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In-field performance analysis of ground source cooling system with horizontal ground heat exchanger in Tunisia

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ABSTRACT

GSHP (Ground source heat pump) system is a promising technology for cooling and heating building in the world. Regrettably, this technology is still not available in Tunisia and it is time to test the GSHP systems in our country. For this purpose, two experimental systems are performed at the Research and Technology Center of Energy (CRTEn), in Borj Cédria, northern Tunisia. Firstly, to evaluate optimal parameters of the GHE (ground heat exchanger), the performance of the GHE with horizontal configuration was analyzed experimentally and analytically. The effect of various parameters such as mass flow rate of circulating water, length, buried depth and inlet temperature of the GHE on the heat exchange rate were examined. Second, water-to-water GSCS (Ground Source Cooling System) with HGHE (Horizontal Ground Heat Exchanger) was performed. The results obtained from this experimental study, are used to evaluate the COP_{hp} (coefficient of performance of the heat pump) and the COP_{sys} (coefficient of performance of the overall system) of the GSCS, which are ranged between 3.8–4.5 and 2.3–2.7, respectively. The results showed that the utilization of the ground source heat pump is appropriated for cooling building in Tunisia, which is characterized by a hot climate.

1. Introduction

Tunisia has a Mediterranean climate characterized by a high level of solar resources. Tunis, the capital, receives an average of 4 kWhm^{-2} day^{-1} with a total insulation period of 3500 h year^{-1}and 350 sunny days per year [1]. While the summer, which lasts six months, is characterized by a very hot climate. Therefore, the energy consumed for space conditioning in Tunisia, mainly based on electric power, is more than third of the total energy consumption in the country [2]. Besides, with the development of the building sector, without taking environmental conditions, and the improvement of living standards into account, this proportion is necessarily in continuous increasing. It represents a significant pollution and a very high energy costs that our country cannot afford. Therefore, it is necessary to develop the use of geothermal energy with through the ground source heat pump systems.

Geothermal energy as environmentally friendly energy source with wide range of applications, the well-known application is for space heating and cooling in residential and commercial buildings by using GSHP (ground source heat pump) system [3]. A GSHP system consists of a heat pump unit coupled with a GHE (ground heat exchanger), its COP (coefficient of performance) is obviously higher than conventional air conditioning systems due to it uses the ground which possess stable temperature as heat sink or source [4]. The COP values of the geothermal systems may be improved by optimizing GHE area [5]. Use of GHEs as part of a GSHPs is an important means of reducing energy consumption in buildings [6]. The performance of the GHE thermal function is also affected by further factors such as the specific thermal properties of the GHE [7] (conductivity, heat exchange coefficient...), the length, buried depth of GHE, mass flow rate and water inlet temperature. The groundwater seepage can alleviate the heat accumulation around pile ground heat exchangers, it can improves heat exchange performance and even get heat transfer quantity per meter pile GHEs to 4 or 5 times or higher than case of pure conduction [8]. Li and Lai [9], developed theoretical study based on *G* function, in order to analyze the impact of difference between properties of materials inside and outside boreholes or piles on the performance of the GHEs. Fossa and Minchio [10] investigated the effect of borehole geometry and ground thermal load profile on hourly thermal response of geothermal heat pump systems. A CFD (computational fluid dynamics) simulation was carried out by Congedo et al. [11] to analyze three main geometries of HGHE (horizontal ground heat exchanger): linear, helical and slinky.

Exergy analysis provides more information on system performance than energy analysis [12], it represents a thermodynamic

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Nomenclature

$\dot{m}$	mass flow rate, kg s^{-1}
COP_{hp}	coefficient of performance of the heat pump
COP_{sys}	coefficient of performance of the overall system
C_p	specific heat of water at constant pressure, kj kg^{-1} °C^{-1}
ΔT	temperature difference between the inlet and outlet GHE circulated water, °C
Δp	pressure loss, kPa
L	exchanger lengths, m
D	exchanger diameter, m
Q_e	heat exchange rate, W
Q_{hr}	heat rejected from the test room, W
Q_{hg}	heat injected into ground, W
T	temperature, °C
d	depth, m
$\dot{E}_x$	exergy rate, W
h	enthalpy
s	entropy
S	heat exchanger external surface, m
S_x	heat exchanger external surface at x section, m
U	overall heat transfer coefficient, W m^{-2} °C^{-1}
w_{sl}	uncertainty associated with system leakages, %
$w_{\dot{m}}$	total uncertainty in measurement of mass flow rate, %
w_{T_i}	total uncertainty in measurement of temperature, %
w_{da}	uncertainty of data acquisition system, %
w_{me}	uncertainty of measurement, %
w_{ro}	uncertainty in rotameter reading, %
w_{te}	uncertainty of the thermocouple, %
$\dot{W}_c$	power input to the compressor, W
$\dot{W}_{\sum p}$	power input to the circulating pumps, W

Greek letters

ρ	water density, kg m^{-3}
λ	conductivity, W m^{-1} °C^{-1}
ε	energy efficiency, %
η	exergy efficiency, %
α	thermal diffusivity, m^2 s^{-1}

Subscripts

in	inlet
o	outlet
f	fluid
g	ground

Abbreviations

GHE	ground heat exchanger
GSCS	ground source cooling system
GSHP	ground source heat pump
HGHE	horizontal ground heat exchanger
HTC	heat transfer coefficient
LMTD	log mean temperature difference
RFC	radiant floor cooling

quantity that reveals the maximum available energy of the system [13]. In the literature, many studies of exergy analysis for GHE are published. Ozgener and Hepbasli [14] have reviewed the studies conducted on exergy analysis of GSHP systems worldwide. Hepbasli [15] has also reviewed comprehensively exergetic analysis and performance evaluation of a wide range of renewable energy resources for the first time to the best of the author's knowledge.

In the last decade, the development of GSHP technology has registered a great interest worldwide. According to the reports of the 2005 World Geothermal Congress, the installed power capacity and number of GSHP systems have increased by 198% and 272%, respectively, from 2000 to 2005, and the total number of the GSHP system installations has exceeded 170,000 in 33 countries by 2005 [16]. Better energy efficiency of ground coupled heat pump systems in comparison with traditional applications leads to continued growth in the number of installations for space conditioning [17].

In the open literature, many research works have been conducted, modeling and testing of ground coupled heat pump systems [18–25]. Recently, in simulation study using TRNSYS, Entchev et al. [26] proved that the GSHP and a hybrid GSHP/fuel cell systems achieved significant overall energy savings of 39% and 24% respectively, compared with conventional system with boiler/chiller. Florides et al. [27] examined, in a simulation study, the effect of temperature and thermal properties of the ground on vertical and horizontal GHEs.

Benli [28] investigated, in experimental study, the performance comparison between (HGSHP, VGSHP) (horizontal and vertical source heat pump systems) for a greenhouse heating. The author concluded that the COP_{hp} and COP_{sys} of VGSHP are higher than HGSHP, but the first installation needs higher costs. Bakirci [29] investigated, in experimental study, the performance of vertical ground source heat-pump system experimentally. The experimental results indicated that the average heat pump COP and all system's COP_S values are approximately 3.0 and 2.6 in the coldest months of heating season.

In the GSHP systems, when the water in the GHE is transferred to the water in the building, the HPs (heat pumps) are then called water-to-water heat pumps. 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 [30].

Guo et al. [31] performed 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. Coşkun et al. [32] carried out the experimental performance investigation of a horizontal ground source compression refrigeration machine, the effect of various parameters on the performance of the system was examined.

Lee and Lam [33] developed a simplified three-dimensional finite difference model for a single cylindrical energy pile for GSHPs systems. The authors investigated the effect of the thermal properties of various regions on the performance of the cylindrical energy pile. Esen and Inalli [34] examined the in situ thermal response test for GSHP system in Turkey in order to determine the thermal property of the ground.

From literature review, there are many experimental and numerical studies deal with the performance evaluation of GSHP system, which the great part is for the GSHP with vertical GHE. In Tunisia, these kinds of experimental studies are still not available.

Because of insufficient information about GSHP performance system in Tunisia, an experimental setup, described in the next section, was performed on reversible water-to-water heat pump with R410A as the refrigerant for cooling mode application. The experiments were conducted in the Research and Technology Center of Energy at Borj Cédria, northern Tunisia.

The main objectives of this study are first to characterize the GHE response and second, to investigate the performance evaluation and energy analysis of the GSCS (ground source cooling system). For this purpose, two experimental systems were performed,