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First in situ operation performance test of ground source heat pump in Tunisia

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A B S T R A C T

The main purpose of this paper is to study the energetic potential of the deployment in Tunisia of the Ground Source Heat Pump (GSHP) system for cooling mode application. Therefore, a pilot GSHP system using horizontal Ground Heat Exchanger (GHE) was installed and experimented in the Research and Technology Center of Energy (CRTEn), Borj Cédria. The experiment is conducted in a test room with a floor area of about 12 m^2. In the floor of the tested room is integrated a polyethylene exchanger (PEX) used as a radiant floor cooling (RFC) system. The experimental setup mainly includes the ground temperature, the temperature and flow rate of water circulating in the heat pump and the GHE, as well as the power consumption of the heat pump and circulating pumps. These experimental data are essentially used to evaluate the coefficient of performance of the heat pump (COP_{hp}) and the overall system (COP_{sys}) for continuous operation mode. The COP_{hp} and the COP_{sys} were found to be 4.25 and 2.88, respectively. These results reveal that the use of the ground source heat pump is very appropriate for Tunisian building cooling.

1. Introduction

The oil crisis of the 1970s stimulated increased funding in the western world for research and development of new and renewable energy technologies which should be environmental friendly and cheap [1]. A form of renewable energy that seems to be well adapted for building cooling is geothermal energy. Geothermal energy as environmentally friendly energy source with wide range of applications such as for space heating and cooling, hot water supply and applications in the agricultural field has been used in practical engineering. The well-known application is for space heating and cooling in residential/tertiary sector using Ground Source Heat Pump (GSHP) system [2].

A GSHP system is mainly comprised of a heat pump and a sub-system for ground heat exchanger (GHE) [3], which can be installed horizontally or vertically. In the heating mode, the GSHP absorbs heat from the ground and uses it to heat the building. In the cooling mode (process reverses) the heat is absorbed from the conditioned space and transferred to the ground. Better energy efficiency of GSHP systems in comparison with traditional applications leads to continued growth in the number of installations for space conditioning [4]. According to the reports of the 2005 World Geothermal Congress, the installed power capacity and number of GSHP systems have increased from 198% (2000) to 272% (2005), to reach a total number of about 170,000 in 33 countries by 2005 [5]. The most commercialized GSHP system is the water-to-water heat pump which is the most interesting ones for the geothermal energy use. The utility degree of such pumps is COP = 3.0–5.0. Consequently, with 1 kW of engaged electrical energy in the work of a heat pump from 3.0 to 5.0 kW of heat energy is obtained. COP value increases by lowering the temperature of a heat pump feeding fluid [6]. The COP values may be also improved by optimizing GHE area by considering thermal interaction between the rows, flow regime in the pipe, and flow rate of the antifreeze solution pump [7], such as, the well designed earth-air heat exchanger can reduce electricity consumption of a typical house by 30% [8]. Li and Lai [9] indicated the existence of optimum parameters based on pure heat transfer, in their thermodynamic optimization of ground heat exchangers with single U-tube by entropy generation minimization method. Kurevija et al. [10] showed by simulating long-term operation of complex geothermal heat pump system with multiple boreholes in various geometric arrays, how spacing of adjacent boreholes and thermal interferences influence required borehole length for heat transfer. In order to obtain various optimum design parameters of a GSHP system with horizontal GHE, Sanaye and Niroomand [11] developed a thermal-economic optimal design method, developed in Visual Basic 6.

In the open literature, many research works have been conducted, modeling and testing of ground coupled heat pump systems [12–19]. Self et al. [20] have recently reviewed the GSHP systems and their comparison with other heating options. A pilot

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Nomenclature

COP	coefficient of performance
C	soil heat capacity (J kg^{-1} °C^{-1})
Cp	specific heat of water at constant pressure (J kg^{-1} °C^{-1})
d	depths (m)
Q_{hr}	heat absorbed from the test room (W)
Q_{hg}	heat transferred to the ground (kW)
T	temperature (°C)
$\dot{m}$	mass flow rate (kg s^{-1})
w_{da}	uncertainty of data acquisition system (%)
w_{me}	uncertainty of measurement (%)
w_{ro}	uncertainty in rotameter reading (%)
w_{sl}	uncertainty associated with system leakages (%)
w_{te}	uncertainty of the thermocouple (%)
w_{T_i}	total uncertainty in measurement of temperature (%)
$w_{\dot{m}}$	total uncertainty in measurement of mass flow rate (%)
W_c	power input to the compressor (W)
$W_{\Sigma p}$	power input to the circulating pumps (W)

Subscripts

a	ambient
f	fluid
g	ground
in	inlet
o	outlet
s	soil

Greek letters

ρ	soil density (kg m^{-3})
λ	soil conductivity (W m^{-1} °C^{-1})
α	soil thermal diffusivity (m^2 s^{-1})

Abbreviations

GHE	ground heat exchanger
GSHP	ground source heat pump
RFC	radiant floor cooling

underground geothermal horizontal loop was constructed, built and operated by Al-Dabbas and Al-Rousan [21]. The experimental results showed that thermal energy stored in rocks can be used to provide homes with heating, cooling, and hot water with low capital cost and zero environmental emissions. The performance comparison between horizontal and vertical source heat pump system was investigated experimentally by Benli [22]. In the same context, a techno-economic comparison of a direct expansion ground-source and a secondary loop ground-coupled heat pump system (DX-GSHP, SL-GCHP) for cooling in a residential building is performed experimentally by Guo et al. [23]. In their study they concluded that the DX-GSHP has a 23.8% higher efficiency and it was more economic than the SL-GCHP in cooling mode. The performance comparison between the horizontal GSHP with the parallel configuration and that with the serial configuration was conducted by Park et al. [24]. Cui et al. [25] developed a finite element numerical model to simulate hybrid ground-coupled heat pump with domestic hot water heating (DHW). Authors concluded that the horizontal GSHP can offer almost 95% of total DHW demand in this case study along with about 70% energy saving compared with the electric heater. A CFD simulations have been carried out by Congedo et al. [26] to analyze three main geometries of horizontal ground heat exchangers: linear, helical and slinky. In their study, the authors concluded that the most important parameter for the heat transfer performance of the system is the thermal conductivity of the ground around the heat exchanger; they also showed that the choice of the velocity of the heat transfer fluid inside the tubes is a key factor for heat transfer performance for all the arrangements. In order to determine the thermal property of the ground Esen and Inalli [27] examined the in situ thermal response test for GSHP system in Turkey. They concluded that the thermal conductivity and effective thermal resistance of the ground vary slightly with the depth.

Tunisia has a Mediterranean climate characterized by a high level of solar resources. Tunis, the capital, receives an average of 4 kW h m^{-2} day^{-1} with a total insulation period of 3500 h year^{-1} and 350 sunny days per year. The summer, which lasts 6 months, is characterized by a very hot climate [28]. Therefore, space conditioning is mainly based on electric power, this energy is more than third of the total energy consumption in the country. Besides, with the development of the building sector, without taking environmental conditions into account and the improvement of living standards, this proportion is necessarily in continuous increases. It represents a significant pollution and a very high energy costs that our country cannot afford. Consequently, the need to develop the use of geothermal energy, with through the ground source heat pump systems, is obvious. From literature review, there is a lot of studies deal with the performance evaluation of the GSHP systems. Besides that the great part of these studies is for GSHP with vertical GHE, just a few researchers investigated the practical operation performance of these systems [29]. Regrettably, this system is still not available in Tunisia, there are only some works which were restricted to soil temperatures [30] and the GHE performance [31], the lone work on geothermal heat pump is a numerical study using TRNSYS performed by Chargui for a green house application [32]. Consequently, it is required to know the performance of this kind of system, in order to make an attention for theses promising technology in our country.

This paper makes a first attempt to investigate performance of GSHP system in Tunisia on field experiment. It consists of an experimental setup on reversible water-to-water GSHP, with R410A as a refrigerant, for cooling mode application. The main objectives of this study are to investigate the performance evaluation and energy analysis of the GSHP system with horizontal GHE. The experimental setup mainly includes the ground temperature, the temperature and flow rate of water circulating in heat pump and GHE as well as the power consumption of heat pump and circulating pumps. These experimental data are essentially used to evaluate the coefficient of performance of the heat pump and the overall system for continuous operation mode.

This paper is organized as follows. Firstly, Section 2: experimental setup describes GSHP systems, presents the measurement equipment, the uncertainly analysis, the soil characteristics and weather data. Section 3: Thermal analysis of the GSHP system, presents the method used to determine the energy performance of the GSHP. Section 4: Results and discussions, analyses the experimental measurement. And finally, Section 5: conclusions: summarizes the results obtained throughout this study.

2. Experimental setup

2.1. System description

The pilot GSHP system represented in Fig. 1 consists mainly of three components, i.e., the heat pump unit, the GHE and the climate test room.