Experimental Study on Automatic Switching of Solar Coupled Groundwater Source Heat Pump System

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Abstract. There have been few practical applications of solar coupled groundwater source heat pump (GWHP) systems in large public buildings, and data on this technology are scarce. A solar coupled GWHP system was investigated in this study. The system uses an underground water source heat pump system for heating in winter, cooling in summer, and providing part of the domestic hot water, and it also uses a solar energy system to prepare domestic hot water. These two types of energy are complementary. The system was tested throughout the cooling season. This experiment ran from May 10, 2021, to September 10, 2021. The results show that the system can guarantee the indoor design temperature and the supply of domestic hot water. The solar water heating system operated for 1233 min in the summer; hot water (2334 m³) was prepared. During the summer, the average energy efficiency ratio of the GWHP unit was approximately 4.88. The energy efficiency ratio of the entire system was approximately 3.34. Such projects can play a key role in demonstrating this type of system.

Keywords: Experimental research; Solar energy; Groundwater source heat pump; Complementary use.

1. Introduction
The utilization of renewable energy and building energy-saving technology has become the focus of attention of many scholars [1]. Solar energy has been widely used as a clean energy source [2]. Europe and the United States are leading the way in solar energy use. In the 1920s, there was an engineering case of using solar collectors to provide domestic hot water in the United States. As an application technology for renewable energy, the application of a GWHP can save energy effectively [3]. However, in China, solar energy utilization is still concentrated in the field of small distributed systems, and the development and application of larger solar energy utilization systems is limited. Solar coupled groundwater source heat pumps (GWHPs) have attracted wide attention as a good form of complementary energy use [4]. Freeman concluded that a parallel system is the most practical system after studying different connection forms of solar energy and heat pump systems[5]. Dikici believed that the coefficient of performance value of a combined solar and WSHP system could reach 3.08; thus, it could be an option for residential heating [6]. The advantage of the GWHP is that the temperature of the low-temperature heat source fluctuates less with climate, which makes the operation of the GWHP system more stable [7]. Emmi et al. studied multi-energy complementary systems to meet the needs of single households. The energy efficiency of the system is much higher than that of ordinary GWHP systems [8]. However, there have been few practical applications of solar coupled GWHP systems in large public buildings. In this study, an experimental test during the entire cooling season was conducted in an actual engineering project. The ability of the system to maintain the room temperature in a building was studied. The stability of a solar coupled GWHP system in large public buildings was...
verified. It is of great significance to popularize this type of system.

2. System Overview

![Schematic diagram of solar coupled GWHP system.](image)

The study site is in Shenyang, China, in a cold region. The building studied is a public building with an actual usable area of more than 50,000 m². The functions of the building include offices, sports activities, and commercial activities. A solar-coupled GWHP system was designed. This test began on May 10, 2021, and ended on September 10, 2021. Figure 1 shows a schematic diagram of the solar-coupled GWHP system. In this system, the GWHP provides cooling in summer for the building, and it provides part of the domestic water. The solar energy is responsible for producing domestic hot water. However, solar energy systems have many limitations, such as not being turned on at night and not being used when solar radiation is not high. To solve these problems, thermal storage tanks must be used to store solar energy temporarily. In addition, GWHP systems must be used as a complementary source of energy to provide domestic hot water when solar power is unavailable. The combined use of these two types of energy ensures the stability of the system operation and has important value in energy saving and environmental protection. Tables 1–4 list the devices used.

| **Table 1. Parameters of solar thermal collector.** |
|-----------------|------------------|-----------------|
| **Equipment**   | **Type**         | **Total area**  |
| Solar thermal collector | Trough collector | 750 m² |

| **Table 2. Other main equipment of solar energy system.** |
|-----------------|------------------|------------------|
| **Equipment**   | **Model** | **Quantity** |
| Heat storage water tank | 100t | 1 |
| Plate heat exchanger | 850kw | 2 |
| Circulating pump | Y2-132S2-2 | 2 |

| **Table 3. Parameters of water source heat pump unit.** |
|-----------------|------------------|------------------|
| **Equipment** | **Model** | **Refrigerating quantity** | **Refrigeration power** |
| Water source heat pump unit | 61XW-470B1 | 1688kw | 271kw |

| **Table 4. Other main equipment of GWHP system.** |
|-----------------|------------------|------------------|
| **Equipment**   | **Model**         | **Quantity** |
| Groundwater well | 250QJ100-54/3 | 8 |
| Plate heat exchanger | 3000kw | 1 |
| Circulating pump | Y2-250M-4 | 3 |
3. Experimental Instruments

| Measurement device                      | Measured parameter | Range          | Accuracy   |
|-----------------------------------------|--------------------|----------------|------------|
| PT100(CMWZP-TP-3P)                      | Water temperature  | -70°C~200°C    | ±0.1°C     |
| Temperature recorder (TR001)             | Air temperature    | -30°C~125°C    | ±0.5°C     |
| Ultrasonic flowmeter(FSCS10C1-00C)      | Water flow rate    | 0~2000m³/3/h   | ±0.5%      |

In this experiment, a PT100 platinum resistor was used to measure the water temperature. An automatic temperature recorder was used to measure the air temperature, including outdoor hourly air temperature and indoor temperature. A flowmeter was used to measure water flow. In addition, the entire system was set up with an automatic monitoring platform, which was responsible for the hourly recording of power consumption. Table 5 lists the specific models of various devices.

4. Results and Discussion

In this experiment, the temperature recorder monitored the outdoor air temperature from May 10, 2021, to September 10, 2021, and this results are shown in Figure 2. At the same time, the indoor temperature was tested. The test results are presented in Table 6. It can be seen that, when using GWHP refrigeration, the average indoor temperature can meet the design requirements and ensure comfort. The operation was stable.

![Figure 2](image)

**Figure 2.** Average outdoor temperature in summer.

| The room number   | Test time         | Indoor temperature(°C) | Design temperature(°C) |
|-------------------|-------------------|------------------------|------------------------|
| Office area       | May 10, 2021      | 25.4~27.8              | 26                     |
| Sports center     | 2021~September    | 25.1~26.1              | 26                     |
| Business area     | 10, 2021          | 26.2~27.9              | 26                     |
Shenyang is a medium-type area of solar resources in China. In the experiment, the preparation of domestic hot water using solar energy in the summer was studied. The results showed that the total time of the solar water supply was 28,791 min. A total of 2815 m$^3$ of domestic hot water at 50 °C was prepared. These can be found in Figures 3 and 4. This considerably relieved the pressure of preparing domestic hot water in the GWHP system. Moreover, it contributed to the heat balance of the groundwater. In cold areas, the heat from the GWHP system is more than the heat supplement, and long-term operation leads to a decrease in groundwater temperature yearly. A solar system can be used as a supplementary heat source to reduce the pressure on the GWHP system. In addition, the intermittency and instability of solar energy can be compensated for by water source heat pumps.

**Figure 3.** Solar water supply time in summer.

**Figure 4.** Solar water supply in summer.

**Figure 5.** Supply and return water temperature at the user side of the GWHP.
Figure 6. Water flow at user side of GWHP.

Compared with a single cooling refrigeration unit, the GWHP system can provide refrigeration in summer and heat in winter, exhibiting good application value. Figure 5 shows the water supply and return temperature of the GWHP system on the user side during refrigeration. In the initial and final stages of refrigeration, the outdoor temperature is relatively low, with a water supply temperature of approximately 12.2 °C and a return water temperature of approximately 7.4 °C. The temperature difference between the supply and return water is approximately 4.8 °C. In the cooling stage, the outdoor temperature is relatively high, the water supply temperature is approximately 11.2 °C, and the return water temperature is 6.4 °C. The temperature difference between the supply and return water is approximately 4.8 °C. Figure 6 shows a comparison between the flow of the pump on the user side and the outdoor temperature. One water pump is opened at the beginning and end of refrigeration, two water pumps are opened in the middle stage of refrigeration, and the water pumps are fixed-frequency water pumps. After the temperature and flow data are obtained, the cooling capacity of the system can be calculated using the following equation:

\[ Q = \frac{c m \Delta t_w}{3600} \]  

Here, \( Q \) is the cooling capacity of the GWHP system (kW·h), \( c \) is the specific heat capacity of water (kJ/(kg·°C)), \( \Delta t_w \) is the difference between the supply and return water temperatures, and \( M \) is the mass flow rate of water (kg/h).

\[ EER = \frac{Q}{W_h} \]  

\[ EER_s = \frac{Q}{W_s} \]

The EER represents the refrigeration coefficient of the GWHP unit, and the EERs represents the energy efficiency ratio of the GWHP system. Here, \( W_h \) represents the power consumption of the compressor in the heat pump unit (kW·h), and \( W_s \) represents the power consumption of the entire system (kW·h), including the power consumption of the compressor and each water pump.
After calculation, the cooling capacity of the GWHP in summer was obtained, as shown in Figure 7. Figure 8 shows the power consumption of the GWHP unit and system. The compressor in the GWHP unit consumes electricity, and the compressor undergoes frequency conversion. The power consumption of the system is not only related to the compressor, but also includes the power consumption of submersible pumps and circulating pumps. This is also shown in Figure 8. At the beginning and end of refrigeration, the outdoor temperature is lower, and the power consumption is lower. In the middle of heating, the outdoor temperature is high, and the system consumes more power. The performance EER of the GWHP unit and system in the cooling season was calculated, and the average EER of the GWHP unit was approximately 4.88. In the early and late stages of refrigeration, the performance coefficient is relatively high; at this time, the unit is under load operation. In the middle stage of heating, the performance coefficient is relatively low. The performance coefficient of the system is also shown in the figure 9. For the entire cooling season, this system energy efficiency ratio was approximately 3.34. It was higher in the early and late stages of refrigeration and lower in the middle stage.

5. Conclusions
(1) The GWHP system can be responsible for providing domestic hot water, but it can also provide
cooling of buildings in summer and heating of buildings in winter. It is cleaner than traditional energy. In the cooling season, the results of continuous monitoring of indoor temperature show that the system can ensure a good cooling effect, and the difference between the design temperature and system temperature is not more than 2 °C.

(2) The solar energy system works for 2815 min in summer and produces 2815 m$^3$ of domestic hot water at 50 °C. This considerably relieves the pressure on the GWHP system to prepare domestic hot water. The solar energy system is also very energy efficient, and only the pump requires electricity. Solar energy systems are environmentally friendly.

(3) The average EER of the GWHP unit in the summer was 4.88. The average EER of the system during summer was 3.34. The system is an effective novel energy technology that can replace traditional energy.

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