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Analysis on Heating Effects of the Vertical Type Geothermal Heat Pump System

Youn Ku Kang*, Young Sun Ryou, Jae Kyung Jang, Young Hwa Kim

Dept. of Agricultural Engineering, National Academy of Agriultural science, RDA, Suwon 441-707, Korea

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Abstract

Purpose: This paper is aimed at analyzing the heating performance of the vertical closed loop type Geothermal Heat Pump System (GHPS) distributing the farm site and providing basic data of the GHPS. **Method:** Seedling greenhouse heating was made from October 2012 to May 2013. The seedling greenhouse was divided into 4 sectors (A, B, C and D zone, total 3,300 m^2) with different temperatures. It was heated from 5PM to 8AM, and during the night the greenhouse was covered by non-woven fabric thermal curtains along the upper 2m of the greenhouse for temperature maintenance. In order to analyze the heating performance of the GHPS, power consumption and operating time of the GHPS, inlet and outlet water temperature of the condenser, temperatures of each zone of the greenhouse, and ambient temperature were measured. **Results:** When operating only one heat pump unit, heat generated in the condenser decreased as the experiment progressed and power consumption increased correspondingly. However, the heating coefficient of performance decreased from 3.3 to 2.0 rapidly. Also, when operating two heat pump units, heat generated in the condenser decreased and power consumption increased. Heating coefficient of performance decreased from 4.5 to 3.7 rapidly. When the set temperature of the greenhouse was 13.7~20.1°C and minimum ambient temperature was -20.8~4.8°C, the annually accumulated heat and power consumption were 520,623 kW, 142,304 kW, respectively. **Conclusion:** When the set temperature of the greenhouse was 13.7~20.1°C and the minimum ambient temperature was 20.8~4.8°C, the annually accumulated heat and power consumption were 520,623 kW, 142,304 kW, respectively. When operating only one heat pump unit, the heating COP was 2.0~3.3, and when operating 2 heat pump units, it was 3.7~4.5. If several heat pumps are installed in one GHPS, it is suggested that all heat pumps be operated except in special cases. Because the scale of the water pumps are set to the scale of when all heat pump units are operating, if even one unit is not operating, the power consumption will increase. That becomes the cause of COP decrease.

Keywords: Coefficient of Performance, Geothermal Heat Pump System, Greenhouse, Heating

Introduction

When energy resources are insufficient, energy conservation and reasonable energy use technology play an important role in national economy and industrial development. The Geothermal Heat Pump System (GHPS) has been distributed since 2009 in order to reduce heating cost in horticulture. Its distribution area is growing continuously. Heating area was 16,263ha in 2011, and 64% of the tax-free oil (mainly diesel) was used for heating the horticulture facilities (Mifaff, 2012).

Currently, GHPS is considered the most effective method for heating to the horticulture facilities. Developed countries have studied various geothermal energy uses, presenting the standards of GHPS, and distributed multiple case data to engineers in order to promote GHPS use (Morrison & Christopher, 1997; Kavnaugh & Rafferty, 1997).

Geothermal technology refers to the utilization of stored heat energy or moisture in soil, and geothermal energy is expected to be an alternative energy source in various industries including agriculture. The vertical type GHPS

***Corresponding author:** Youn Ku Kang
Tel: +82-31-290-1813; **Fax:** +82-31-290-1840
E-mail: ykk0977@korea.kr

can be divided into two types depending on the heat exchanger type: the closed loop type and the open loop type.

The vertical type of geothermal heat exchanger may be used when the soil is too shallow for trenching or when one does not want to disturb the existing landscaping. The closed loop type uses soil as heat source and the open loop type uses water drawn from the bottom of the deep rock well as its heat source. The open loop type may cause groundwater contamination.

In Korea, the closed loop type is used in most agriculture facilities for heating and cooling. GHPS was launched by Heinrich Zoelley in 1912 (Ball *et al.*, 1983). Due to its excellent heating and cooling performances, many countries have conducted further studies for over 30 years. Developed countries, including Europe and Japan, are researching actively for various heat sources. Especially, as for the system, the U.S. is making active Geothermal Energy Programs under U.S. Department of Energy and the National Renewable Energy Laboratory (NREL) support. Oklahoma State University and Institute of Geothermal Bore Technologies are also actively conducting research to develop the popular type GHPS under U.S. government support. Bose analyzed changes in soil temperature around vertical ground heat exchangers by numerical analysis (Bose, 1988). Doherty, *et al.* (2004) from the Millennium Eco-Experimental House of Nottingham University, examined GHPS performance using the U-tube type geothermal exchanger with depth 18 m, outer diameter 32 mm, and the horizontal geothermal exchanger with outer diameter 25 mm, length 150 m, depth 2 m. Lund & Freeston (2005) reported that GHPS distribution had a growth of 59% since 1995, growing 9.8% annually. Lund (2003) reported that, as of 2000 in U.S., the distribution unit number of GHPS was about 450,000, growing 50,000 a year, and assumed that it would reach about 1.5 million by 2010. Hepbasli and Akdemir (2003) analyzed energy and exergy of the vertical type GHPS. Kavanaugh (1998) made a test module to measure the pressure drop and head loss of pipes in GHPS plumbing fixtures and offered the pressure drop and head loss values.

In Korea, the installation area of GHPS has been growing and it is reported that the area has reached about 200ha in agriculture. The objective of this paper is to analyze the heating performance of the vertical closed loop type GHPS distributed throughout the farm site.

Materials and Methods

The vertical closed loop type geothermal heat exchanger was used in this study. After drilling a borehole with diameter 15 cm, depth 200 m, high density PE pipes with outer diameter 27 mm, inner diameter 21 mm were inserted into the boreholes. The gap between the boreholes was 5 m and we drilled a total of 26 boreholes. We also installed two water-to-water type heat pumps with a capacity of 175 kW (50 RT). The thermal storage tank made of FRP

Table 1. Specifications of the vertical type geothermal heat pump system and the boiler

Items			Specifications
Geothermal heat exchanger	Bore hole	Diameter Depth Gap	Outside diameter : 15cm 200 m × 26 ea 5 m
Heat pump	Compressor	Type Capacity Voltage	High temperature scroll type 175 kW × 2 units (Refrigeration base) 380 V, 3 Phase
	Condenser / Evaporator Refrigerant		Flat type heat exchanger R507a
Thermal Storage tank	Material Diameter × Height Insulation thickness		Fiber reinforced plastics(FRP) 4.7 m × 3.1 m 5 cm(By urethane foam)
Fan coil unit	Type The number Remark		Vertical standing 8 They were installed front and rear in the greenhouse
Boiler	Capacity The number Type(fuel)		233 kW 1 Gun type burner(Diesel)

material and the exterior was made of 5 cm of polyurethane for insulation. The diameter of the tank was 4.7 m, its height was 3.1 m, and 52.5 tons of warm water was stored in it. The warm water in the thermal storage tank was sent to pan coil units installed in the greenhouse. 8 of the vertical type pan coil units were installed front and rear in the greenhouse. Table 1 shows specifications of the vertical closed loop type GHPS and boiler used in this study.

The GHPS was installed in 3,300 m^2 seedling greenhouse in Icheon, Gyeonggi-do. Figure 1 shows the schematic diagram of the geothermal heat exchangers installation site. Figure 2 is the aerial photo of the greenhouse. Figure 3 shows the schematic diagram of the system. Figure 4 is the photo of the GHPS and its pipe lines.

As shown in Figure 3, the heat transfer fluid (water) gains heat from geothermal heat exchangers and flows into the evaporator passing through header and the

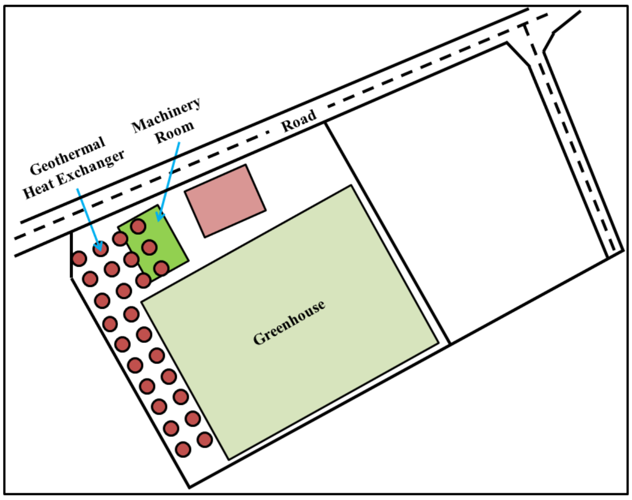

Figure 1. Schematic diagram installation site of the geothermal heat exchangers.

Figure 2. The aerial photo of the greenhouse.

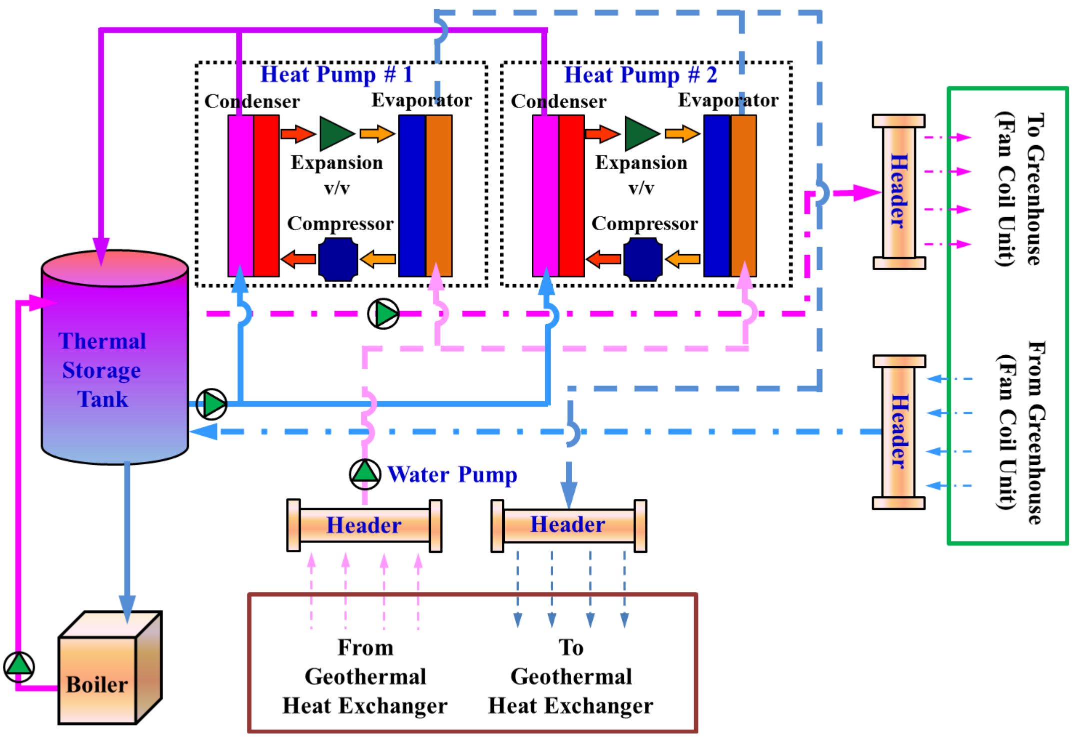

Figure 3. Schematic diagram of the system.

Figure 4. Photo of the system and the pipelines.

pipelines. The heat transfer fluid (water) transfers the heat to the refrigerant in the evaporator. The heat evaporates the refrigerant in the evaporators. The evaporated refrigerant flows into the compressor, and then is compressed and heated. The refrigerant, compressed and heated, flows into the condenser and transfers the heat to the heat transfer fluid flowing through the thermal storage tank and the pipelines. The hot water is stored in the thermal storage tank, and then the hot water is sent to the greenhouse. The hot water is used for heating the greenhouse.

The heat pumps were installed into two units, and the heat transfer fluid flowing through the condenser or the evaporator either separates or meets.

The seedling greenhouse heating operated from October 2012 to May 2013. The greenhouse was divided into 4 sectors (A, B, C and D zone, total 3,300 m^2), and the 4 zones could be managed in different temperatures. The greenhouse heating operated from 5 pm to 8 am every day. During night the greenhouse was covered by non-woven fabric thermal curtains along the upper 2 m of the greenhouse for minimizing heat loss. Table 2 indicates the monthly average greenhouse temperature, and the maximum, average and minimum ambient temperatures. The oil boiler was also used for heating during periods of extreme cold.

To analyze the heating performance of the GHPS, the condenser outlet water temperature (leaving water temperature of the condenser; LWT of the condenser), the condenser inlet water temperature (entering water temperature of the condenser; EWT of the condenser), temperatures of each zone of the greenhouse, and ambient temperature were measured.

Also, we measured the total electrical power consumption of the GHPS and the flow rate of water to the condenser. Operating state of the GHPS and the boiler were managed and monitored by Control and Monitoring system.

The coefficient of performance was calculated by equation (1).

$$COP_h = \frac{\rho_w \cdot \ V_w \cdot \ c_w \cdot \ (T_{w,o} - T_{w,i})}{P_{HP}} \quad (1)$$

where, COP_h : Heating coefficient of performance, P_{HP}: Total electric power consumption of the GHPS(kW), ρ_w: Density of heat transfer fluid(water) (kg/m^3), V_w : Volumetric flow rate of heat transfer fluid(m^3/s), c_w: Specific heat of heat transfer fluid (kJ/kg℃), $T_{w,i}$, $T_{w,o}$: condenser inlet and outlet temperature of heat transfer fluid (°C)

Table 2. Monthly average greenhouse temperature, and the maximum, average and minimum ambient temperatures

Month	A zone temp. (°C)	B zone temp. (°C)	C zone temp. (°C)	D zone temp. (°C)	Max. ambi. temp. (°C)	Ave. ambi. Temp. (°C)	Min. ambi. temp. (°C)
Oct.	19.0	19.5	15.4	15.2	24.2	9.1	-0.7
Nov.	19.0	19.2	13.8	13.7	15.0	1.8	-6.2
Dec.	17.9	19.5	14.5	12.9	7.7	-6.8	-17.2
Jan.	17.4	18.7	15.4	15.3	4.8	-6.8	-20.8
Feb.	17.5	19.5	16.7	16.4	12.0	-3.2	-17.7
Mar.	18.6	19.8	17.7	17.6	23.5	2.4	-6.0
Apr.	18.6	19.7	18.0	18.0	25.8	7.2	-2.8
May	20.0	20.1	19.2	19.1	32.0	22.0	4.8

Results and Discussion

Variations of leaving and entering water temperatures of the condenser in heat storage time (5:00 PM of October 1st, 2012 to 10:50 PM of October 3rd, 2012)

Figure 5 shows variation of the leaving and entering water temperatures of the condenser, as in the difference of leaving and entering water temperatures of the condenser and the GHPS operation state when storing hot water in the thermal storage tank (5:00 PM of October 1st, 2012 to 10:50 PM of October 3rd, 2012). As mentioned above, the leaving water temperature (LWT) of the condenser indicates the condenser outlet water temperature and the entering water temperature (EWT) of the condenser inlet water temperature. The line expressed as 0, 1, or, 2 in the figure indicates the operation state of the GHPS, where 0 indicates the stop state, and 1 and 2 indicates an operation state. Which is from 0 minute to 319 minutes and from 369 minutes to 386 minutes, number one heat pump (the dashed line) was not operated, and number two (the solid line) heat pump was only in operation (a and c sections in Figure 5), but for 48 minutes from 320 minutes to 368 minutes, number one and two heat pumps both were operated (b section in Figure 5).

As shown in the figure, it took 386 minutes to increase the entering water temperature of the condenser from 14.1°C to 43.6°C. The entering and leaving water temperatures (EWT and LWT) of the condenser increased linearly with time. Based on the leaving water temperature of the condenser when operating only one heat pump unit, the leaving water temperature of the condenser increased by about 0.07°C per minute (for 319 minutes, the water temperature increased from 18°C to 39.9°C). But when operating two heat pump units, it increased by about 0.1°C per minute (for 48 minutes, the water temperature increased from 42.4°C to 47°C). It should be two times arithmetic when operating two heat pump units vs. one, because number one and number two heat pumps were the same scale (175 kW). But it was not so. It is considered to be because the entering water temperature of the condenser was higher when operating two heat pump units, That is to say, as the entering water temperature of the condenser increased, heat transferring refrigerant and the water in the condenser gradually decreased. The difference of the leaving and entering water temperatures of the condenser gradually decreased with time from 3.9°C to 3.1°C. Also, it indicates that as the entering water temperature of the condenser increased, the heat transferring refrigerant and the water in the condenser gradually decreased.

Variations of the total electric power consumption and heating COP in heat storage time (5:00 PM of October 1st, 2012 to 10:50 PM of October 3rd, 2012)

Figure 6 shows variations of the total electric power consumption and heating COP in heat storage time (5:00 PM of October 1st, 2012 to 10:50 PM of October 3rd, 2012). The total electric power consumption indicates electricity power consumed by the entire GHPS, which includes the heat pump, water pumps, etc.

As shown in the figure, when operating one heat pump unit (0 minute ~ 319 minutes), the heat generated in the

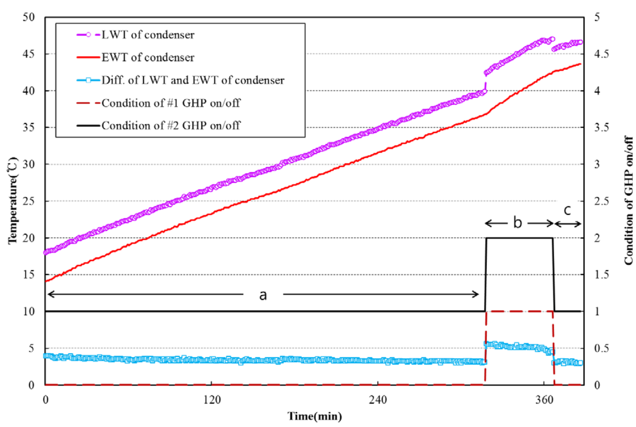

Figure 5. Variations of leaving and entering water temperatures of the condenser through the duration from 5:00 PM of October 1st, 2012 to 10:50 PM of October 3rd, 2012.

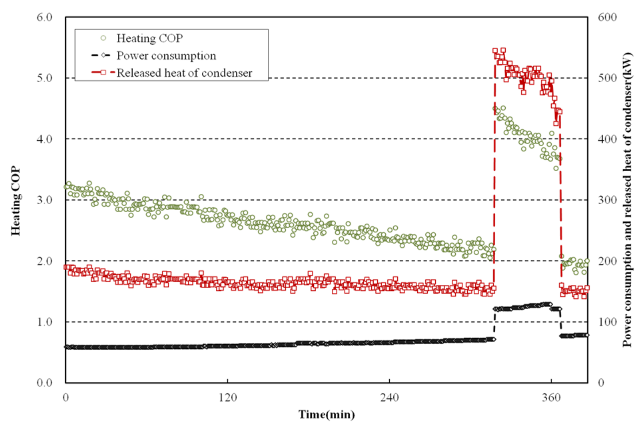

Figure 6. Variations of the total electric power consumption and heating COP through the duration from 5:00 PM of October 1st, 2012 to 10:50 PM of October 3rd, 2012.

condenser decreased as the experiment progressed, and the power consumption increased correspondingly. However, the heating coefficient of the performance rapidly decreased from 3.3 to 2.0. Also, for 48 minutes (from 320 minutes to 369 minutes), when operating two heat pump units, the heat generated in the condenser decreased and power consumption increased. And heating coefficient of performance rapidly decreased from 4.5 to 3.7. It was considered to be because the entering water temperature of the condenser became higher as the experiment progressed which causes the temperature difference between the condenser inlet and outlet (the difference between LWT and EWT of the condenser) to be lower (refer to Figure 5) and power consumption to go higher.

As mentioned above, because the heating COP is the value of the heat generated by the condenser divided by the total power consumption (see equation 1), the heating COP when operating two heat pump units should be very similar to the heating COP when operating one heat pump unit. Theoretically, the heat generated by the condenser when operating two heat pump units should be two times greater than the heat generated by the condenser when operating one heat pump unit. Naturally, the total power consumption when operating two heat pump units should be two times greater than the total power consumption when operating one heat pump unit. Therefore, the heating COP when operating two heat pump units should be similar to the heating COP when operating one heat pump unit. But in this experiment, the heating COP when operating one heat pump unit was in the range 2.0 to 3.3 and the heating COP when operating two heat pump units was in the range of 3.7 to 4.5. It is because of the installation method of the pipelines, the scale of the water pumps, etc.

In general, when installing large scale heat pumps, the heat pump is divided into small scales and then installed. For example, when installing a 300 kW scale heat pump, the heat pump was installed in two units (175 kW × 2 units) for maintenance and control. But the pipeline was integrally installed. As shown in Figure 3, the heat pumps were installed into two units; the pipelines streaming the heat transfer fluid (water) were integrated. The heat transfer fluid flowing through the condenser or the evaporator either separates or meets. It means that the scale of the water pumps should fit with the scale of the two heat pump units. If one heat pump unit is operated, it means that the power consumption is higher than the power consumption of two heat pump units operating, and the heating COP when operating one heat pump unit is smaller than the heating COP when operating two heat pump units.

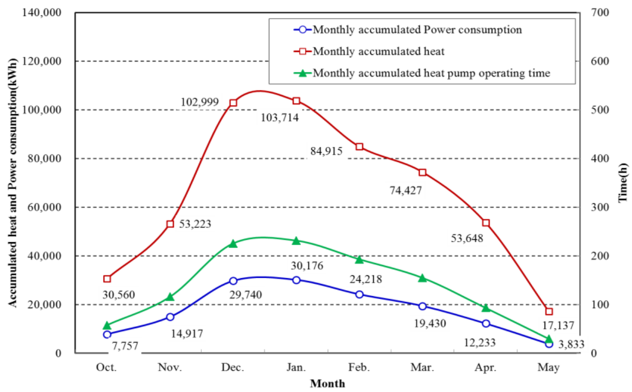

Figure 7. Variations of monthly accumulated heat, monthly accumulated power consumption and heat pump operation time.

If several heat pumps are installed in a GHPS, it is suggested that all heat pumps operate, except to special cases. This is considered to be the economical operating method of the GHPS.

Variations of monthly accumulated heat, power consumption, and heat pump operation time

Figure 7 shows monthly accumulated heat, power consumption, and heat pump operating time.

When the set temperature of the greenhouse was 13.7~20.1°C and the minimum ambient temperature was -20.8~4.8°C, the monthly accumulated heat was greatest in January, followed by December, February, March, April, November, October, and May in at order. The monthly accumulated heat in January was about six times greater than that in May.

The annually accumulated heat and power consumption were 520,623 kW, 142,304 kW respectively. And the output energy (the annually accumulated heat) was about 3.6 times greater than the input energy (the annually accumulated power consumption).

Conclusion

The aim of this study was to analyze the heating effects on the 3,300 m^2 seedling greenhouse through the 350 kW (175 kW×2 units) scale vertical closed loop type geothermal heat pump system from October 1st, 2012 to May 31st, 2013 and provide basic data of the GHPS.

When the set temperature of the greenhouse was 13.7~20.1°C and the minimum ambient temperature was -20.8~4.8°C, the annually accumulated heat and power consumption were 520,623 kW, 142,304 kW respectively.

The heating COP when operating one heat pump unit was 2.0~3.3, and the heating COP when operating two heat pump units was 3.7~4.5.

If several heat pumps are installed in a GHPS, it is suggested that all heat pumps operate, except to special cases. This is because the scale of the water pumps fits with the scale when all heat pump units are operating, and if one unit among all the units is not operated, then the power consumption increase, and becomes the cause of the decreasing COP.

Conflict of Interest

The authors have no conflicting financial or other interests.

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References

Ball, D. A., Fisher, R. D and D. L. Hodgett. 1983. Design methods for ground-source heat pump. ASHRAE Trans. 89(2B):416-440.

Bose, J. E. 1988. Closed-loop ground-coupled heat pump design manual. Stillwater, OK : Oklahoma state university, Engineering Technology Extension.

Cane, D., Morrison, A and K. Christopher, 1998. Operating experiences with commercial ground-source heat pump systems. ASHRAE.

Doherty, P. S., Al-Huthaili, S., Riffat, S. B and N. Abodahab. 2004. Ground source heat pump - description and preliminary results of the Eco House system. Applied thermal engineering 24:2627-2641.

Esen, H and M. Inalli. 2006. Technoecomic appraisal of a ground source heat pump system for a heating season in eastern Turkey. Energy Conversion and Management 47:1281-1297.

Hepbasli, A and O. Akdemir. 2003. Energy and exergy analysis of a ground source (geothermal) heat pump system. Energy conversion and management 45:737-753.

Inalli, M and H. Esen. 2004. Experimental thermal performance evaluation of a horizontal ground-source heat pump system. Applied thermal Engineering 24:2219-2232.

Kavanaugh, S. P. 1998. Development of design tools for ground-source heat pump piping. ASHRAE Trans. 104(1):932-937.

Kavanaugh, S. P and K. Rafferty. 1997. Ground-source heat pumps: Design of geothermal systems for commercial and institutional buildings. ASHRAE.

Lund, J. W and D. H. Freeston. 2001. World-wide direct use of geothermal energy 2000. Geothermics 30:29-68.

Lund, J. W. 2003. Direct-use of geothermal energy in the USA. Applied Energy 74:33-42.

Lund, J. W., Freeston, D. H and T. L. Boyd. 2005. Direct application of geothermal energy:2005 Worldwide review. Geothermics 34:691-727.

Mei, V. C and V. D. Baxter. 1990. Experimental study of direct-expansion ground coil heat exchanger. ASHRAE Trans. 96(1):450-459.

Ministry for Food, Agriculture, Forestry and Fisheries. 2012. Vegetable production performance and flower cultivation status. 11-1541000-000017-10. Gwacheon. Gyounggi.: Ministry for Food, Agriculture, Forestry and Fisheries.