Corrigendum

Corrigendum: Performance monitoring and verification of a groundwater source heat pump heating system in a greenhouse (IOP Conf. Ser.: Earth Environ. Sci. 680 012044)

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Performance monitoring and verification of a groundwater source heat pump heating system in a greenhouse

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Abstract. The traditional heating of greenhouse is mainly by burning coal and fuel; this has some disadvantages such as low energy efficiency and high carbon dioxide emissions. As a renewable energy, groundwater source heat pump (GWSHP) has been widely concerned, and its heating application in greenhouse has a significant impact on energy saving and emission reduction. This paper introduces the GWSHP, and establishes a heating system combined with an existing fuel oil heater (FOH) in a horticultural greenhouse in Gunma Prefecture, Japan. The GWSHP bore most of the heat load, and the FOH was only used as an auxiliary heat source at low temperature. A heating cycle operation monitoring was carried out from November to May of the following year, and the fuel oil saving rate and energy saving rate of the system were calculated to be 74.4% and 22.3% respectively. The results show that the combined heating of GWSHP and FOH is energy-saving and environmentally friendly, and can be widely used in areas rich in groundwater.

1. Introduction

In winter, in order to avoid freezing damage to greenhouse crops caused by low temperature and snow at night, and to improve agricultural output and economic benefits, it is a common measure for growers to use fossil fuels for heating in agricultural greenhouse[1]. In Japan, 17388ha of facility horticulture is equipped with heating facilities, accounting for 41% of the total construction area of facility horticulture, of which 37% are heated by fossil fuels, and the greenhouse gas emissions from heating increased by 219% compared with 1990[2]. However, the high dependence on fossil fuels in agricultural production, the fluctuation and depletion of fossil fuels prices and other factors have a certain impact on growers. In addition, the extensive use of fossil fuels brings global warming and air pollution is also a problem that cannot be ignored. Therefore, greenhouse heating in winter uses renewable energy as much as possible, which is of great significance to reduce the use of fossil fuels and greenhouse gas emissions[3, 4].

Geothermal is a renewable energy, which has considerable energy saving potential and application prospect compared with traditional fossil energy heating[5-8]. A lot of research work has been done on the application of ground source heat pump technology to replace traditional fossil heating in agricultural greenhouses[9-12]. A few researchers have focused on the use of GWSHP technology in
greenhouse heating[13,14], even less on the long-term performance of GWSHP technology in combination with local conditions and resources.

The horticultural greenhouse studied in this paper is located in the mountainous area with rich groundwater in Gunma Prefecture, Japan. An existing irrigation well is used to supply groundwater to the introduced GWSHP of the greenhouse heating system. The GWSHP and the combined heating system with the existing FOH is established without increasing the drilling cost. GWSHP bears most of the heat load. In winter, when the night temperature is low, it is difficult to maintain the suitable growth temperature of greenhouse crops only by using GWSHP. FOH is used as an auxiliary heat source for joint heating to give full play to the energy-saving characteristics of GWSHP, meet the growth demand of greenhouse crops, and achieve the best combination of energy-saving and economy. On the basis of long-term monitoring of the system operation, it is of great significance to analyze the system's fuel oil saving rate and energy saving rate, and to explore the application of groundwater source heat pump in facility agriculture.

2. Experimental greenhouse and method

2.1. Experimental greenhouse

The experimental greenhouse is located in Kurohime-cho, Kiryu City, Gunma Prefecture, Japan. The greenhouse is a double-roofed multi-span building with a total floor area of 540 m², 45m long, 6m wide, 4.5m high, and about 25° roof slope. The greenhouse roof is insulated with three layers of polyethylene film and fluorine resin film. The greenhouse mainly grows ornamental flowers such as begonias. The optimum temperature for the growth of begonias is 15°C-25°C. When the temperature is 15°C-25°C, the growth rate of begonias is relatively slow, and when the temperature is 5°C-10°C, the growth of begonias will stop. In winter, the local temperature is lower than the suitable temperature for begonias, and the experimental greenhouse is heated by FOH to increase the indoor temperature to meet the requirements of begonias growth. The FOH model is HK-3023, with an output power of 87.2kW, using A-type fuel oil of 9.7L/h. The fuel oil consumption during heating period (November to May of the following year) was about 11.56KL. The area is rich in groundwater, and there is already an 80m deep well for irrigation which has been installed with a pump. The pump capacity is 200 L/min. In order to reduce fuel oil consumption and improve the energy-saving and environmental protection performance of the system, the greenhouse heating system was reformed. Used the existing irrigation well to introduce the GWSHP system and formed a combined heating system with the existing FOH in the greenhouse.

The GWSHP system as the main heating source, bore most of the heat load, while FOH, as the auxiliary heat source, only worked under the condition of insufficient heat pump heating at low temperature. The system consisted of three parts: (1) groundwater loop. Considering the quality of groundwater and equipment cleaning and maintenance, the system adopted indirect water supply mode, and a special groundwater heat exchanger was installed between the GWSHP and the water tank. The water in the water tank was transported to the groundwater heat exchanger at the flow rate of 125L/min. Indirect water supply could effectively prevent the heat pump unit from scaling and corrosion, prolong the service life of the heat pump unit and reduce the maintenance cost. (2) GWSHP loop. The GWSHP model is GSHP-3003URF, the refrigerant is R410A, the heating power is 28.0 kW,
and the thermoelectric power is 6.5kW. (3) Indoor air loop. The heated air was blown into the greenhouse through the existing FOH fan, which could achieve rapid heating with large air volume and made the greenhouse temperature rise rapidly. The greenhouse heating system is shown in Figure 1.

2.2. Greenhouse operation and monitoring
Greenhouse temperature control was carried out using a temperature controller. Set the optimal growth temperature of begonias at 18°C as the indoor target temperature, and the system operation is shown in Figure 2. When the indoor temperature dropped below the target temperature, GWSHP prioritized action and continued to operate uninterrupted to reduce operating costs. When outdoor temperature was low and GWSPH's heating could not continue to meet the indoor temperature requirement, FOH turned on and worked in conjunction with GWSHP to heat the greenhouse. When the indoor temperature rose to 25°C, FOH stopped running and the indoor temperature would slowly drop. If the indoor temperature dropped below the target temperature of 18°C, FOH would restart operation and heat the greenhouse to meet the requirements. When FOH was not running, due to the rise of outdoor ambient temperature, the indoor temperature of the greenhouse would continue to rise only when GWSHP was running alone. If the upper limit setting temperature was reached, GWSHP would stop running.

Figure 2. Schematic diagram of system operation

The system began to operate continuously from November to the end of May of the following year, during which time the following items were mainly monitored. (1) indoor and outdoor temperature of greenhouse; inlet and outlet temperature of groundwater, antifreeze and heat exchanger; (2) flow rate of antifreeze and groundwater; (3) power consumption of GWSHP and water pump. The temperature was measured by platinum resistance temperature sensor (Pt100), the flow was measured by electromagnetic flowmeter, and the power consumption was measured by clamp wattmeter. Figure 3 shows the temperature changes at each monitoring point on February 12, 2015.

Figure 3. Changes of temperature at the monitoring point with time on February 12, 2015

3. Results & Discussion
The monthly mean outdoor temperature during a heating period was used to evaluate the fuel oil saving and energy saving effect of the system. According to the temperature monitoring data, the day when the daily mean outdoor temperature was almost the same as the monthly mean outdoor temperature was selected as the representative day of the month. The running times of GWSHP and
FOH on representative days of each month are shown in Table 1. These data will be used to calculate and analyze the effect of fuel saving and energy saving.

| Operating time of greenhouse heating system |
|---------------------------------------------|
| Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May. |
| Running time (hour/day)                     |
| FOH  | 1:10:33 | 2:56:30 | 2:16:50 | 2:34:00 | 1:14:23 | 0:00:00 | 0:14:20 |
| GWSHP | 14:59:39 | 15:47:09 | 16:02:19 | 15:48:00 | 15:20:59 | 15:00:59 | 8:45:30 |
| Monthly mean outdoor temperature           |
| 8.1  | 1.2  | 0.3  | 0.8  | 4    | 10.3 | 17.2 |

### 3.1. Fuel oil saving verification

According to Table 1, the total running time of the GWSHP during the heating period was 2954.0 hours, while that of FOH was only 311.5 hours. The running time ratio of GWSHP and FOH was about 9.5:1. The results show that GWSHP bore the main load of greenhouse, and FOH was only used at the peak heat load to ensure that the indoor temperature could be effectively maintained above 18°C at night. From the monthly running time of the system, we can also see that when the outdoor temperature was low, the running time of GWSHP was long, and the running time of FOH was relatively long. In May, when the outdoor temperature was relatively high, the running time of FOH was relatively short, with an average of only 14.3 minutes/day, indicating that the operation of GWSHP could meet most of the heat load. The higher the outdoor temperature, the shorter the running time of FOH. Generally speaking, the heating effect of the combined heating system composed of GWSHP and FOH to the greenhouse was stable, and the renovation scheme was reasonable and reliable.

![Figure 4. Monthly fuel oil consumption before and after modification](image)

![Figure 5. Monthly fuel oil saving rate of the modified system](image)

Monthly fuel oil consumption before and after system modification is shown in Figure 4. It can be seen that the monthly fuel oil consumption of the system has been greatly reduced after the modification. During the heating period, the total fuel oil consumption of FOH decreased by 8.601kL, and the fuel oil saving rate reached 74.4%. According to Figure 5, fuel oil consumption has been reduced by more than 60% each month. In January when the outdoor temperature was relatively low, the monthly mean outdoor temperature was 0.3°C, and the GWSHP operation alone could not meet the heating requirements. The total time of FOH interrupted operation on the typical day was 2.28h, the fuel oil consumption was reduced from 2.119kL to 0.672kL, and the fuel oil saving rate was 68.3%. In April and May, when the outdoor temperature was relatively high, the monthly mean outdoor temperature was above 10°C, GWSHP bore the main heat load, the FOH operation time was short, and the fuel saving rate reached more than 90%. After the modification, the fuel oil consumption of the system was affected by the external temperature. When the outdoor temperature was relatively high in November, April and May, the use of FOH could be further reduced and the fuel oil saving rate could be further improved.
3.2. Energy saving verification

Before the modification, the energy consumption of the system was mainly FOH fuel oil consumption, and after the modification, the energy consumption of the system included the energy consumption of FOH fuel oil and the energy consumption caused by the electric operation of GWSHP and water pumps. In order to facilitate the evaluation of the energy consumption of the system, electricity and burning A-type fuel oil were converted into standard crude oil, in which the crude oil conversion standard coefficient of A-type fuel oil is 1.01, and the average crude oil conversion standard coefficient of electricity during the day and night is 0.248 L/kWh. The monthly energy consumption of the system before and after the modification is calculated as shown in Figure 6. The total energy consumption of the system was reduced by 2.606 kL crude oil and the energy saving rate reached 22.3%. Among them, 1 kL crude oil = 0.926 toe, toe refers to tonne of oil equivalent.

In December, January and February, when the outdoor temperature was low, GWSHP and FOH run longer than other months, and the energy saving rate was slightly lower than 20%. However, in April and May, when the outdoor temperature was high, GWSHP bore the main heat load, the operating time of FOH was short, and the energy saving rate reached more than 27% (Figure 7).

The heating capacity of GWSHP was 28.3 kW, the power consumption was 7.0 kW, the power consumption of water pump and fan was 1.5 kW. The coefficient of performance (COP) of GWSHP was 4.04 and the COP of the system was 3.33.

3.3. Discussion

From the above results, it can be seen that the energy consumption of the modified system is mainly composed of GWSHP, power consumption of water pump and fuel of FOH. The less FOH is used, the higher the energy saving rate. Therefore, in order to improve the energy saving rate, combined with the temperature changes during the heating period, consider improving the heating capacity of GWSHP to reduce the use of FOH, but the improvement of GWSHP heating capacity will increase electricity consumption and increase the one-time input cost of equipment, which should be comprehensively considered. In addition, when the outdoor temperature is high, the use of FOH is less or not, so it is necessary to reduce electricity consumption to improve the energy saving rate. In order to meet the requirements of the temperature in the greenhouse, it is possible to reduce the amount of water pumped by the pump to reduce the power consumption and further reduce the energy consumption.

4. Conclusions

Based on the operation monitoring of the combined heating system of GWSHP and FOH, this paper analyzed and verified the fuel oil saving and energy saving effect of the system after the modification of the greenhouse during the heating period. The following conclusions are obtained. (1) The combined heating scheme of groundwater source heat pump and FOH is reasonable and reliable, and
the heating effect is stable. (2) The fuel oil saving rate of the system during the heating period reached 74.4%. (3) The energy saving rate of the system during the heating period reached 22.3%. The coefficient of performance of GWSHP was 4.04, and the COP of the whole system was 3.33. (4) For the areas rich in groundwater, the introduction of the GWSHP system on the basis of the original traditional heater in the greenhouse can effectively reduce the initial equipment investment and operation costs of users, and improve the energy saving rate of the system.

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