Experimental Study of A Solar Assisted Ground Source Heat Pump for Heating

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***Abstract*—An experimental study is performed to determine the performance of the solar assisted ground source heat pump (SAGSHP) by using a solar-ground source heat pump hybrid system in the city of Ningbo. The result shows that comparing with the ground source heat pump (GSHP), when the ratio of solar energy to the whole energy is 28.7%, the coefficient of performance (COP) of the heat pump and system can improve 15.8% and 11.2%, respectively. The solar assisted ground source heat pump has a significant performance advantage. Therefore, SAGSHP is feasible in technology according to the experimental study results.**

***Index Terms*—solar assisted ground source heat pumps, experimental study, coefficient of performance**

I. Introduction

Solar-ground source heat pump is an energy utilization technology of high efficiency, energy saving and environmental protection. Since the concept of solar collector and ground source heat pump combination was proposed by Penrod in 1956 [1] and the system design process and methods were conducted in 1969 [2], [3], a great deal of theoretical and simulation work has been accomplished. R. Yumrutas [4]-[6] analyzed and calculated solar heat pump system. The result shows that the type of soil has a great influence on the transient temperature field and the annual average COP of a heat pump, the low soil thermal conductivity can improve the system's performance. Andrew D. Chiasson and Cenk Yavuzturk [7] used TRNSYS as a simulation mean for the first time, then proved that in cold areas, the hybrid ground source heat pump system is economically feasible. Reference [8] simulated the solar-ground source heat pump system in cold climate, and obtained the distribution of soil temperature field and recovery rate, then determined the optimum operating time distribution of the system and solar collector areas. Ref. [9] proposed the optimum operational mode and the optimized system design in Qingdao.

A number of studies have been carried out by various researchers in order to analyze the performance of solar-ground source heat pump systems, while most studies are performed by theoretical and simulation means, the studies related to experiment are few in numbers. The lack of experimental data of solar-ground source heat pump system leads to weak awareness of operating performance. Therefore, it is important for mastering the operating performance to do the experimental study on solar-ground source heat pump system. The objective of this study is to experimentally analyze the performance of solar assisted ground source heat pumps by using a solar-ground source heat pump hybrid system in the city of Ningbo, then obtained the variation of operating performance of SAGSHP, and verified the heating performance of solar assisted ground source heat pumps is better than ground source heat pump. SAGSHP for heating is feasible in technology.

II. Experimental System

In order to determine the performance of solar assisted ground source heat pumps, an experimental study is performed by using a solar-ground source heat pump compound system in the city of Ningbo. The experimental system composed of two independent solar-ground source heat pump system with the same parameters, which as shown in Fig. 1. The system mainly consists of six parts: ground source heat pump system, ground heat exchanger system, air condition system, automatic control system, solar collector system and domestic hot water system. The main components and technical specification of system are given in Table Ⅰ. Conversion from the heating cycle to the cooling cycle is obtained by means of a four-way valve. Fig. 2 shows the picture of the system.

III. Results and Discussion

This paper has an experimental study of GSHP and SAGSHP to determine the performance of a heat pump system with solar collectors. At 8:30am turned on two sub-systems and at 16:30pm turned off the systems. The operating time of the sub-systems lasted 8 hours. The

Manuscript received June 19, 2013; revised September 4, 2013

doi: 10.12720/joace.2.2.146-149

systems have the function of automatic collection. Therefore, the computer can automatically collect the inlet and outlet temperatures and the flow rate in fan coil circuit, the inlet and outlet temperatures and the flow rate in ground heat exchanger circuit, the power of heat pump and solar irradiance every 30 seconds. Due to the massive data, the authors selected the average data in typical time period during system operating to analysis.

The variations of inlet water temperature of the ground exchanger are shown in Fig. 2. The average water temperature of ground source heat pump was 18℃. After using the solar energy as a auxiliary heat source, the average temperature improved by 20.6℃. It is obvious that the temperature of SAGSHP is higher than the temperature of GSHP, with a value of 2.6℃. This difference is due to the fact that the fluent of ground source heat pump circulates between evaporator and ground heat exchanger, but the fluent of solar assisted ground source heat pump absorbs heat not only from the soil but also the hot water.

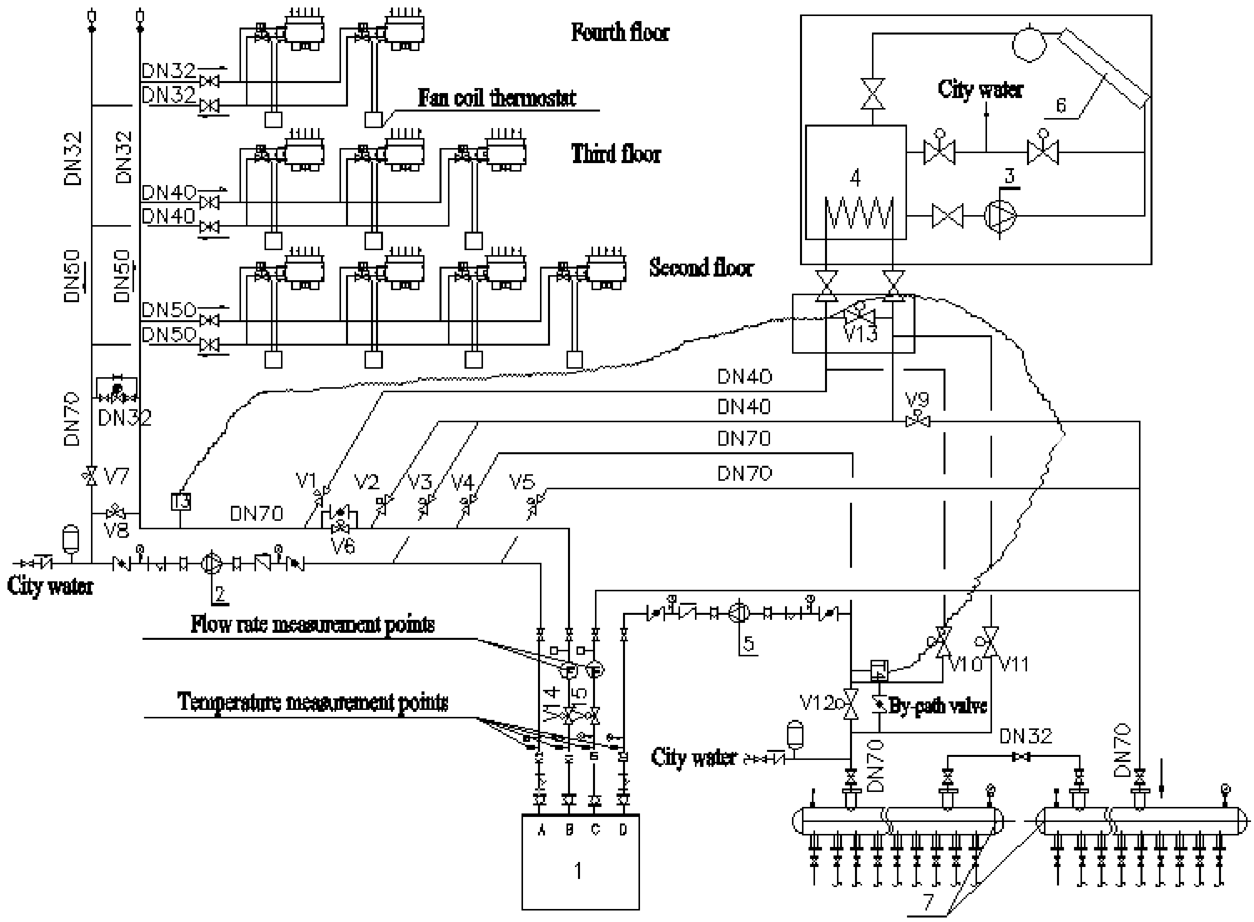

Figure 1. Schematic diagram of experimental system.

TABLE I. THE MAIN CHARACTERISTICS OF SYSTEM

S/N	Components	Technical specification
1	Water-to-water heat pump	Cooling capacity: 18.5kW, cooling power: 3.9kW; heating capacity: 27.5kW, heating power: 5.1kW, number: 2
2	Chilled water pump	Flow rate: 4.5m^3/h, pump head: 26m, power: 0.75kW, number: 2
3	Heat water pump	Flow rate: 1.2m^3/h, pump head: 10m, power: 160W, number: 2
4	Domestic hot water tank	Volume: 200L, number: 2
5	Cooling water pump	Flow rate: 5.5m^3/h, pump head: 22m, power: 0.75kW,number: 2
6	Solar collector	Effective absorber areas: 1.95m^2×2, flat-type
7	Ground heat exchanger	Composed of two U-tube, borehole space: 4m, borehole depth: 75m, number: 16

Fig. 3 shows the instantaneous power of the heat pump. As can be seen from the figure, the variation of the power of heat pump with two operation modes is basically the same. At first the power increased gradually as the operating time advanced, and reached the maximum value (5.5kW) at 10:30am, then stopped operating 5 minutes, at last restarted. When the ground source heat pump is working, the heat only obtained from the soil and the electrical power. While using solar energy as the auxiliary heat source, the inlet water temperature of ground heat exchanger increased. As a consequence, the heat obtained from soil and the electrical power of the heat pump's compressor reduced. It is obvious that the electrical power of SAGSHP is less than the power of GSHP, which can be seen from Fig. 3. The average power of the ground source heat pump was 5.3kW, while the average power of solar assisted ground source heat pump decreased to 4.5kW.

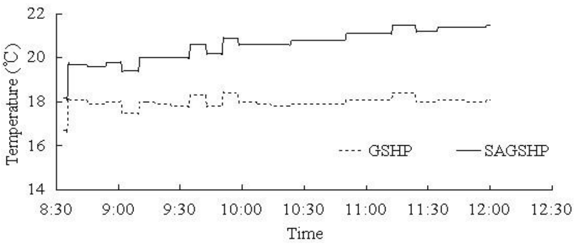

Figure 2. The inlet water temperature of ground heat exchanger.

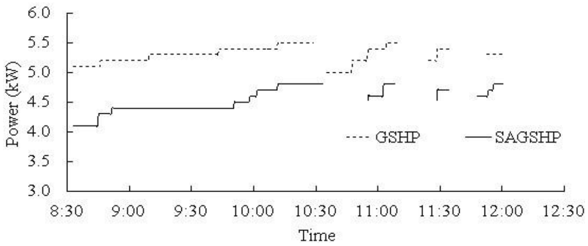

Figure 3. The power of heat pump units.

On Fig. 4 and Fig. 5, the COP of heat pump and system is calculated every 30 seconds as (1)-(3).

The COP of the heat pump is calculated as:

$$COP = \frac{Q}{W_{hp}} \tag{1}$$

where Q is the useful heat which obtained from the condenser and W_{hp} is the power of heat pump?

The COP of the whole system:

$$COP = \frac{Q}{W_{hp} + W_{\Sigma P}} \tag{2}$$

where $W_{\Sigma P}$ is the power of other equipments such as the pump?

The useful heat obtained from the condenser Q is also calculated as:

$$Q = c\,\dot{m}(T_1 - T_2) \tag{3}$$

where c is the solution specific heat, $\dot{m}$ is the solution flow rate, T_1 and T_2 are inlet and outlet temperatures in fan coil circuit.

The useful heat received from the collector and transferred to heat transfer fluid, which can be calculated as (4) [10]:

$$Q = \eta . A . G \tag{4}$$

where η is the collector efficiency, for the most solar collector system in China η is about 90%, A is the collector area. G Is solar irradiance, the experiment measured G is *163322.3*.

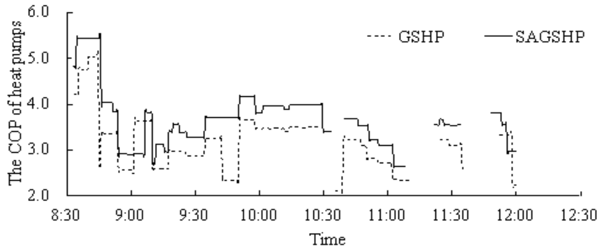

Figure 4. The COP of heat pumps.

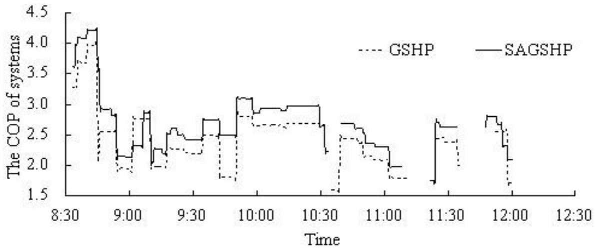

Figure 5. The COP of systems.

Fig. 4 and 5 demonstrate that the performance of SAGSHP is better than GSHP. As shown in Fig. 4, the heat pump COP of SAGSHP and GSHP is 3.67 and 3.17, respectively. As can be seen from the Fig. 5, the whole system COP of SAGSHP and GSHP is 2.69 and 2.42, respectively. The calculated values of SAGSHP are given in Table Ⅱ. As can be seen from the table, the ratio of the soil, solar energy and electric energy to the whole energy is 51.1% (5484.38 kW), 28.7% (3249.79 kW) and 20.2% (2291.58kW), respectively. Consequently, the average COP of heat pump and whole system were increased by 15.8% and 11.2%, respectively. Can be seen from Table Ⅱ and Fig. 2-Fig. 5, after using solar energy as the auxiliary heat source, the inlet water temperature of ground heat exchanger and coefficient of performance have improved. Therefore, SAGSHP for heating is feasible in technology.

This can be clearly seen on the Fig. 4 and Fig. 5 where the heat pump or the system COP significantly decreases after working for several hours. Indeed, the longer the operating time, the lower the heat pump. When the heat pump is turned off during several minutes, the heat flux of the ground warm up the boreholes and the fluent in ground heat exchanger, which explains why the heat pump performs worse and worse when the system is continuous working. Therefore, the continuous working of heat pumps during several hours is not optimal in terms of performance.

TABLE II. THE CALCULATED VALUES

The useful heat obtained from the condenser/kW	The useful heat extracted from the heat pump/kW	The useful heat extracted from the ground/kW	The useful heat extracted from the solar/kW	The electrical power of the heat pump's compressor/kW	Increase ratio of the heat pump COP	Increase ratio of the heat pump COP
12694.48	11321.76	5780.39	3249.79	2291.58	15.8%	11.2%

IV. CONCLUSIONS

An experimental study is performed to determine the performance of solar assisted ground source heat pumps by using a solar-ground source heat pump hybrid system in the city of Ningbo. From the analysis of the experimental results, the following conclusions can be drawn:

1) Comparing with the ground source heat pump, when the ratio of solar energy to the whole energy is 28.7%, the inlet water temperature of ground heat exchanger improves 2.6℃, the power of the heat pump reduces 0.8kW, the COP of heat pump and system can improve 15.8% and 11.2%, respectively. Solar assisted ground source heat pump heating has a significant performance advantage.

2) Owing to the long time of soil temperature recovery, the continuous working of heat pump during several hours is not optimal in terms of performance.

3) Practice and research show that the SAGSHP has the great efficiency and energy-saving effect. Therefore, using the auxiliary heating device is completely feasible in technology.

ACKNOWLEDGMENT

The authors wish to thank Zhongchao Zhao, Weixian Feng, Xuemei Gong, Haojun Mi, Hua Cheng, Long Yun. This work was supported in part by a grant from National Natural Science Foundation of China (51205177) and National Natural Science Foundation of Jiangsu province (BK2012277).

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