energy loss was high. As compared to the gas consumption of boiler, the electricity consumption by the heat pumps for each heat source was four to six times lower, indicating that the heat pumps are better than the boiler in terms of energy saving and economic feasibility. The following analysis was performed on the basis of the previous results.

3. Economic Assessment

3.1 Overview of Heating Cost Calculation for Each Case

The energy prices applied to the heating cost analysis were the winter gas price for industrial uses, 20.8447 KRW/MJ ($0.02/MJ), with reference to the Seoul City Gas price standards (Anon. A), and the electric power price for agricultural uses, 1,210 KRW (Basic Price) + 41.9 KRW/kWh ($0.04/kWh) energy charge, with reference to the price standards of Korea Electric Power Corporation (Anon. B). When calculating the gas price, the heat utilization efficiency of the boiler was assumed to be 80%. The rated electric power of the heat pumps for each heat source was determined by assuming that 3.5 KW is handled by 1 RT for heating of 33 m^2 area, and the COP was assumed to be 3.0, which was the reference value of the heat pump using air heat. As a result, the heat pump capacity was 1050 KW for heating of 10,000 m^2, and the contract electric power was 350 KW. The initial investment was calculated by applying the unit price of 1,300,000,000 KRW/ha ($1,268,911.7/ha) which is given by Agriculture and Fishery Industry Energy Utilization Efficiency Improvement Project (Ministry for Food, Agriculture, Forestry, and Fisheries of Korea) in the case of the geothermal heat pump. In other heat pump cases, the unit price of 1,000,000,000 KRW/ha ($976,085.9/ha) is applied, which was the facility investment cost calculated by the Jeju Branch of Korea Rural Community Corporation in the hot waste water utilization project in 2011 (Heo, T. H. 2012).

3.2 Operation Cost Calculation

To calculate the operation cost of each system, gas and electricity consumption was calculated by using cooling and heating loads and COP of each system. Then monthly consumption for winter was converted into price and compared with each other.

Table 2. Total calculated fuel consumption and operation cost (Unit: 1,000₩, $)

		Heating Consumption	Gas Operation Cost [₩/MJ]	Electric Operation Cost [₩/kWh]	Total Operation Cost [₩]($)
Case_1 (MJ) [Gas]	Jan.	2,691,216	56,097	-	143,418 ($139,988.3)
	Feb.	1,911,240	39,839		
	Dec.	2,277,900	47,482		
Case_2 (kWh) [Electricity]	Jan.	180,331.02	-	7,979	20,126 ($19,644.7)
	Feb.	124,687.54		5,647	
	Dec.	145,000.53		6,449	
Case_3 (kWh) [Electricity]	Jan.	112,897.22	-	5,153	13,335 ($13,016.1)
	Feb.	79,825.29		3,768	
	Dec.	95,221.81		4,413	
Case_4 (kWh) [Electricity]	Jan.	166,931.40	-	7,417	18,467 ($18,025.4)
	Feb.	116,987.65		5,325	
	Dec.	126,511.75		5,724	
Case_5	Jan.	139,079.32	-	6,250	16,133

(kWh)	Feb.	98,337.65		4,543	($15,747.2)
[Electricity]	Dec.	117,304.79		5,338	
Case_6	Jan.	133,638.69	-	6,022	15,551
(kWh)	Feb.	94,490.78		4,382	($15,179.1)
[Electricity]	Dec.	112,715.95		5,146	

Table 2 shows the operation cost of each case according to the gas or electricity consumption. The calculation results showed that the cost of gas price consumed by a conventional boiler in winter was about 143,418,000 KRW ($139,988.3) cost. With respect to the electricity price of the heat pumps in each case, for heat pump using air heat was 20,126,000 KRW ($19,644.7), for power plant waste heat water was 13,335,000 KRW ($13,016.1), for sea water was 18,467,000 KRW ($18,025.4), for river water was 16,133,000 KRW ($15,747.2), and for geothermal heat was 15,551,000 KRW ($15,179.1). This result showed that about 91% of the winter heating energy cost was reduced by using the heat pump using power plant waste heat water having the highest efficiency in comparison with the energy cost of a gas boiler. In addition, even when the heat pump using air heat, having the lowest efficiency, was used, about 37% of the winter heating energy cost was reduced in comparison with the energy cost of the gas boiler. Therefore, the cost assessment showed that the heat pump using power plant waste heat water was the most economical in terms of operation cost.

3.3 Life Cycle Cost Analysis

Table 3. Cost/Benefit analysis for the Cases (Unit : 1,000₩, $, ha)

Description	Case2	Case3	Case4	Case5	Case6
Equipment cost	1,000,000 ($976,086)	1,000,000 ($976,086)	1,000,000 ($976,086)	1,000,000 ($976,086)	1,300,000 ($1,268,912)
Annual reduction in energy expenses	123,290 ($120,342)	130,080 ($126,969)	124,950 ($121,962)	127,290 ($124,246)	127,870 ($124,832)
Payback period	8.11 yr.	7.69 yr.	8.00 yr.	7.86 yr.	10.17 yr.

Table 3 shows the initial investment payback period of the heat pumps for each heat source, as analyzed by the LCC analysis in comparison with the gas boiler. Although more initial cost is required to install the heat pumps for each heat source in a large-scale horticulture facility, since the operation cost represented by the energy cost was lower, the facility cost payback period was about 7.69 years in the case of the heat pump using power plant waste heat water and about 10.17 years in the case of the heat pump using geothermal heat. The initial investment payback period of the heat pump using geothermal heat was longer than that of other heat pumps because the investment cost was higher due to the cost for installing an underground heat exchanger. On the other hand, since the cooling energy was not taken into account in the analysis of the present study, the payback period may be much shorter than the analyzed values as the application of the heat pumps enables cooling in summer, increasing production and saving cooling energy. In addition, since the heat pump facilities are semi-permanent, when the initial facility investment is resolved, long-term and stable cooling and heating energy supply may be realized for individual farms, resulting in efficient agricultural production.

4. CONCLUSION AND IMPLICATIONS

The present study considered heat from air, power plant waste, sea water, river water, and geothermal, which are the available alternative energy sources, as heat source for heat pumps that can be installed in a large-scale horticulture facility. In addition, the electricity cost according to the electricity consumption by the heat pump using each heat source was compared with the gas cost of a general gas boiler to analyze the economic feasibility. The conclusions made on the basis of the analysis are as follows:

(1) The performance of a general gas boiler and heat pumps for each heat source was analyzed. With respect to the heat pumps for each heat source, the COP of the heat pump using air heat was 3.11, for power plant waste heat water was 5.31, for sea water was 3.54, for river water was 4.31, and for geothermal heat was 4.49, indicating that the heat pump using power plant waste heat water has the best performance.
(2) The gas consumption by the gas boiler and the electricity consumption by the heat pumps for each heat source were analyzed for the winter season. The gas consumption by the gas boiler was 1911.21 MWh. The electricity consumption by the heat pumps for each heat source was 450.02 MWh, 287.95 MWh, 410.43 MWh, 354.72 MWh, and 340.85 MWh, in the order of air heat, power plant waste heat water, sea water, river water, and geothermal heat. The result indicated that the energy consumption was the lowest for heat pump using power plant waste heat water, since the temperature of power plant waste heat was higher and the energy loss by the compressor was lower.
(3) The current energy unit price was applied for analyzing energy consumption. The gas cost in winter was 143,418,000 KRW ($139,988.3). The electricity cost in winter was 20,126,000 KRW ($19,644.7), 13,335,000 KRW ($13,016.1), 18,467,000 KRW ($18,025.4), 16,133,000 KRW ($15,747.2), and 15,551,000 KRW ($15,179.1) in Cases 2 to 6, respectively. It shows that, compared to gas cost of general gas boiler, up to 91% of heating energy cost was reduced by using heat pump using palnt waste heat water having the highest efficiency.
(4) The initial cost and operation cost were analyzed to calculate the investment cost payback period. In comparison with the gas boiler, the investment cost payback period of the heat pump using air heat was about 8.11 years, one using power plant waste heat water was about 7.69 years, using sea water and river water was about 8.00 years and about 7.86 years, respectively, and the one using geothermal heat was about 10.17 years. The heat pump using geothermal heat showed the longest investment cost payback period due to the initial investment cost increased by installation of an underground heat exchanger.

The present study did not include cooling energy saving analysis. The investment cost payback period may be much shorter than the values presented in this study. Future integrated studies may be conducted to perform a more precise analysis in order to provide fundamental data for increasing the efficiency of agricultural production.

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