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Experimental study of thermal performance of a ground source heat pump system installed in a Himalayan city of India for composite climatic conditions

T. Sivasakthivel [a,b,c,*], K. Murugesan [a], Surya Kumar [a], Pingfang Hu [b], P. Kobiga [c]

[a] Department of Mechanical and Industrial Engineering, Indian Institute of Technology Roorkee, Roorkee, India
[b] School of Environmental Science and Engineering, Huazhong University of Science and Technology, Wuhan, China
[c] Tokyo University of Agriculture and Technology, Koganei, Tokyo, Japan

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ABSTRACT

Space heating and cooling appliances consume a significant amount of energy in buildings. In recent decades, ground source heat pump (GSHP) systems have become popular for space heating applications in many countries. However, countries like India need both space heating and cooling and hence its performance needs to be evaluated in both heating and cooling functions for economical operation. The experimental results obtained for both modes of operation are discussed in detail in this paper. Details of the experimental setup used, measurements, performance of ground heat exchanger (GHX) used and calculation of COP, effectiveness and extraction/injection are explained. Using the experimental data the coefficient of performance (COP) of heat pump and GSHP are obtained. The average COP of the GSHP system obtained during space cooling was found to be 21% less than the value obtained for heating mode operation and also heat extraction by the GHX fluid is observed to be high at the starting of the operation. In heat injection mode, as the operational time increases, the surrounding soil temperature also increased thus creating more resistance for heat flow. The average effectiveness of GHX was found to be 0.29 and 0.33 in heating and cooling mode operations respectively.

1. Introduction

Ground source heat pump (GSHP) is one of the promising technologies for providing thermal energy for space heating/cooling applications. This technology is well utilized for space heating applications in European and Western countries. However, in the past decade some of the Asian countries started focusing on the technical challenges of ground source heat pump systems for both heating and cooling applications [1–4]. When the climatic conditions of India is considered, during winter season of almost 3–4 months most of the northern states which are located near to the Himalayas require space heating, which is currently carried out using electric heating [5,6]. As it is well understood from Thermodynamics that using electricity for space heating will produce enormous exergy destruction and also using the high grade electricity mostly generated by burning fossil fuels in thermal power plants for resistance heating results in very poor second law efficiency [7]. At the time when India is focusing on various sources of electricity generation to meet the ever growing demand, there is a necessity to find a more efficient heating system in order to save electricity [3]. Due to fast developing economy of the country, there is an enormous increase in demand for electricity for indoor comfort. As mentioned before the same northern states which experience severe winter also experience severe summer season. Hence the GSHP technology which can operate both for space heating and cooling will be suitable for Indian climatic conditions. Climatic conditions of India vary from region to region such that some parts of the country only require cooling and some parts require only heating and some regions require both heating & cooling [6]. As GSHP can be used for space heating, cooling and hot water production, it is essential to understand how this technology has been employed for each of the application in detail.

1.1. GSHP for space heating

Ozyurt and Ekinci [1] studied the performance of a GSHP system for space heating application in Turkey. During the experimental

* Corresponding author at: Department of Chemical Engineering, Tokyo University of Agriculture and Technology, Koganei, Tokyo, Japan.
E-mail address: sivasakthivel.t@gmail.com (T. Sivasakthivel).

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Nomenclature

GSHP	Ground source heat pump
COP	Coefficient of performance
GHX	Ground heat exchanger
SAGSHP	Solar assisted ground source heat pump
HGSHP	Hybrid ground source heat pump
TRNSYS	Transient system simulation
EWT	Entering water temperature
LFT	Leaving fluid temperature
FFR	Fluid flow rate
DXGSHP	Direct expansion ground source heat pump
EER	Energy efficient ratio
HCD	Heating, cooling and domestic hot water
HP	Heat pump
sys	System
T	Temperature
ε	Effectiveness
C_p	Specific heat
$\dot{Q}$	Rate of heat transfer
q	Flow rate
$\dot{m}$	Mass flow rate
$\cos\phi$	Power factor
I	Current
V	Voltage
P_{pump}	Pump power consumption
P_{comp}	Compressor power consumption
P_{fan}	Fan power consumption
cond	Condenser
evap	Evaporator
in	Inlet
out	Outlet

trial runs, GSHP was able to fulfill the required heating demand and they suggested that for GSHP system floor heating is better than radiant heating. In Korea, Kim et al. [2] studied the heating performance of a GSHP system installed in a school building. It was found that in partial load operation the COP of heat pump in heating mode varied from 4.3 to 8.3. Aikins et al. [4] suggested some methods to improve the use of GSHP system in Korean market. Naili et al. [7] studied the possible uses of GSHP system for Tunisian climatic conditions and their results show that the heat exchange rate increases with increase in GHX length. In Poland, Maryanczyk et al. [8] used GSHP system for space heating a building. The GSHP system was able to meet on an average 15% of building heating load. Esen et al. [9] carried out experimental study on a GSHP system coupled with horizontal GHX for space heating applications in Turkey and also they created a numerical model to predict the temperature distribution in the vicinity of the heat exchanger. Their numerical results are closer to their experimental data.

Kim et al. [10] studied the performance of a SAGSHP system. It was found that SAGSHP system was more sensitive to heat pump operating temperature and when operating temperature was increased from 40 to 48 °C then the compressor work increased by about 20%. Rad et al. [11] proposed a hybrid GSHP (HGSHP) system combined with a solar thermal collector for space heating applications and observed that the use of 6.81 m^2 area of solar collector had resulted in 15% reduction in length of GHX and this is equivalent to a reduction of 7.64 m length of GHX per square meter area of solar collector. Dai et al. [12] carried out experimental study on the influence of modes of operation on the heating performance of a SAGSHP system. The results indicate that the solar thermal energy could be used to accelerate the soil recovery. In some cases SAGSHP systems are reduced to simple direct expansion ground source heat pump (DXGSHP) system, where refrigerants itself directly absorbs the heat from the ground rather than getting it from ground water circuit. Wang et al. [13] analyzed a DXGSHP with R22 as refrigerant in heating mode installed in China. During the operation of the heat pump, the indoor room temperature varied from 18 to 20 °C and the average heat transfer was 54.4 W/m. The maximum and average COP of the system in heating mode was found to be 6.08 and 4.73 respectively. Carli et al. [14] studied the energy performance of a DXGSHP system with borehole heat exchangers in heating mode. Results indicate that the direct expansion system has higher energy performance and requires lower total borehole length compared to common GSHP system. Wang et al. [15] carried out experimental trial runs on a SAGSHP system combined with thermal energy storage. Their results indicate that after one year of storage, the heat pump was able to extract 75.5% of stored energy and also during heating operation; the solar collector was able to supply 49.7% of total energy for heating. Reda and Laitinen [16] presented a new control strategy for SAGSHP system aiming to maximize the solar energy use and energy savings.

1.2. GSHP for space cooling

Even though much of the GSHP studies are focused on space heating applications, some researchers have attempted to evaluate the performance of GSHP systems in cooling operation also. Zhai et al. [17] studied the performance of a GSHP system in cooling mode operation and they found that after one year of operation the soil temperature increased by 0.5 °C and they recommended to use multiple GHX with minimum distance between the heat exchangers as 4–5 m in order to avoid heat accumulation in the ground. Karabacak et al. [18] attempted to reveal the relationship between cooling performance of a GSHP system and meteorological data. These meteorological data includes solar radiation, wind speed, relative humidity and ambient temperature. Results indicate that COP increases with decrease in solar radiation and wind speed. Park et al. [19] investigated the performance of water to refrigerant type GSHP installed in a school building in Korea, for cooling season. They monitored outdoor temperature, the ground temperature, and inlet and outlet water temperatures of the GHX. They observed that the COP_{HP} and $COP_{overall}$ of GSHP were 7.3 and 5.9, respectively. Kwon et al. [20] investigated the influence of cooling performance of water-to-water GSHP system by using counter flow and parallel flow methods. It was found that the heat transfer rate of the counter flow evaporator is higher than that of the parallel flow evaporator and also the cooling capacity of the GSHP increased with increase in compressor RPMs and entering water temperature (EWT).

In some cases GSHP's can be combined with other technologies to meet the high demand of cooling. Most of them are coupled with cooling towers/chillers to reduce the length of the GHX. These types of combinations are called hybrid GSHP (HGSHP) system. Sagia et al. [21] studied the performance of a HGSGP system to meet the energy demand of a cooling dominated office building. They concluded that, borehole length increases when cooling tower capacity decreases. Park et al. [22] compared the performance of GSHP with HGSHP by varying the leaving fluid temperature (LFT) of the GHX. At the LFT of the GHX of 40 °C, the COPs for the HGSHP with parallel and serial configurations were 18% and 6% higher than that of the GSHP, respectively. The performance of a hybrid cooling system that combines a screw water chiller with a GSHP was analyzed at various cooling loads by Jeon et al. [23]. They found that the COP of the GSHP was lower than that of a conventional chiller in the monitored building, but HGSHP system helped to stably provide the required cooling capacity at high load conditions. For the hybrid cooling system, the resting period for the thermal recovery of the underground condition should be considered carefully for