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Investigation on a solar-groundwater heat pump unit associated with radiant floor heating

Hongting Ma[a,b], Cong Li[a,b,*], Wenqian Lu[a,b], Zeyu Zhang[a,b], Shaojie Yu[a,b], Na Du[a,b]

[a] School of Environmental Science and Engineering, Tianjin University, Tianjin 300072, China
[b] MOE Key Laboratory of Efficient Utilization of Low and Medium Grade Energy, Tianjin University, Tianjin 300072, China

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ABSTRACT

In order to evaluate the performance of a solar-groundwater heat pump (SGHP) unit associated with radiant floor heating, a experimental installation was designed and established, the performance was measured and compared with the conventional central heating system(CCHS). The results shown that the new system has an energy-saving rate of 30.55% compared with the CCHS. The floor heating systems can save energy 18.96% compared with the traditional radiator. In the present experiment, the solar energy contribution rate was about 24%. Taking the basic energy (primary energy) consumption as a benchmark, the SGHP can reduce energy consumption by 30.55% compared with the traditional regional boiler room heating system. As the solar fraction increases from 0% to 100%, the COP of heat pump units and overall system are increased 6.44% and 19.34%, respectively

1. Introduction

The solar-groundwater heat pump unit was first proposed by Jordan and Threlkeld [1] in 1955, but it was developed after the outbreak of the oil crisis in the 1970s. Because of the direct use of solar energy, the evaporating pressure and temperature of the heat pump unit will be increased obviously, and this could significantly improve the coefficient of performance (COP) of the heat pump unit compared with the conventional heat pump unit. Subsequently , many in-depth researches and applications on the solar heat pump had been implemented in United States, Turkey, Sweden and other countries [2–6].

The study on the solar energy heat pump in China is relatively late. The experimental devices of the solar heat pump heating system as well as the measuring instrument system were designed and investigated, the results shown that the system would be effective on environmental protection and reducing traditional energy consumption [7,8].

Dai et al. [9] studied the influence of operation modes on the heating performance of solar assisted ground source heat pump units, the results indicated that the solar energy could be used to accelerate the soil recovery when the heat pump unit is turned off. Bi and Chen [10] carried out simulation experimental research on solar energy and ground source heat pump running alternately, the results showed that solar and geothermal energy are well complementary to each other. Pärisch et al. [11] investigated the heat pump behavior under non-standard conditions for the operation of ground source heat pump (GSHP) in combination with solar collectors. The higher temperatures and varying flow rates in comparison to non-solar systems have been taken into account. The results showed that rising source temperatures can significantly increase the COP of heat pump as the source temperature is below 10–20 °C. Hu et al. [12] experimentally investigated the operation mode of solar-ground composite source heat pump in subtropical regions, and proved that this system is feasible because of the abundant solar energy resources and high ambient temperatures, but its feasibility in northern cold regions needs to be verified. Yang et al. [13] carried out experimental studies on the performance of a solar-ground source heat pump unit (SGHPU) operated in different heating modes. The results indicated that for the combined operation mode, the system operation efficiency during day can be improved by the assistance of solar energy, and the excess solar energy collected during day can be stored in ground by the ground heat exchangers (GHE) to improve the operation performance of ground source heat pump (GSHP) during night. Zhou [14] and Zhang [15] studied a solar-ground composite source heat pump unit, the results showed that the system had a good stability and feasibility, but the energy saving wasn't analyzed quantitatively. Kadir et al. [16] investigated the performance of the solar-ground source heat pump system in the province of Erzurum having cold climate. The results indicated that the coefficient of performance of the heat pump and system were found to be in the range of 3.0–3.4 and 2.7–3.0, respectively. Hu et al. [17] studied the heating performance and energy distribution of a system with the

* Corresponding author at: School of Environmental Science and Engineering, Tianjin University, Tianjin 300072, China.
E-mail address: 1002794046@qq.com (C. Li).

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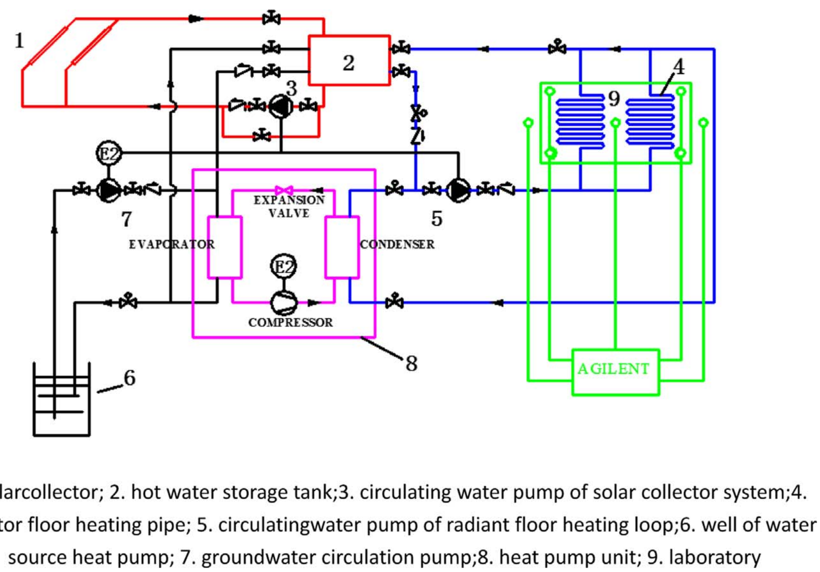

Fig. 1. Schematic representation of solar-water source heat pump unit. 1.solar collector; 2. hot water storage tank; 3. circulating water pump of solar collector system; 4. radiator floor heating pipe; 5. circulating water pump of radiant floor heating loop; 6. well of water source heat pump; 7. groundwater circulation pump; 8. heat pump units; 9. Laboratory.

combination of ground-source heat pump and solar collector or a solar-assisted ground-source heat pump unit, the results showed that the average fluid temperature in the borehole heat exchanger can be increased with the assistance of solar collector, this will improve the COP of the heat pump. Ma et al. [18] discussed a feasibility study of air-conditioning using a ground source heat pump (GSHP) with vertical mounting, coupled with a solar collector. The study showed the feasibility of using a heating/cooling GSHP for the particular soil type. Reda [19] focused on different control strategies of a solar assisted ground source heat pump for cold climate. The results showed that the proposed strategy was effective from a specific borehole depth. Chen et al. [20] presented a solar assisted ground coupled heat pump (SAGCHP) system. The results showed that the optimized system under the specified load conditions had a collector area of 40 m^2 and a borehole length of 264 m. The annual total heat extraction plus 75% of the hot water requirement can be provided by solar energy in the optimized design.

Han et al. [21] investigated the performance of a residential ground source heat pump unit in sedimentary rock formation. The results showed that there is no long term performance deterioration due to the shift of the underground based line temperature as seen in large scale ground heat exchanger (GHE) applications. Intermittent operation mode was found to achieve higher energy efficiency than continuous operation mode. Qiang et al. [22] presented a novel solar-ground source heat pump system (SGSHPS) designed for heating, cooling, and producing domestic hot water, the results showed that the system with ground heat exchanger (GHE) and solar collectors installed in series had better performance than the system that used the solar heat to restore soil temperature in cold regions. Onder and Arif [23] reviewed the studies conducted on the energy and exergy analysis of four groups of solar assisted heat pump systems （SAHPS）, and the result showed that solar-assisted ground source heat pump systems (SAGSHPS) gave more solar energy potential. Self et al. [24] reviewed the geothermal heat pumps, including heat pump technology, earth connections, current world status and recent developments. By comparing geothermal heat pump technology and conventional heating systems in terms of costs, CO_2 emissions and other parameters, it can be drawn that geothermal heat pump use is economically advantageous when the price of electricity is low. Zhi et al. [25] reviewed the progress of ground source heat pump(GSHP) combined with hybrid energy systems(HES) all over the world, and surveyed the development of the hybrid ground source heat pump(HGSHP) system in China and presented the basic proposals for development in the future to make up the gap in the field of HES and HGSHP. A ground source heat pump unit (GSHP) was investigated by experiment and modeling. The results indicate that it is important to analyze the performance of GSHP and check whether the design was appropriate and the simulation predictions were consistent with real experimental measurements. The performance simulation results of a complete ground source heat pump unit model built in TRNSYS was analyzed and compared with experimental measurements [26].

However, there are seldom reports about the comparison between a solar-groundwater heat pump (SGHP) unit associated with radiant floor heating and a conventional central heating system (CCHS) under the same indoor and outdoor environments. The present work aims to design and evaluate a multi-energy complementary heating system with a heat source of solar-groundwater heat pump, and to compare with the traditional heating system experimentally. The advantages of energy saving and comfort have been investigated experimentally and theoretically.

2. Description of experimental setup

The solar-groundwater heat pump unit consists of a solar collector system, a water source heat pump unit and a radiant floor heating system. Because the solar irradiance is relatively low during winter in Tianjin area, the solar energy system is designed as indirect expansion system so as to have a good adaptability in low solar irradiance and an advantage of flexible installation. The alternate running mode of solar-groundwater heat pump unit can reduce the running time and power consumption of the submersible pump, restore the groundwater temperature effectively and improve the comprehensive utilization efficiency of the system on the premise of making full use of solar energy [27]. Therefore, the present experimental system is designed as alternate running mode, solar energy and groundwater is used as the low temperature heat source alternately according to the water temperature in the heat storage tank. In the present work, the switch between solar energy and geothermal energy as well as the control of indoor temperature are conducted by a self-developed automatic control system. During the experiment, indoor air temperature is controlled at 18–20 °C. The operation strategy of the system is to give priority to the use of solar energy resources. The schematic diagram of the system is shown in Fig. 1.

According to Fig. 1, the solar collector consist two groups of vacuum