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Experimental study of ground source heat pump system for heating mode under climatic condition of northern Tunisia

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Abstract: The work focuses on testing the geothermal energy for space heating in the climatic conditions of northern Tunisian, by assessing the performance of the ground source heat pump (GSHP) system. This is to solve a problem of high consumption of energy in buildings sector in Tunisia. Therefore, an experimental platform including a ground heat exchanger (GHE) coupled to a ground heat pump (GHP), which is connected to a test room is tested in the Research and technology Center of Energy, Borj Cedria site.
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 (COPhp) and the overall system (COPsys).
The results show that the use of geothermal energy is a promising solution for reducing the building sector's energy consumption in Tunisia.

Mots clés :

Geothermal energy; ground heat exchanger; ground heat pump; heating mode; energetic study.

1. Introduction

Worldwide, the building sector is a major energy consumer. According to the International Energy Agency [1], it is the third of world energy consumption. In particular, the amount of energy consumed for air conditioning increased by about 60% between 2000 and 2010 [2].

In Tunisia, space conditioning depends mainly from electricity, knowing that natural gas provided 94% of the electricity in Tunisia [3], its represents a very high energy bills that our country cannot afford. Indeed, the prediction of the final energy demand by sector, conducted by the National Agency for Energy Management (ANME), shows that in 2030 the building sector would be the first consumer sector energy (Figure 1). Other than the increase of the energy consumed, the use of this energy is accompanied by an increase of pollution.

Therefore, it is necessary to replace current conditioning units, large energy consumers, with new technologies including better energy efficiency. This can only be assured by the development of renewable energy use.

The need for alternative energy sources cheap and environmentally friendly has led to the development of geothermal systems for residential and commercial heating and cooling applications. [4]

Surface geothermal is the form of renewable energy most suited to the field of heating and cooling buildings. For example, the geothermal potential surface in Tunisia is very important. Indeed, the soil temperature measurements in the site of Borj Cédria, about a meter deep, is about 20 ° C in winter and 25 ° C in summer.

The exploitation of the surface geothermal energy requires usually the use of a geothermal heat pump (GHP) in order to concentrate the temperature level provided by the energy from the ground before restoring in the building.

In its operation, the GHP procedure is the same as a refrigerator or conventional air conditioning system, but with the advantage of using a renewable energy source (geothermal).

GSHP are chosen according to the energy requirements of buildings to be packaged. Indeed, only one unit is sufficient for a home or small commercial building, while for commercial buildings, larger areas, several GSHP should be used.

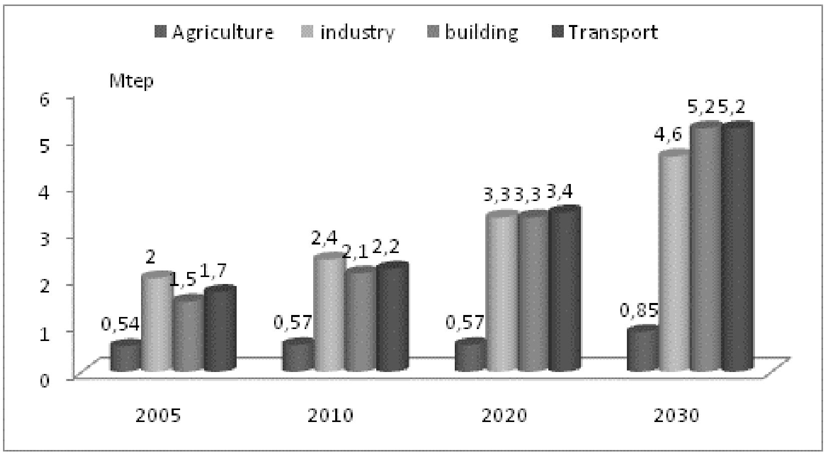

Figure 1: predict of final energy demand by sector by 2030 (ANME)

The use of geothermal systems for space conditioning is a rather old technology. Indeed, the first geothermal heat pump (GSHP) was invented in 1912 by Heinrich Zoelly, it was then sold for the first time by Donald Kroekeren in 1946 [5].

Water to water GSHP is the most commercialized technology. Several researches both experimental and numerical have been conducted on GSHP systems [6-14].

In general, measuring the feasibility of a heat pump is linked to the evolution of its coefficient of performance (COP), which is the ratio of useful energy (transferred to the building) and the energy consumed by the GSHP system. Compared to air source heat pump (ASHP), the GSHP can reach very high COP, since they use the ground where the temperature is always lower than ambient temperature in summer and always higher than ambient temperature in winter. Indeed, An economic comparison between GSHP system with horizontal shape, and secondly, an ASHP system was conducted by Small and Meyer [15]. The experimental study, performed in the climatic conditions of South Africa, showed that the use of horizontal exchangers is the best solution. The same result was found by De Swart and Mayer [16] using a reversible heat pump.

Cui et al. [17] developed a numerical model based on the finite elements to simulate a GSHP with hot water. The authors concluded that the horizontal ground heat exchanger (HGHE) could provide nearly 95% of the total demand of hot water with about 70% of energy saving compared to electric heating. To further improve the geothermal system, to have high COP, many system parameters need to be optimized [18], Li and Lai [19] have optimized a U buried exchanger using a thermodynamic process of minimizing the production of entropy. The authors indicated the existence of optimal settings based on the heat transfer.

Sanay and Niroomand [20] developed in Visual Basic 6 a method of thermal design - economic optimum for various parameters of geothermal system with horizontally buried exchanger. Bansal et al [21] have studied experimentally and numerically (using Fluent software) the effect of the length of horizontal buried air exchanger on its thermal performance. In their study, the authors concluded that the best performance is obtained for a length exchanger equal to 100 m, a diameter equal to 0.2 m and an air velocity of about 5 $m.s^{-1}$.

Some parameters are recommended, particularly as regards the burial depths and the spacing between the tubes constituting the buried exchanger. Indeed, Floridas et al [22] have experimentally determined the variation of the ground temperature according to its depth. They concluded that the soil temperature remains nearly constant beyond 5m throughout the year. In their study they found that the depth of the HGHE is typically 1.5 to 2 m with an optimum spacing of 30 cm.

Lee and Lam [23] developed a 3D simulation, a model based on the finite difference method for a geothermal heat pump coupled to a cylindrical buried exchanger. The authors studied the effect of thermal properties of different regions of Hong Kong on system performance.

The effect of the thermal conductivity of soil and continuous operating time of the thermal performance of the buried exchanger was evaluated by Misra et al. [24]. The analysis was performed using the simulation platform CFD FLUENT.

Recently, Luo et al. [25] have experimentally examined the thermal performance of a GSHP system for heating and cooling. The main results of their study show that long-term performance of the system's efficiency has increased by 8.7% for the cooling mode while it decreased 4.0% for heating.

The interest of Tunisia to develop geothermal energy opens new opportunities for economic development, especially as it is a source of energy that can help to reduce the problems of high energy consumption in the building sector.

The objective of this study is to introduce and to test, in Tunisia, the thermal potential of the soil, especially the surface geothermal energy, via the use of the GSHP system for heating individual room. The Experimental study of the performance of such systems in the climatic conditions of our country can allow drawing conclusions about the feasibility of geothermal energy in our country. The knowledge of the behavior of this system is also required because, unfortunately, in the literature, no analysis for space heating exists in the Tunisian context.

In Tunisia, the test of the GSHP system is performed only for cooling purpose [26-29], indeed there is lack for information for space heating. Therefore, this study makes the first endeavor to test the GSHP system for heating space in Tunisia.

This paper is organized as follows. Firstly, section 2: experimental setup describes the GSHP system, presents the measurement equipment and the uncertainly analysis. Section 3: Thermal analysis of the GSHP system, presents the method used to determine the 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.

Nomenclature

COP	coefficient of performance
Cp	specific heat of water at constant pressure, J kg^{-1} °C^{-1}
d	depths, m
Qht	heat transferred to the test room, W
Qha	heat absorbed from 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 (%)
$\dot{W}_c$	power input to the compressor, W
$\dot{W}_{\Sigma p}$	power input to the circulating pumps, W
Subscripts	
f	fluid
g	ground
in	inlet
o	outlet
out	outdoor
s	soil
w	water
Abbreviations	
RFH	radiant floor heating
GHE	ground heat exchanger
GHP	geothermal heat pump
GSHP	ground source heat pump

2. Experimental setup

2.1. Description

The GSHP system consists mainly of three components, i.e., the GHE (1), the heat pump unit (2) and the climate test room (3) (Fig. 2)

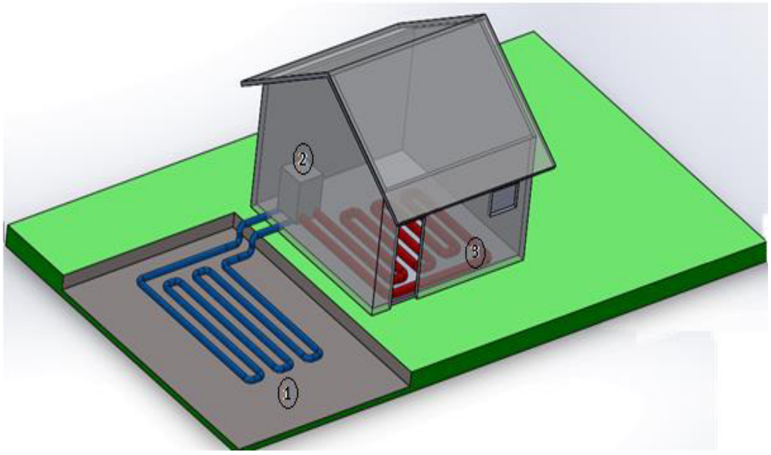

Figure 2 : Descriptive Scheme of the GSHP conditioning system

The heat pump (HP) unit utilized in the experimental set-up is a reversible water-to-water Ageo CIAT type. The heating capacity, the power input and the motor rotation speed of the heat pump, in rated conditions, are 16 kW, 3.2 kW and 2900 r mn-1, respectively

The GHE consists of 100 m of high-density polyethylene tube (PEHD) 0.025 m of pipe diameter installed horizontally at 1 m depth in the ground. The distance between the pipes was 0.5 m.

The GSHP is connected to a tested room with a floor area of 12 m^2. The test room is equipped with a radiant floor heating (RFH) system, consisting of a reticule polyethylene exchanger (PEX). The RFH tubes are covered by two layers, a concrete of 0.03 m and a 0.1 m floor ceramic.

The GSHP system was installed in the "Centre de Recherches et des Technologies de l'Energie (CRTEn)" and tested in 2015-2016 heating season.

2.2. Measurement equipment

The measurements equipment used in the experimental setup are cited below:

- The water temperatures, entering and leaving the GHE, and the floor heating system were measured by two wire PT500 resistance thermometer sensors.
- The ground temperatures were measured by copper-constantan thermocouples buried at different levels in the ground.
- The water mass flow rate was measured by a flow meter.
- The air temperatures inside the room were measured by four wire PT100 resistance thermometer sensors mounted at different levels in the room center.
- The input electrical power of the compressor was measured by electrical energy meter
- The electrical power of the circulating pumps was measured by a Wattmeter.
- The outdoor air temperatures, relative humidity, wind velocity and solar radiation were measured by a Meteorological station.

All the temperature sensors were connected to a multi-channel data acquisition system type HP Agilent, which were stocked in a PC station.

2.3. Uncertainty analysis

Errors due to temperature measurement are: (i) uncertainty of data acquisition system, about ±0.1% °C, (ii) measurement error, ±0.2% and (iii) uncertainty of the thermocouple, ±0.1% °C. The uncertainty was obtained from a catalog of the instruments. Errors came from the measurement of the mass flow rate are: (i) uncertainty of the flow-meter, about ±0.1% and (ii) uncertainties due to measurement, about ±0.1%. The total uncertainties for measured and calculated parameters as per cent are given in Table 1**.**

Table 1: Total uncertainties for measured and calculated parameters

Item	Symbol	Unit	Total uncertainty (%)
Measured parameters			
Temperature at GHE inlet	$T_{in\text{-}GHE}$	$°C$	±5,71
Temperature at GHE outlet	$T_{o\text{-}GHE}$	$°C$	±5,14
Temperature at CCP inlet	$T_{in\text{-}RFH}$	$°C$	±1,71
Temperature at CCP inlet	$T_{o\text{-}RFH}$	$°C$	±2,00
Outdoor temperature	T_a	$°C$	±3,89
Indoor temperature	T_{moy}	$°C$	±3,48
Soil temperature	T_g	$°C$	±3,57
GHE circulating water mass flow rate	$\dot{m}_{ws}$	$kg\ s^{-1}$	±0.14
CCP circulating water mass flow rate	$\dot{m}_{wf}$	$kg\ s^{-1}$	±0.14
Calculated parameters			
Heat transferred to the building	Q_{ht}	W	±5,19
Heat absorbed from the ground	Q_{ha}	kW	±11,75
COP of the heat pump	COP_{hp}	-	±0,54
COP of the overall system	COP_{sys}	-	±0,88

3. Thermal analysis of the GSHP

The heat transferred to the test room, Qht (i.e., load) is calculated using the following equation:

$$Q_{ht}=\dot{m}_{wf}\ C_{P_W}\left(T_{of}-T_{inf}\right) \qquad (1)$$

The heat absorbed from the ground is calculated using the following equation:

$$Q_{ha}=\dot{m}_{ws}\,C_{P_W}\left(T_{os}-T_{ins}\right) \qquad (2)$$

The COPhp is estimated by the heat transferred to the building divided by the power consumed by the compressor, it is expressed by the following equation:

$$COP_{hp}=\frac{Q_{hr}}{\dot{W}_c} \qquad (3)$$

The coefficient of performance of the overall system COPsys is then estimated by the heat transferred to the building divided by the power input to the overall GSHP system, it can be expressed as follow

$$COP_{sys}=\frac{Q_{hr}}{\dot{W}_c+\dot{W}_{\Sigma p}} \qquad (4)$$

Where $\dot{W}_{\Sigma p}$ represents the total power of the pumps.

4. Results and discussion

The experiment was conducted in a test room at the Research and Technology Center of Energy (CRTEn). The results are obtained during heating season 2015/2016, and more precisely in March 6, 2015 when the average daily temperature is about 11.22 °C.

4.1. The ground temperature

Ground temperature is a very important parameter in the installation of ground heat exchangers. The temperature of the soil at different levels from 0 to 1.2 m compared to the ambient temperature is shown in Figure 3.

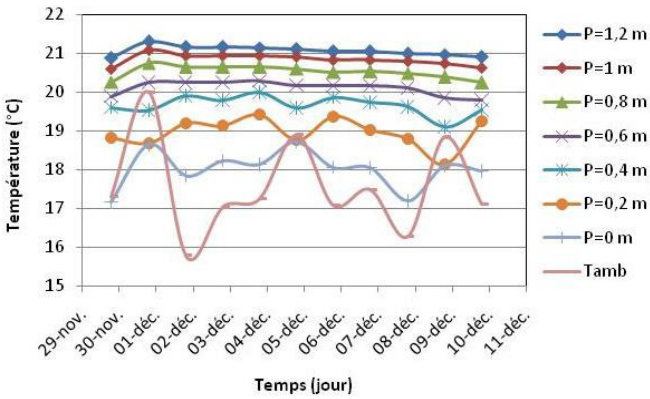

Figure 3: Variation of the temperature in function of the depth

The ground temperature profile shows that the temperature fluctuation decreases as we move away from the ground surface. Indeed, at 1 m deep, the temperature is almost constant, it is not affected by the external environment, and this is due to the high thermal inertia of the ground. The temperature at 1 m depth e is of the order of 21 ° C making the ground a source of energy for heating buildings using a geothermal heat pump.

4.2. The room temperature

In Figure 4 is shown the variation of the average temperature (Tmoy) of the test room compared to the outdoor ambient temperature (Tamb) as function of time.

The figure shows that after activation of 10h heating system, test room temperature gradually increases from about 15 °C to be around 22 °C. Therefore the GSHP system has provided thermal comfort.

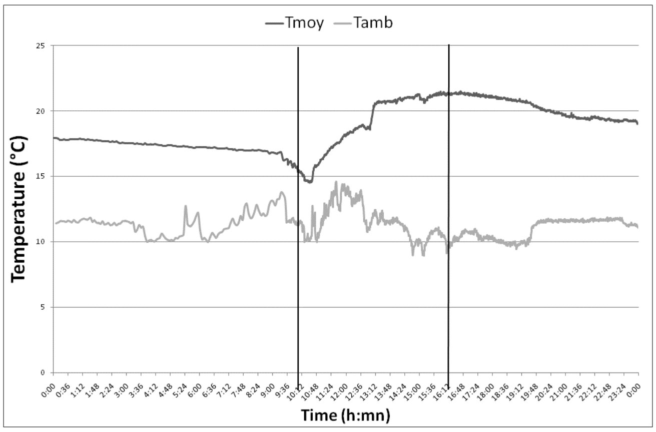

Figure 4: Recorded outdoor and indoor air temperatures during the experimental setup.

The heating system stopped at 16h, only we kept the flow of hot water from the tank to the floor heating system, the results show that the testing room temperature decreases slowly and thanks to the amount of energy transferred by the heat pump to the Lord puffer its last activation.

4.3. The RFH inlet and outlet temperature

To determine the water temperatures at the inlet (TEI) and the outlet (TSI) transmission system, the heating floor, we were installed two sensors PT500 at the collector, the results are represented in Figure 5.

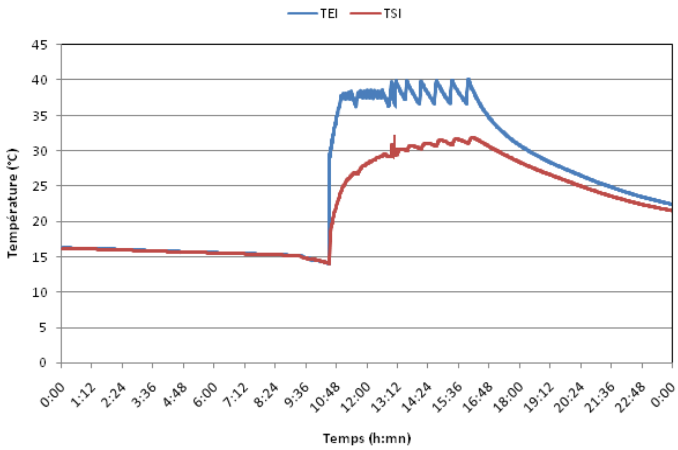

Figure 5: variation of the RFH inlet and outlet temperatures as function of time

We can observe in this figure that both TEI and TSI temperatures gradually increase during the activation of the heating system. After the stabilization of the climate system, TEI and TSI vary between 37-40 °C and 31-31.4 °C, respectively.

The shaped TEI saw tooth is due to the discontinuous operation of the compressor. It is noteworthy that the discontinuous operation of the compressor is a choice adopted in order to limit the power consumption of the heat pump, and subsequently to improve the coefficient of performance of the heat pump and the whole system.

4.4. The amount of heating energy

The heat transferred to the test room, by means of the floor heating system, which is calculated by the equation (1) is shown in Figure 6.

It may be noted in Figure 6 that just after the activation of the heating system the amount of heating energy reaches 3 kW, and then it decreases to fluctuate between 1.9 and 1.2 kW. The large demand of energy in the beginning of the heating is due to the low room temperature which requires a great energy for heating

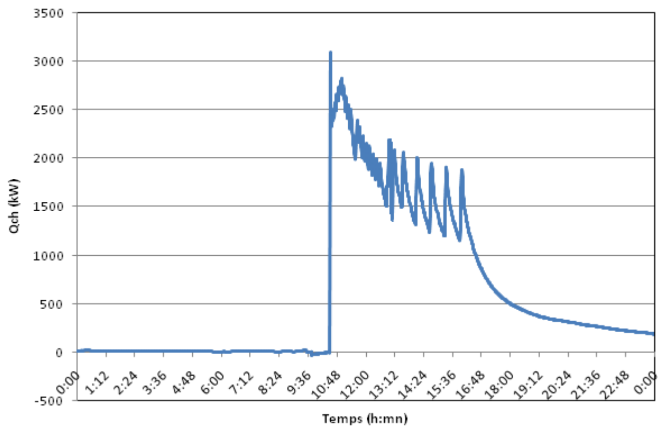

Figure 6: Change in the amount of heating energy depending on the time

At the end of the experience, and when we stopped the heating system the amount of heating energy decreases exponentially over time and this is due to the hot water in the storage tank as is explained above.

4.5. The GHE inlet and outlet temperatures

The GHE inlet and outlet temperatures, (TeE) and (TSE), are measured by two PT500 sensors, the results are shown in Figure 7.

it can be seen in Figure 7 that after activation and stabilization of the heating system (at 13h 12mn) both teE and TSE keep temperatures significantly the same size.

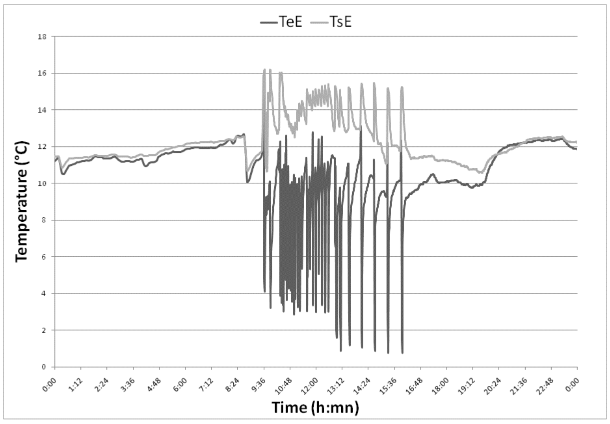

Figure 7: Variation of the water temperatures at the inlet and the outlet GHE

The inlet temperature of the buried exchanger (T) reaches a minimum value of about 0.8 °C, corresponding to the cold temperature of the condenser. While the outlet temperature of the ground heat exchanger (GHE) reaches a value of about 15.5 ° C. The gain obtained in term of temperature difference is about 14 ° C, reflecting the importance of extracting the energy from the ground.

4.6. The amount of heat recovered from the ground

The variation in the quantity of heat recovered from the ground by the GHE, calculated by equation (2), is shown in Figure 8.

The amount of energy recovered from the ground during the operation of the compressor and after stabilization of the system reaches a maximum of about 5 kW, which shows the importance of geothermal energy in our country.

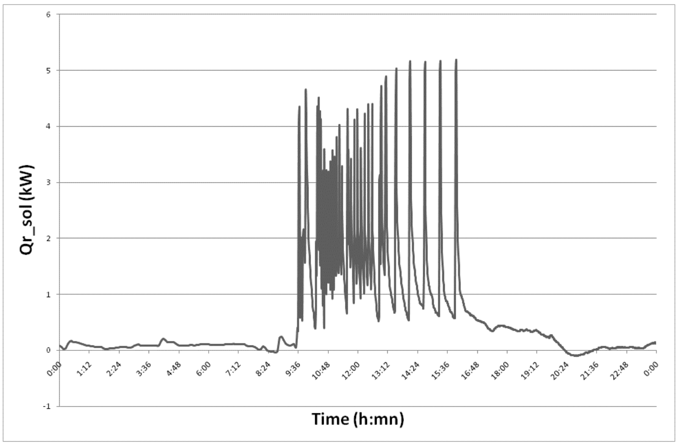

Figure 8: Change in the amount of heat recovered from the soil by the earth heat exchanger

It is also important to note that the shape of the curve is saw tooth because the operation on / off the compressor.

4.7. The performance factor of the heat pump and the whole system

In Figure 9 are shown the coefficients of performance of the heat pump (COPpac) and the whole system (COPsys) which are calculated according to equations 3 and 4.

We can observe in this figure that the COPpac and COPsys are high at the beginning of the experiment 6 and 4, respectively, and they diminish in agreement with what is found in the literature [16.17]. This result is explained by the thermal response of the ground (usually abbreviated as TRT). Indeed, after the operation of the system and specifically of the compressor, the soil temperature in the vicinity of the heat exchanger decreases over time, therefore, the amount of recovered heat from the ground decreases. Subsequently, the electricity consumption of the heat pump increases, for this reason, the COPpac and COPsys decrease.

After system stabilization, the average values of COPpac and COPsys are of the order of 4 and 3 respectively.

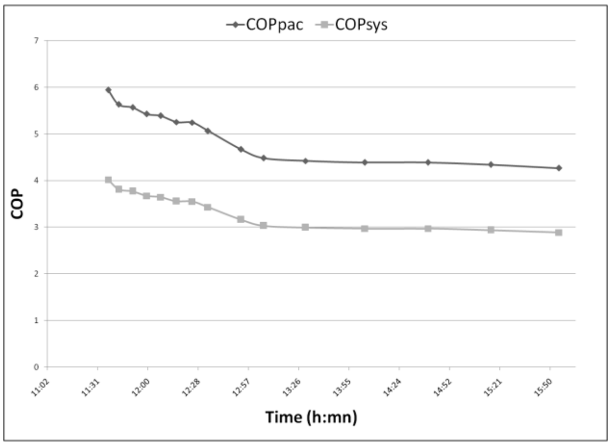

Figure 9: Change in COP geothermal heat pump and the entire system

5. Conclusion

The valorization of the thermal potential, in particular, surface geothermal, in Tunisia was studied using a geothermal heat pump coupled to two systems, the buried exchanger located outside and the heating floor located inside. The results of the experimental study allowed us to conclude that:

- the thermal potential of the ground in Tunisia offers good exploitation of the heat exchanger buried horizontally; In fact the variation of the temperature of the ground shows that in winter, at a depth of 1m, it is always lower than that of the outside air.

- The water temperatures at the inlet and outlet of the buried exchanger reach a maximum value of 0.8 ° C and 15.5 °C respectively. These results reflect the ability of the soil to extract energy through the buried exchanger.

- The amount of energy recovered from the ground by the buried exchanger is of the order of 5 kW.

- The coefficient of performance of the heat pump and the complete system, using the heating floor as the emission system, are of the order of 4 and 3 respectively

In order to achieve a more efficient system, several important design properties have to be respected, such as improving the pumping performance (circulation pump), improving the physical properties of the material of the buried exchanger (such as thermal conductivity), Reduction of pressure losses (pipe roughness, pressure drop across the various heat pump components, etc.).

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