Performance analysis of horizontal ground source heat pump systems for cooling in southern climate

Sabrin KORICHI[*,1], Nabiha NAILI[2] , Bachir BOUCHEKIMA[1], Messaouda AZZOUZI[3]

[1]*Laboratory of New and Renewable Energies in Arid and Saharan Areas–LENREZA.University of Kasdi Merbah-Ouargla Po Box 511 30000 Ouargla Algeria*
[2]*Laboratory of Thermal Processes, Research Center of Energy Technologies, Hammam Lif, B.P. 95, 2050 Tunis, Tunisia (CRTEn)*
[3]Department of Electrical Engineering, Faculty of Science and Technology, University Ziane Achour of Djelfa, 17000 Djelfa Algeria

*Corresponding author: sabrinskemr@gmail.com ; Tel.: +213 0675530562

Abstract: The aim of this present study was to verify the reliability of the simulation model of the ground source heat pump, for this purpose a TRNSYS model has been built for a GSHP coupled with horizontal ground heat exchanger (HGHX) used for cooling a demonstration unit equipped with radiant floor located at the Research Center and Technologies of Energy (CRTEn), Tunisia and a good agreement was obtained between the simulation and experimental results. After the thermal modeling of GSHP including HGHX which were done using TRNSYS software, the optimum design parameters of the system for the severe hot zone were estimated subject to a list of economic constraints.The results obtained from this study demonstrate that the utilization of ground source heat pump is a promising and profitable solution for the cooling in the Southern climate; it is possible to lower the mean indoor air temperature below 26 °C and raise the average relative humidity to reach 65%.

Key Words:

Ground-source heat pumps; Ground heat exchanger; Horizontal closed loop;Optimization;Thermal modeling.

I. Introduction

The consumption of energy in residential buildings has gained an increasing interest recently due to the rising demand for efficient energy use and higher comfort standards [1]; it reaches about 40% of the world's energy use [2]. Therefore, the building sector represents the largest source of greenhouse gas emissions (GHG) and ecological problems in the world and it is necessary to highlight the use of new renewable technologies such as geothermal energy as a solution to reduce the large energy consumption and environmental problems.

The ground source heat pump (GSHP) system is a clean and sustainable solution for the heating and cooling of buildings by pumping heat from or to the shallow subsurface to provide thermal loads to the buildings. Compared with other renewable technology, the ground coupled heat pump system has an important advantages such as its no location restriction for employing and no time dependant nature which means that it can be used everywhere in the world especially in areas where the amount of energy stored in the subsurface is greater than its annual requirements for heating and cooling.

In recent years, numerous studies have been published concentrated in the theory and design [3], modeling and simulation [4], testing [5] and [6] and thermoeconomic analysis [7] and [8] of the GCHP systems. However, there are many unsuccessful projects, especially in the design of big systems for this purpose the researches have mainly focused to shows the benefits of conducting a pre-design analysis to sizing the system, developing a software program based on a proper model of the ground source heat pump and obtaining the optimum design parameter of GHP including the heat exchanger [9] and [10]. The main objective of this paper is to develop a dynamic simulation model using TRNSYS of a practical HGSHP used for cooling a demonstration building located in the North of Tunisia. The model of the building quipped with radiant floor and it has been verified by experimental data. Then more useful results will be obtained by the simulation model for southern climates and more particularly for Ouargla, city located in the South-East of Algeria.

II. Materials and methods

2.1. Description of CRTEn ground source heat pump projet

The experimental system installed in the Laboratory of Thermal Processes (LPT) at the Research Center and Technologies of Energy (CRTEn), Tunisia. The GSHP system used to provides the air conditioning for 12 m^2 area and it consists of a heat pump unit with a cooling capacity of 14.7 kW connected to an internal and external circuits. The internal circuit includes a radiant floor system, a Chilled ceiling panel system, a water storage tank and a circulation pump. On the other hand, the external circuit comprises a circulation pump and heat exchanger of 50 m length buried at 1 m of depth. Fig. 1 shows the schematic diagram of the HGSHP system.

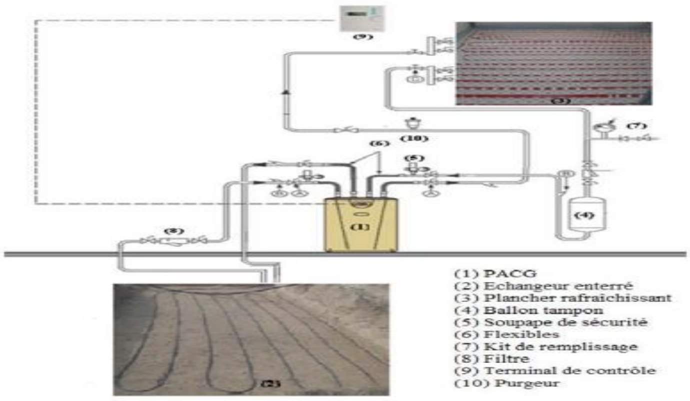


Fig.1. Schematic diagram of the GSHP experimental system [5]

2.2. The model of the system in TRNSYS

This section presents the validation of TRNSYS type against experimental measurements of one of the three heat exchangers of the CRTEn ground source heat pump projet (fig 2), a TRNSYS model of the experimental system was developed, including the TRNBuild model of the building (climat teste room) and a ground heat exchanger (type556).

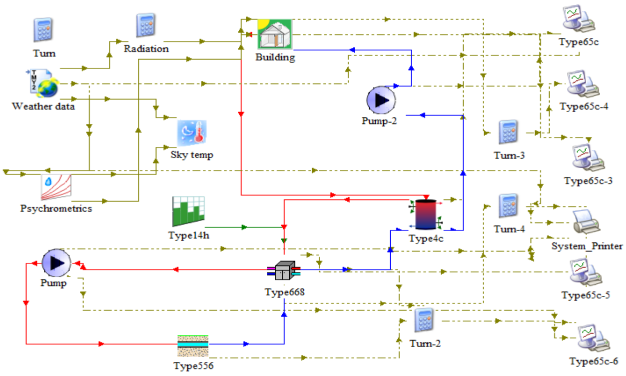


Fig.2. TRNSYS model of GSHP system

3. Results

3.1. validation

In order to test the reliability of the simulation model that we have developed, The model has been validated with the consideration of experimental measurements of mass flow, pipe length, buriel depth as inputs for the TRNSYS model at each simulation time step (5 min). The experimental measurements has been compared against the simulated inlet and outlet fluid temperature at the GHX, the heat exchange rate and the coffecient of perfermance (COP) .

3.1.1. Weather data

In the TRNSYS environment, the weather data is typical meteorological year TMY2 [11]. The weather data were collected from the weather stations and converted to the TMY2 data format by processing actual meteorological data. However, theTMY2 data must be validated using actual meteorological measurements, The TMY2 data used for this simulation and average actual outdoor temperature which were collected from the meteorological NRG weather station installed in the CRTEn, Borj Cédria area [6]   are illustrated in Table1. It can be seen that the experimental and simulated external temperature are approximately the same.

Table 1: Comparison of experimental and simulation average outdoor temperature (°C)

Months	JAN	FEV	MAR	APR	MAI	JUN	JUL	AUG	SEP	OCT	NOV	DEC
TMY data	11,51	11,99	13,27	15,53	19,35	22,86	27,33	26,73	23,57	20,04	15,37	12,05
actual weather data	10,12	11,1	12,93	15,74	19,67	23,32	27,95	26,47	23,3	19,57	14,83	11,27

3.1.2. Temperature comparison

Table 2 reports the comparison between experiments and simulation results of the outlet and inlet temperature (Tin and Tout, T_{in-RF} and T_{out-RF}) and temperature differences (ΔT) of the GHX and RF system water, we can observe from this illustration that the maximum absolute error between the simulation and experimental results of Tin and Tout does not exceed 0.38 and 0.034 °C, respectively and the deviation of ΔT is 0.35°C. The same for the RF system, we can concluded from this table, that the maximum error of T_{in_RF} and T_{out_RF} between the simulation and experimental results does not exceed 0.8 and 0.2 °C, respectively and the deviation of ΔT is 1°C. Table 3 shows the maximum and the minimum indoor temperatures for one typical day in cooling mode, by comparing these values; it is easy to see that the simulation results are very close to the experimental results.

Table 2: Comparison of average water temperatures at the external circuit for a typical heating and cooling day (°C)

	RF			GHX		
	T_{in_RF}	T_{out_RF}	ΔT	T_{in}	T_{out}	ΔT
actual data	13	15	2	55	30	25
type 556	12.2	15.2	3	55.034	30.38	24.65

Table 3: Comparison of average indoor temperature of the "test room" (°C)

	Actual data		Type556	
Average indoor temperature	T_{max}	T_{min}	T_{max}	T_{min}
T	27	23	25.6	23.4

3.1.3. Energy comparison

Table 4 shows the actual data and the simulation results of the amount of heat exchange and the coefficient of performance. The comparison of the experimental and simulated values of the drill outputs presents very satisfactory results and the differences can be attributed to the uncertainties of the experiment. Therefore, it can be concluded that the developed models of the behavior of the heat pump can be considered valid and will be used in the following of this manuscript.

Table 4: The Coefficient of performance of the heat pump and the amount of heat transfer

Energy parameters	actual data	type556
COP	3.96	3.95
Q_b	1.4KW	1.374KW
Q_g	9KW	8.9KW

3.2. Testing example for southern climate

In this section, we use the TRNSYS system model for further analysis of cooling a similar building in the southern regions and more particularly for Ouargla City, Algeria where the climate is extremely hot during the cooling seasons.

3.2.1. Optimization results

Because of the high investment cost of the ground heat exchanger instalation and the large cost of long-term electricity consumption, a termal optimization program were developed in TRNSYS to study the effect of the pipe length, burial depth and mass flow rate variations on the thermal performance subject to a list of economic constraints.

a) The effect of the GHX length

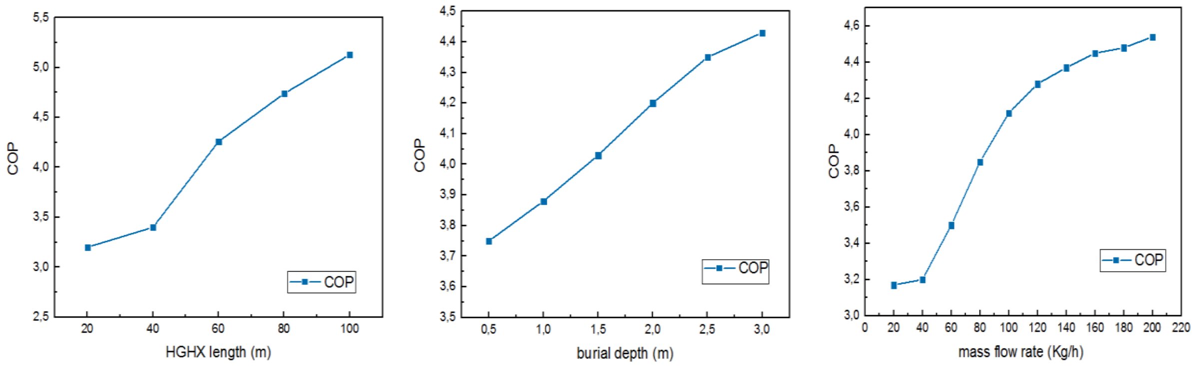
In Fig.5, (a). To find the optimal pipe length in the design of the GHX , the coefficient of performance (COP) of the heat pump is shown as function of the pipe length in constant mass flow rate, pipe diameter and burial pipe depth (80 kg/h, 0,025m , 1m). The coefficient of performance of the HP increase with the increase of pipe lenght caused by increased heat exchanger area, we can also observed that from 60 m length the improvement of COP becomes smaller gradually, which explain that in this case study the optimal pipe length of the GHX is 50 m.

b) The effect of the depth

In Fig.5, (b). To find the optimal burial pipe depth in the design of the GHX , the coefficient of performance (COP) of the heat pump are shown as functions of the burial pipe depth in constant mass flow rate, pipe diameter and pipe length (80 kg/h , 0,025m , 50m). The COP increases with the increase of burial pipe depth, The significant difference in COP values found by passing from 0.5 to 2 meters is explain that in the lower depths, the soil is less affected by external weather conditions, this result is proven in section (3.2.2). Therefore, in this case study the optimal burial pipe of the GHX is 1 m.

c) The effect of mass flow rate

In Fig.5, (c). The coefficient of performance (COP) of the heat pump is shown as function of the mass flow rate in constant burial depth, pipe diameter and pipe length (1m, 0,025m , 50 m). The COP increases with the increase of the flow rate of the water circulating in the heat exchanger, until reaching a significant value of around 4.2 for a flow rate of 100 kg/h. In higher mass flows rate, this increase is slowed by the pressure drops. Therefore, the optimal flow of the GHX is 100 kg/h.



(a) (b) (c)

Fig.5. Effect of the design parameters on performances of heat pump: (a) Effect of the HGHX length (m) ; (b) Effect of the burial depth (m) (c); Effect of mass flow rate (Kg/h)

3.1.1. Typical days performance

In this section, the effects of the optimum design parameters on the operation of the horizontal ground source heat pump system (T_{amp},RH) is performed in typical days of cooling mode as follows:

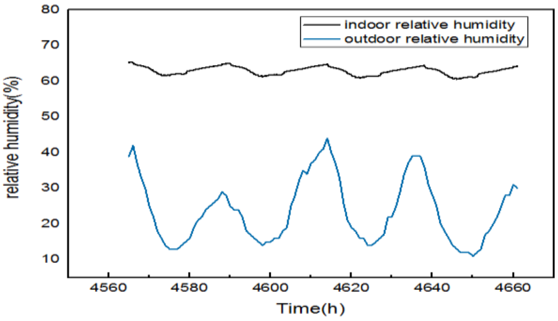


Fig.6. Comparison between indoor and outdoor relative humidity

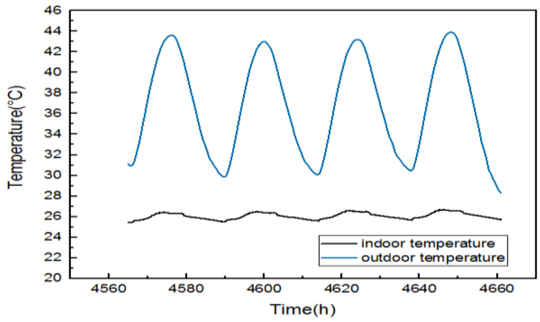


Fig.7. Comparison between indoor and outdoor temperatures

In order to show the rentability of GSHP system for cooling a typical space, we represent in Fig.6 and Fig.7 the variations in indoor and outdoor climat conditions during cooling simulations periodes . It can be seen from this figure that the indoor air temperature in a comfortable range, vary between 24-26.4, for an indoor relative humidity range between 60-65%, while the outside air temperature and relative humidity ranging between 30-44°Cand12-42%,respectively.

IV. Conclusion

In this study, the thermal modeling as well as the feasibility of the horizontal ground source heat pump used for cooling a residential unit under the meteorological conditions of the Southern and Northern climates was analyzed and evaluated using environment TRNSYS. Some conclusions obtained are as follows:

1) The simulated results are deemed to be reasonable; the comparison of the experimental and simulated values of the system presents very satisfactory agreement.

2) Based on the results obtained in this study, the use of geothermal heat pump technique is promising for southern climates, the indoor temperature and relative humidity can reaches 25 and 65%respectively.

Acknowledgements

This research was partly supported by the basic research project by the “Laboratoire des Procédés Thermiques (LPT)”, “Centre de Recherches et des Technologies de l’Energie (CRTEn)”, Tunisia. And by the laboratory of new and renewable energy in arid and saharan zones – LENREZA, Algeria.

V. References

[1] Chargui, R., Sammouda, H., & Farhat, A, Geothermal heat pump in heating mode: modeling and simulation on TRNSYS, International journal of refrigeration 35.7 (2012) 1824-1832.

[2] Ghedamsi, R., Settou, N., Gouareh, A., Khamouli, A., Saifi, N., Recioui, B., & Dokkar, B, Modeling and forecasting energy consumption for residential buildings in Algeria using bottom-up approach, Energy and Buildings 121 (2016) 309-317.

[3] Kavanaugh, S. P., & Rafferty, K. D, Geothermal heating and cooling: design of ground-source heat pump systems. ASHRAE, 2014.

[4] Cacabelos, A., Eguía, P., Míguez, J. L., Granada, E., & Arce, M. E, Calibrated simulation of a public library HVAC system with a ground-source heat pump and a radiant floor using TRNSYS and GenOpt. Energy and Buildings 108 (2015) 114-126.

[5] Naili, N., Hazami, M., Attar, I., & Farhat, A, In-field performance analysis of ground source cooling system with horizontal ground heat exchanger in Tunisia. Energy 61 (2013) 319- 331.

[6] Naili, N., Hazami, M., Attar, I., & Farhat, A, Assessment of surface geothermal energy for air conditioning in northern Tunisia: direct test and deployment of ground source heat pump system. Energy and Buildings 111 (2016) 207-217.

[7] Kayaci, N., & Demir, H, Long time performance analysis of ground source heat pump for space heating and cooling applications based on thermo-economic optimization criteria. Energy and Buildings 163 (2018) 121-139.

[8] Luo, J., Xue, W., Hu, T., Xiang, W., & Rohn, J,Thermo-economic analysis of borehole heat exchangers (BHE) grouted using drilling cuttings in a dolomite area. Applied Thermal Engineering 150 (2019) 305-315.

[9] Sanaye, S., & Niroomand, B,Thermal-economic modeling and optimization of vertical ground-coupled heat pump. Energy Conversion and Management 50.4 (2009) 1136- 1147.

[10] Sanaye, S., & Niroomand, B, Horizontal ground coupled heat pump: Thermal-economic modeling and optimization. Energy conversion and management 51.12 (2010) 2600-2612.

[11] Lyu, C., Leong, W. H., Zheng, M., Chen, G., Ye, S., & Liu, Y, Verification and analysis of a dynamic simulation model of ground-coupled heat pump with solar seasonal heat storage system. Procedia Engineering 205 (2017) 3154-3161.