Invited Paper

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# Greenhouse Heating and Cooling with a Heat Pump System using Surplus Air and Underground Water Thermal Energy*

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**Abstract**

Energy saving is an important issue for greenhouse farming. Natural and sustainable energy sources are critical to energy conservation. In this study, greenhouse heating and cooling technology was developed using a heat pump system that used surplus air thermal energy (SATE) and underground water thermal energy (UWTE) as heat sources. The greenhouse system was operated during February and March 2012. The SATE and UWTE system was successfully utilized for heating. Temperature control between desired set-points was also achieved. The heat pump system performed at average COP of 3.25 and 2.84 in February and March, respectively. In conclusion, greenhouse energy conservation was achieved by utilizing SATE and UWTE.

[Keywords] energy saving, heat pump, surplus energy utilization, greenhouse environmental control, natural energy

## I Introduction

Most modern greenhouses include heating and cooling systems. Boilers and electric heaters are usually used for heating, and natural or forced ventilation methods and air conditioners are used for cooling (Nelson, 2003); however, such environmental control units consume large amounts of energy. Sources of energy include oil, gas or coal based on fossil fuels, as well as electricity, which itself is generated via the consumption of fossil fuels. Therefore, the benefits of greenhouse operations are affected by the rise of international energy prices. Furthermore, the use of large amounts of fossil fuels for greenhouse heating and cooling may contribute to global warming. In order to address this problem, it is necessary to identify new energy sources for greenhouse heating and cooling.

In this study, we focus on surplus air thermal energy (SATE) and underground water thermal energy (UWTE) as new energy sources. A greenhouse is an energy-creating building that converts solar radiation into air thermal energy. If solar radiation is intense, indoor greenhouse temperatures can easily increase, even in the cold season. Such temperatures are often too high to grow plants, therefore requiring the greenhouse to be cooled. This situation can be treated as a use of SATE. A previous study estimated the amount of SATE required for such tasks (Suh *et al*., 2009). When SATE is stored in greenhouse water tunnels during the daytime, nighttime temperature drops can be alleviated in the winter (Lee *et al*., 2011). Likewise, a greenhouse system utilizing SATE was designed for a small glass house (Yang *et al*., 2012).

Underground water also includes a significant amount of thermal energy. Because many greenhouses in Korea have underground water sources that are free, UWTE may be a sustainable new energy source. Indeed, UWTE and geothermal energy have long been considered as heat sources for heat pumps (Chen *et al*., 2005; Kang *et al*., 2007).

The objective of this study was to develop a greenhouse heating and cooling system with a heat pump using SATE and UWTE in the greenhouse as heat sources. The use of a heat pump was necessary because surplus thermal energy in the air and underground water sources are low in temperature. We proposed a control algorithm to operate this system, and to evaluate its performance during February and March 2012.

## II Materials and Methods

### 1. Experimental greenhouse

The experimental setting used in this study was a multi-span arch plastic greenhouse located in Hwaseong-si,

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Gyeonggi-do, Korea. The total area of the greenhouse was 5000 m$^2$, 1000 m$^2$ of which was isolated using thermal screens and utilized as an experimental zone (Fig. 1). The greenhouse included double layered thermal screens. We grew *Cymbidium hybida swartz* in the greenhouse during the experiments.

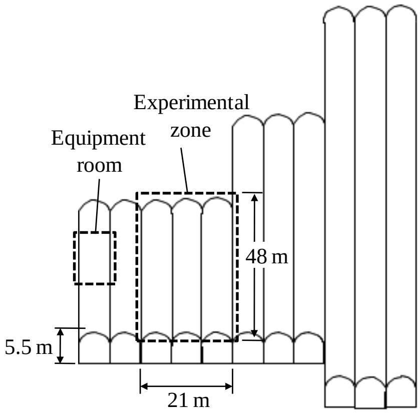



Fig. 1 Plane view of the experimental greenhouse and test zone

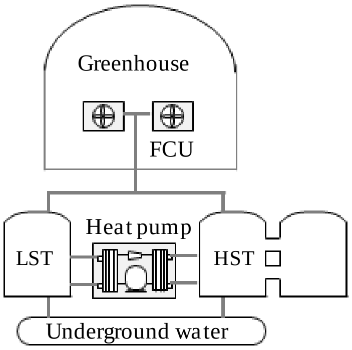
## 2. Heating and cooling system with a heat pump

The heat pump system consisted of a heat pump (13 kW), two high temperature heat storage tanks (HST, 20 m$^3$) and a low temperature heat storage tank (LST, 10 m$^3$). The heat storage tanks contained water. The heat pump condenser and evaporator were connected to the HST and the LST, respectively. The heat pump moved thermal energy from the LST to the HST. The HST and LST were connected to the fan coil units (FCU) in the greenhouse. The FCUs were selectively connected to the LST or HST using 3 way valves. Underground water was pumped into either the LST or HST. Fig. 2 (a) shows the system including the greenhouse, heat storage tanks, heat pump, and underground water. Twenty FCUs were installed and the capacity of each was 0.75 kW.

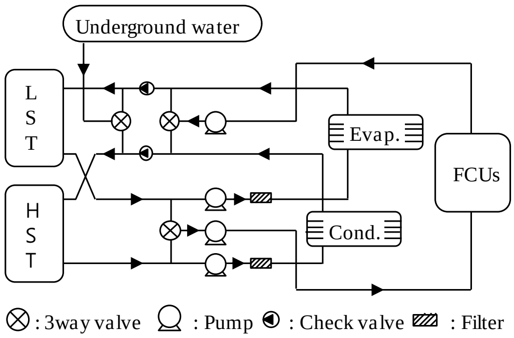
Underground water was pumped at rate of 44 L min$^{-1}$. The pipe connection structure and direction of water flow are shown in Fig. 2 (b). Filters were installed at the inlets of the heat pump. Each heat storage tank had only 1 inlet and 1 outlet, and water selectively circulated the heat pump and the FCUs using 3-way valves, the structures of which are shown in Fig. 3. To simplify the system, all pumps, valves, filters, and water flow meters were integrated in a plumbing module as shown in Fig. 3 (b). FCUs were attached at a distance of 1 m over the plant canopy.

## 3. Control algorithm for system operation

In the concept used to design this study, cooling equaled thermal energy recovery, and heating was used to consume

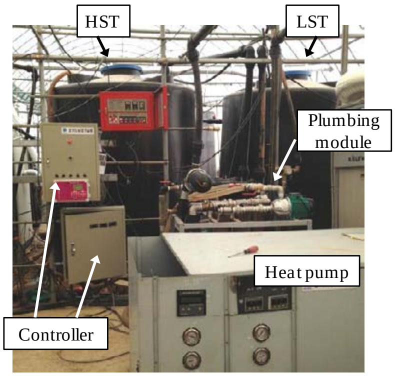



(a) System structure

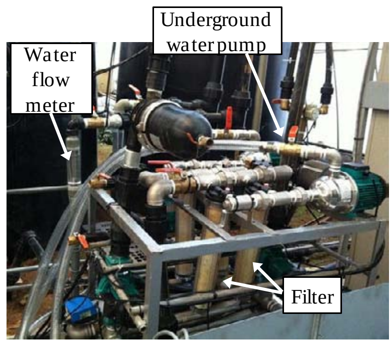



(b) Pipe connection and water flow

Fig. 2 Schematic diagram of the heating and cooling system with a heat pump (Evap. and Cond.: evaporator and condenser in the heat pump)




(a) Overview of the greenhouse system




(b) Integrated plumbing module

Fig. 3 Components of the greenhouse system