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Study of Heat and Mass Transfer Through an Earth to Air Heat Exchanger Equipped with Fan in South West of Algeria

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ABSTRACT

Earth to air heat exchanger is a very old technique used 3000 years B.C in arid regions where that was called Qanat. In the present experimental study, the potentials of earth to air heat exchanger to provide thermal comfort for winter weather conditions in South west of Algeria described as arid region are investigated. An EAHE made of 66 meter of PVC tube and buried at 1.5 meter underground in agriculture zone equipped with 33 W fan was studied. Thermal and hygrometric analysis of air passing inside the tube form inlet to outlet was conducted. The results show the system was able to create two thermal regimes: heating regime with a gain of 13 °C (from 00h to 11h and from 17h to 23h) and cooling regime (from 12h to 16h) with 6 °C in the same day. Relative humidity was reduced by 32 % of 90 % of studied cases which stops the development of micro-organism and reducing Internal Air Quality.

1. INTRODUCTION

Heat exchangers used in several sectors and in very diverse fields that require the fluid heat transfer. Gómez et al. [1] presented a CFD tool, implemented in Open FOAM and executed in a Cloud environment, to simulate the performance of shell and tube heat exchangers. Agbossou et al. [2] proposed 3D finite element modelling of helical coil ground heat exchangers focusing on the real geometry of the heat exchanger and the energy extracted from the ground. Alimonti et al. [3] analyzed the available literature on the wellbore heat exchangers. Bahiraei et al. [4] reviewed and summarized recent investigations conducted on use of nanofluids in heat exchangers including those carried out on plate heat exchangers, double-pipe heat exchangers, shell and tube heat exchangers, and compact heat exchangers. Bone et al. [5] presented a methodology to develop accurate and computationally efficient on- and off-design models of heat exchangers that exhibit complex nonlinear behaviours. Chen et al. [6] developed a novel method combined signal flow graph of a single heat exchanger with the transfer function of streams for the dynamic behaviors of heat exchanger networks problems, which are determinate factors of the process control and operation optimization in the processing industries. Estrada et al. [7] reported the design of earth-air heat exchangers based not only on sensible heat transfer, but also on latent heat exchanges. They compare the impact of the climate of Brazil and south of France on the relevance of such systems. Gao et al. [8] reviewed the latest research on ground heat exchangers from several new perspectives and demonstrated their potentials in achieving zero energy buildings. Gu et al. [9] numerically studied the heat transfer coefficient, flow resistance and thermal performance in the shell side. Ilori et al. [10] investigated the thermal and pressure drop performance of compact tube heat exchanger under oscillatory flow conditions using experimental and numerical methods. Jiang et al. [11] proposed a new methodology for heat exchanger network retrofit to fully evaluate the performance of a heat exchanger network. Kayabasi and Kurt [12] derived relations between effectiveness and expense coefficients. They prepared an economic simulation model to simulate the heat exchangers in all flow types and monitor the savings in a facility. Laukkanen and Seppälä [13] studied the effect of using nanofluids in streams transferring heat from different processes by optimizing the total annual cost of a heat exchanger network. Majuri et al. [14] examined the types and construction practices of ground heat exchangers (GHEs) in the northern conditions typical of Finland, as well as the range of problems in GHEs experienced by the practitioners. Muszynski [15] described the comprehensive study on the effect of microjet array geometrical parameters on the heat transfer enhancement in the modular heat exchanger.

Belaid and Hireche [16] carried out a numerical study to assess the effect of heat exchangers plates inter-spacing on the performance of a thermoacoustic refrigerator. Piotrowska and Skowronski [17] performed an analysis of temperature oscillation parameters in transient states of heat exchange systems through an investigation carried out using a measuring stand with a heat exchanger model. Song et al. [18]

used the graphite modified poly (vinylidene fluoride) hollow fibers as the heat transfer medium to investigate the heat transfer processes including liquid-liquid, condensation and evaporation systems. Sun et al. [19] presented two system configurations of the enhanced ejector heat exchanger to improve the regulating characteristics and the heat transfer performance. Whalley and Ebrahimi [20] considered the modelling and dynamic analysis of shell and tube heat exchangers in their contribution. Wu et al. [21] experimentally investigated the feasibility of an expanded-graphite paraffin phase change material heat exchanger operating as a condenser in an instant air source heat pump water heater. Xia et al. [22] analyzed the heat exchanger network synthesis problem based on entransy theory. Zhang et al. [23] demonstrated the successful fabrication of a gas-to-gas manifold-microchannel heat exchanger through DMLS (direct metal laser sintering) using Inconel 718. They experimentally tested the heat exchanger with N2 on the hot-side at 600 °C and air on the cold-side at 38 °C. Other studies can be found in the literature as Menni et al. [24-43].

In the present experimental study, the potentials of earth to air heat exchanger to provide thermal comfort for winter weather conditions in South west of Algeria described as arid region are investigated.

2. EAHE UNDER EXPERIMENTATION

For the present study, an earth to air heat exchanger (EAHE) was made of 66 meters PVC tube with a diameter of 110 mm and buried at 150 cm underground in agriculture zone. The system was equipped with a fan at the inlet (33 Watt) where external air was injected at 3 m/s. Temperature and relative humidity sensors were installed at EAHE inlet and outlet, see Figure 1.

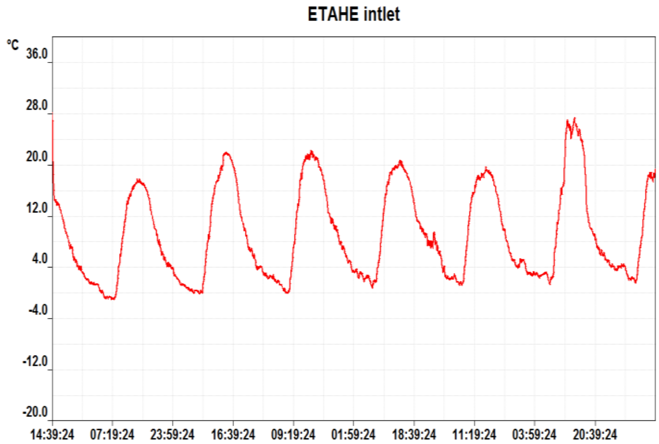
Figure 1. Earth to air heat exchanger inlet and outlet

3. RESULTS AND DISCUSSIONS

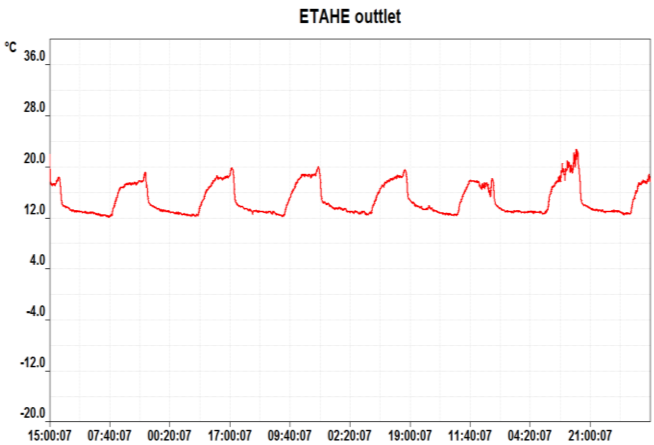
The experimental study was conducted between December 2018 and February 2019. For outside, the temperature was situated between -1 °C for the lowest and 27 °C for the highest. In the same time, 12.2 °C was the lowest temperature value for EAHE outlet and the highest was 22.5 °C. Even with outside temperature was (-1) °C, EAHE rise this negative temperature to 12.2 °C by approximately 13.2 °C which reduce at least half of heating needs for this cold climate.

Earth to air heat exchanger work as thermal regulator of air passing through the buried tube. The difference between the highest and lowest value of temperature was 20.15 °C for inlet while it was 7.5 °C for EAHE outlet, see Figure 2. This results show the capacity of the technique equipped of exterior fan of reducing the range of temperature variation and to give more stability of the system even with sever climate conditions in comparison to system without fan studied before depended greatly to local weather conditions.

For relative humidity, it was situated between 13 and 59 % for EAHE inlet and 15 to 31 % for the outlet, see Figure 3.



(a)



(b)

Figure 2. Earth to air heat exchanger (a) inlet and (b) outlet

To show the earth to air heat exchanger thermal and hygrometric capacities, $\Delta T = T_{inlet} - T_{outlet}$ and $\Delta RH = RH_{inlet} - RH_{outlet}$ are calculated, as shown in Figures 4 and 5, respectively.

For thermal regime, hourly and daily mean temperature differences are also calculated. It was observed that 80 % of the values were negatives which means that $T_{inlet} < T_{outlet}$ and only 20 % of the differences were positives ($T_{inlet} < T_{outlet}$), see Figure 6. Generally, $T_{inlet} < T_{outlet}$ means that the system rises the air temperature during its passage through the buried PVC tube to create a heating regime. It was observed also that the heating regime took place between 00h to 11h and 17h to 23h. In this period, outside air temperature is very low and EAHE contribute in increasing it where the gain reaches between 4 to 13 °C. This results leads to an ameliorated heating regime and a big adaptation of the system to local climate conditions.

For hygrometrique regime, hourly and daily mean relative humidity difference between the system inlet and outlet was positive $RH_{inlet} > RH_{outlet}$, see Figure 7.

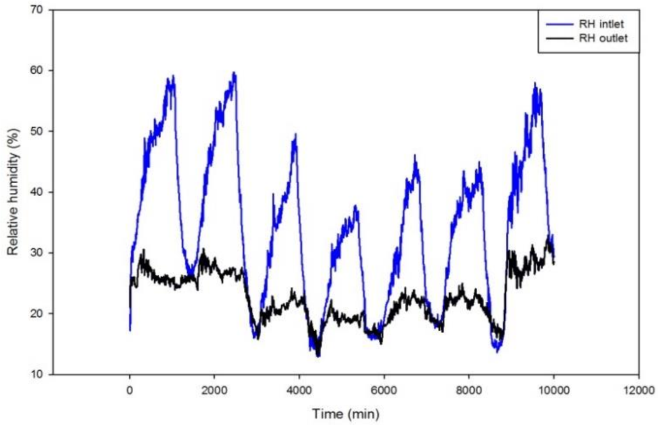


Figure 3. EAHE inlet and outlet relative humidity (%)

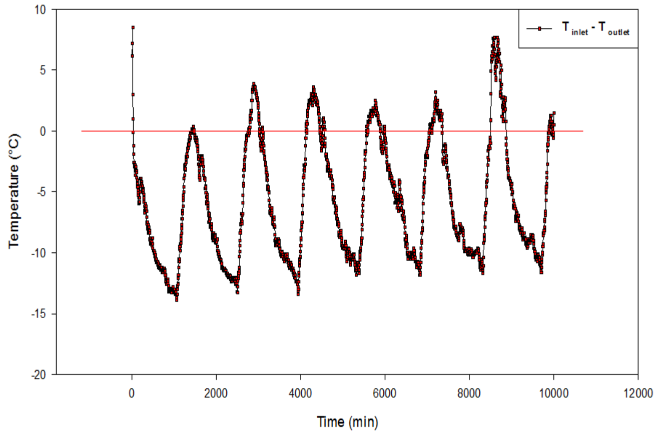


Figure 4. Air temperature difference between inlet and outlet

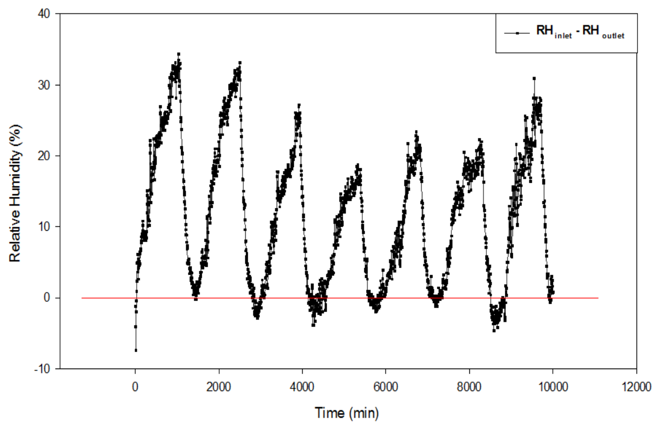
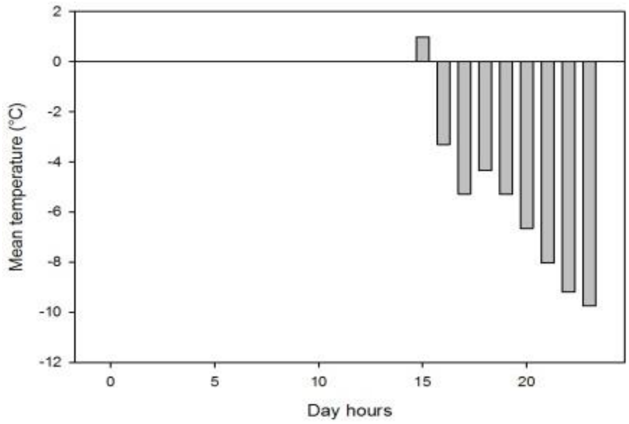


Figure 5. Air relative humidity difference

A dehumidification process occurs when fan is running which leads to decrease the relative humidity with maximum value of 32 % between 5h to 8h in the morning. The fan with velocity of 3 m/s plays dehumidification roles reducing condensation phenomena inside the tube. Condensation phenomena sometimes can develop micro-organisms which reduce internal air quality IAQ and the ad of the fan at the inlet of the system can reduce these effects to improve occupant's health and comfort. Analysis of dew points of both inlet and outlet show that it was between -2 to -12 °C. DPoutelt was lower in comparison with those for of the inlet. These results confirm the role played by the fan for improving IAQ and thermal comfort, see Figure 8.



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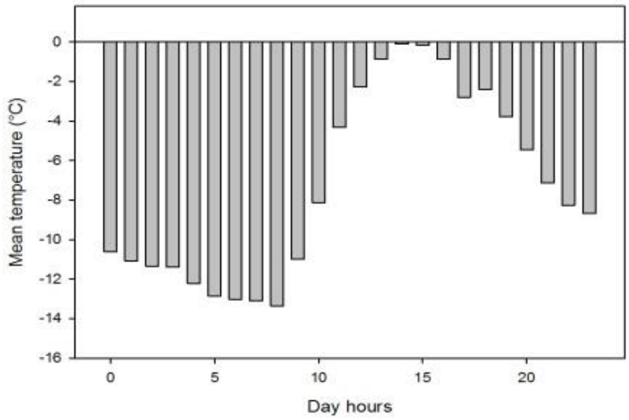

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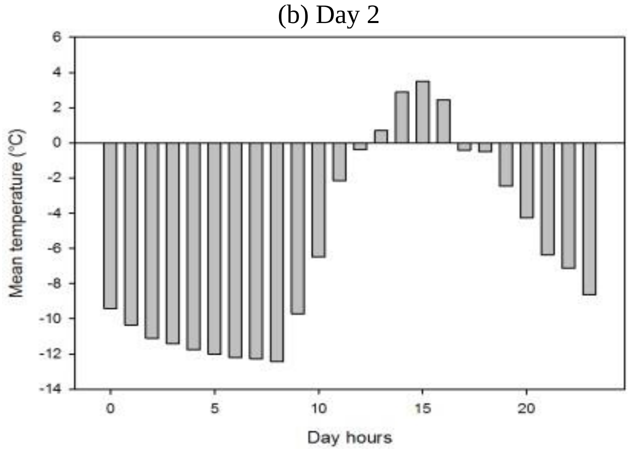

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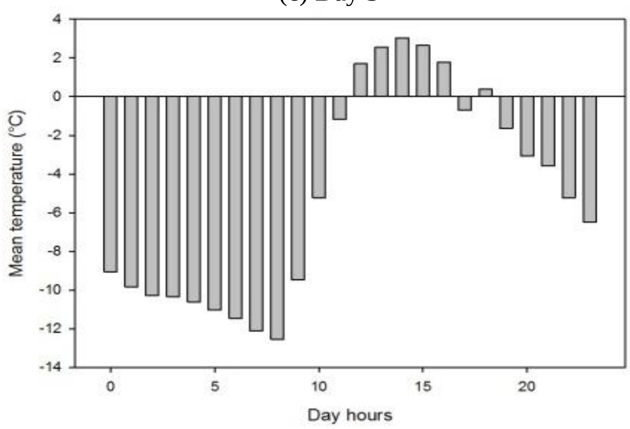

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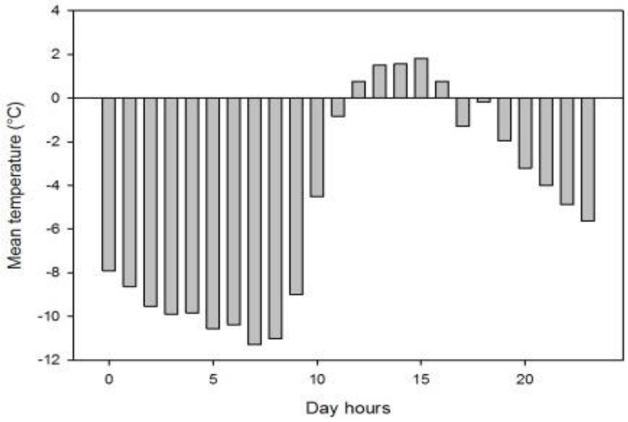

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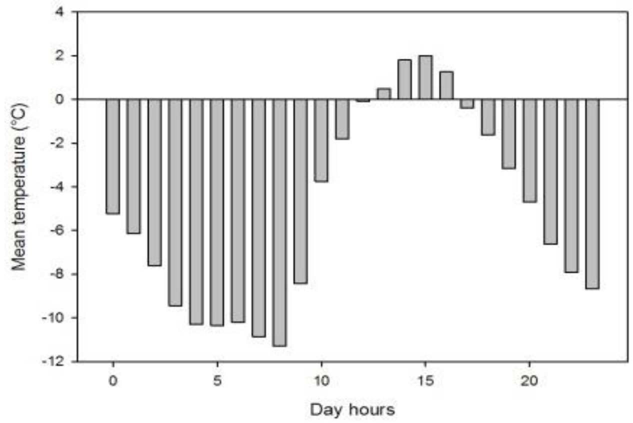

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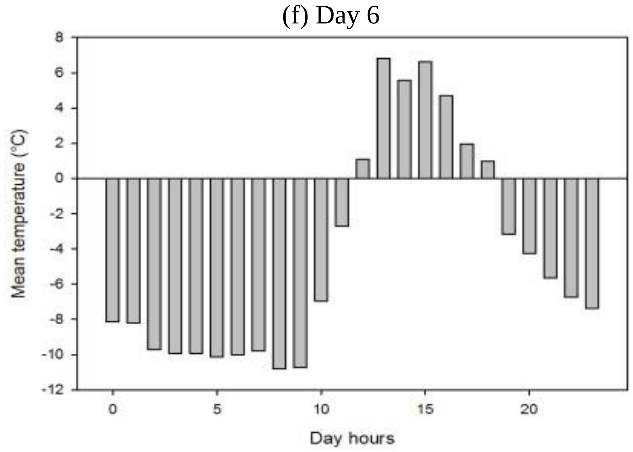
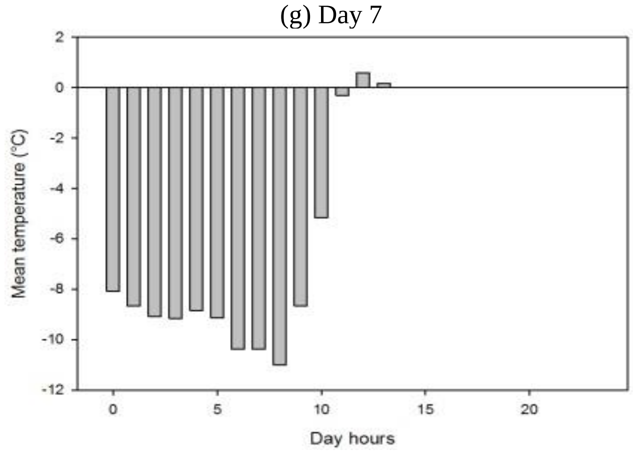
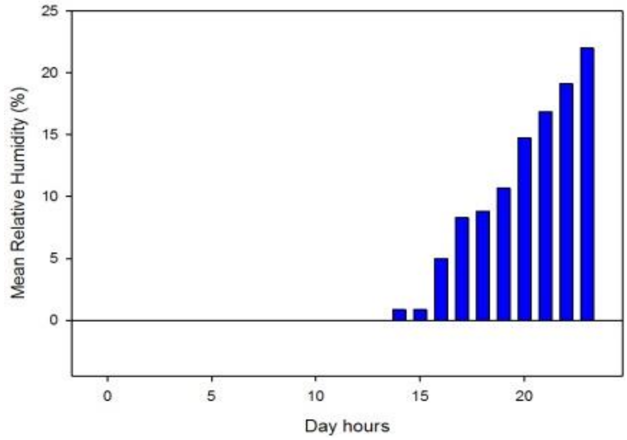


(g) Day 7



(h) Day 8

Figure 6. Hourly and daily temperature difference between inlet and outlet



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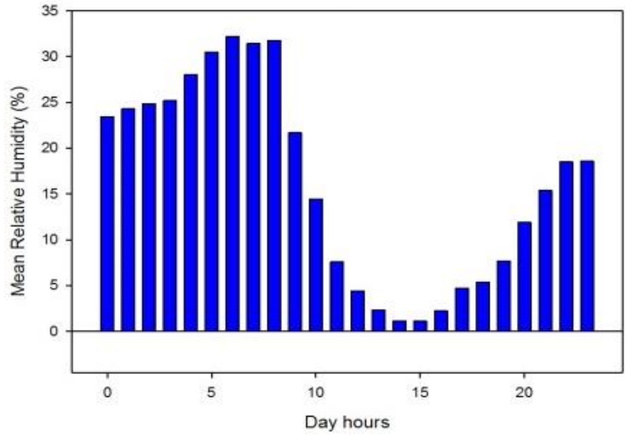

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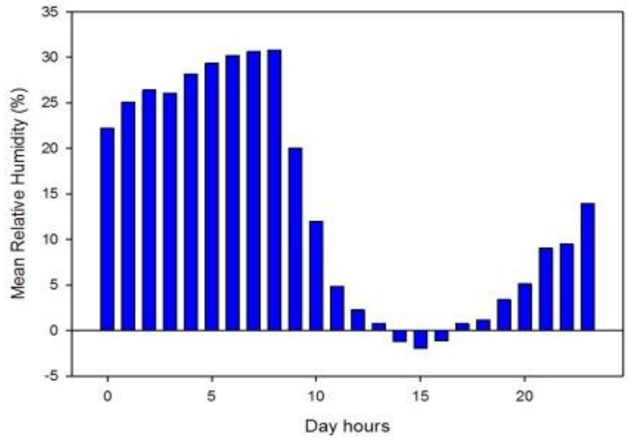

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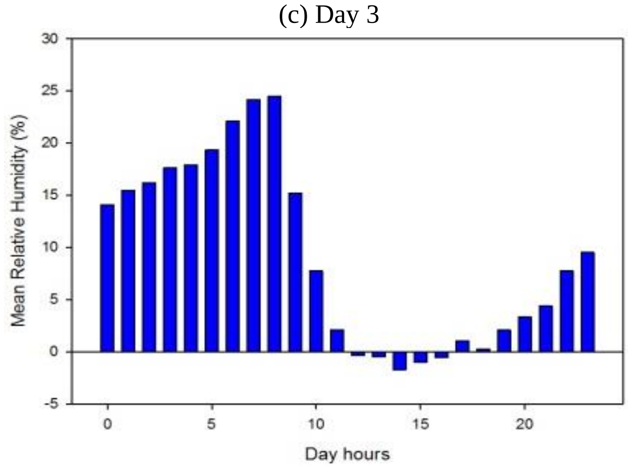

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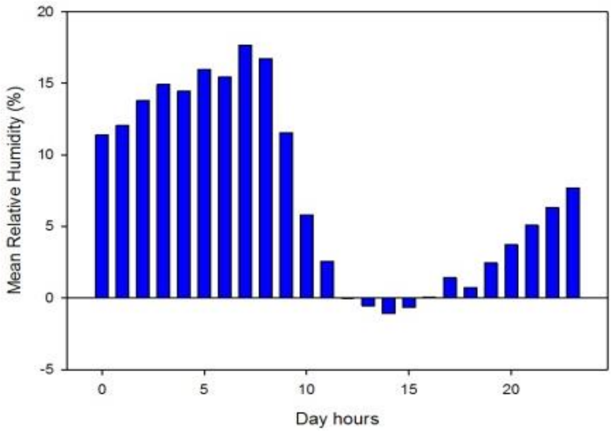

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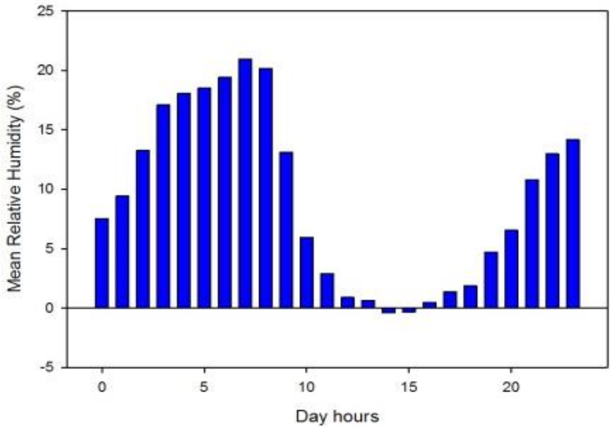

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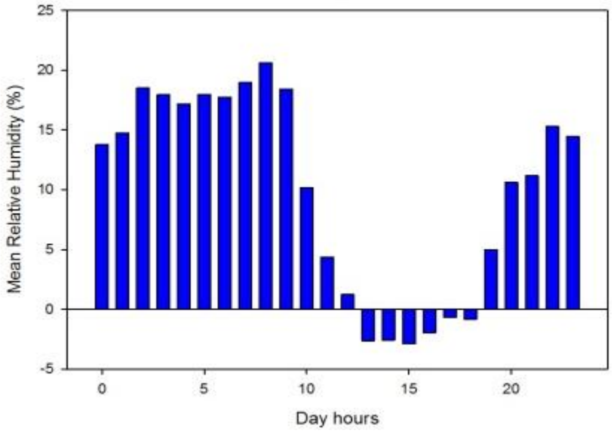

(g) Day 7

Figure 7. Hourly and daily RHΔ between inlet and outlet

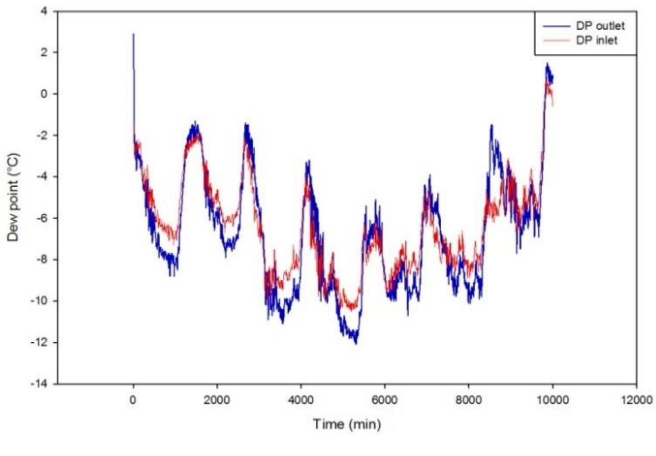

Figure 8. Earth to air heat exchanger inlet and outlet dew point

4. CONCLUSION

EAHE is a very old technique used in Persia 3000 years B.C and it was called Qanat and used to provide thermal comfort in arid regions. In the present study, an EAHE made of 66 meters of PVC tube buried at 1.5 m underground in the south west of Algeria was investigated experimentally. Heat and mass transfer occurring inside tube were analysed.

The results show that earth to air heat exchanger work as a thermal regulator of air passing through the buried pipe under 1.5 meter of the ground surface. Thermal regulation of EAHE was clearly observed by reducing the range of temperature variation between inlet (from 20 °C) and outlet (at 8 °C).

Instability in outlet air temperature is one of the advantages of this technique. By using the present studied configuration, instabilities are reduced to maximum and prediction of outlet temperature become easier.

It was also observed the big dependence of the EAHE with external tube to local climate conditions and the same time the big adaptation of this technique to those variations and this led to the creation of two thermal regimes as follow:

Heating regime: from 00h to 11h and from 17h to 23h where exterior air temperature was very low and during its passage inside the tube, the air gain 13 °C where ground work as a heating source. Cooling regime: from 12h to 16h where ground work as a heat sink reducing air temperature at EAHE outlet by more than 6 °C.

These two regimes improve thermal comfort in arid regions with different climate conditions.

Hygrometrique regime was characterized by a reduction in relative humidity in 90 % of the cases by 32 % and 10 % of cases where RH rise by 3 %. Those results have advantage and disadvantage.

The advantage is the elimination of condensation phenomena where dew point was situated between -2 and -12 °C. Condensation inside buried tube may develop micro-organisms and reduce internal air quality IAQ.

Disadvantage of relative humidity reduction is internal hygrometrique comfort is directly affected where RH must be at least 50 %. This situation can be corrected by introducing a humidification mechanism at the outlet of EAHE connected directly to living space.

Great potentials are presented by earth to air heat exchanger in arid regions for thermal comfort and natural ventilation.

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