Applied Thermal Engineering 109 (2016) 718–726

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

# Experimental study of a multi-energy complementary heating system based on a solar-groundwater heat pump unit

Hongting Ma, Cong Li *, Wenqian Lu, Zeyu Zhang, Shaojie Yu, Na Du

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

## HIGHLIGHTS

- A SGHPS associated with radiant floor heating is investigated.
- The new heating system has significant energy-saving effect.
- The new heating system could meet the heating demand of stability and feasibility.
- Economic analysis is conducted on the SGHPS and CCHS.

## ARTICLE INFO

*Article history:*
Received 16 June 2016
Revised 16 August 2016
Accepted 21 August 2016
Available online 22 August 2016

*Keywords:*
Solar energy
Water-source heat pump
Radiant floor heating system
Conventional central heating system

## ABSTRACT

A solar-groundwater heat pump (SGHP) unit associated with radiant floor heating has been designed and established located in Tianjin, China, the performance was measured and compared with the conventional central heating system (CCHS) under the same indoor and outdoor environments. The experimental results showed that the energy-saving rate of SGHP is 30. 55% compared with CCHS. The energy-saving rate of floor heating systems can achieve 18.96% compared with the traditional radiator, and economic analysis has been conducted on the new type of heating system and the conventional central heating system. In present experiment, the solar energy contribution rate was about 27%. The result proved that SGHP could save energy significantly and meet the heating demand of stability and comfortableness.



**Contents**



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

http://dx.doi.org/10.1016/j.applthermaleng.2016.08.136

**Nomenclature**

| | |
|---|---|
| COP | coefficient of performance |
| SGHP | solar-groundwater heat pump |
| CCHS | conventional central heating system |
| GSHP | ground source heat pump unit |
| GHE | ground heat exchanger |
| HGSHP | hybrid ground source heat pump |
| SAHPS | solar assisted heat pump systems |
| SAGSHPS | solar-assisted ground source heat pump systems |
| SPF | seasonal performance factor |
| HDD | heating degree days |
| CDD | cooling degree days |
| $Q_{t,f}$ | total heat consumption of the heating system (kJ) |
| $E_e$ | electrical energy consumption of the new heating system (kW h) |
| $e_1$ | energy saving rate (%) |
| $Q_c$ | amount of energy saving (kW h) |
| Q | total energy consumption of the traditional radiator heating system (kW h) |
| $Q_{zh}$ | total energy consumption during the heating season (GJ) |
| $Q_h$ | building designed heating load (kJ/h) |

## 1. Introduction

### *1.1. Research background*

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. Ozgener [2] reviewed the studies of SAHPS systems in Turkey and around the world and the conclusion was that the effective use of SAGSHP systems with suitable technology in the modern locations will play a leading role on the world in the foreseeable future. Subsequently, Kaygusuz [3] investigated the performance of a solar heating system with a heat pump experimentally and theoretically. An experimental set-up was constructed in the province of Erzurum in order to investigate the performance of a solar source and energy stored heat-pump system [4]. Dikici and Akbulut [5] investigated a solar-assisted heat pump (SAHP) system with flat plate collectors and tested for domestic space heating as well as the coefficient of performance of the SAHP system.

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, and the system would be effective on environmental protection and reducing traditional energy consumption [6,7].

### *1.2. Literature review*

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 [8]. 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 [9]. Residential ground source heat pump unit can achieve higher energy efficiency with intermittent operation mode than continuous operation mode. 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 [10]. Qi et al. [11] 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. As regard the particular soil type, an air-conditioning using a ground source heat pump (GSHP) with vertical mounting, coupled with a solar collector was studied by Boakli Hacene et al. [12]. It had been shown the feasibility of using a heating/cooling GSHP for the particular soil type. Compared with four groups of solar assisted heat pump systems (SAHPS), the solar-assisted ground source heat pump systems (SAGSHPS) gave more solar energy potential [13].

Zhou et al. [14] and Zhang et al. [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. Hu et al. [16] 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. A solar-ground source heat pump system was installed 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 [17]. Bi and Chen [18] 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. [19] investigated the heat pump behavior under non-standard conditions for the operation of ground source heat pump (GSHP) in combination with solar collectors. The results showed that rising source temperatures can significantly increase the COP of heat pump as the source temperature is below 10–20 °C. Dai et al. [20] 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. Yang et al. [21] carried out experimental studies on the performance of a solar-ground source heat pump unit (SGHPU) operated