Feasibility and Modeling studies for thermal performance of an earth to air heat exchanger in South East Algeria

Abdessamia hadjadj[1], Boubaker Benhaoua[1,2], Abdelmalek Attia[1]*

[1]*Laboratory of Valorisation and Technology of Sahara Resources (VTRS), University of El Oued, Algeria*
[2]*Renewable Energy Development unit in Arid Zones (UDERZA), University of El Oued, Algeria*

Corresponding author: hadjadj-abdessamia@univ-eloued.dz

Abstract; ***This paper presents a study on the energy performance of an earth-air heat exchanger (EAHE), In order to check the temperature factor in their effect on heat exchangers, the aim of this paper is to influence the ambient temperature on the performance of EAHE systems in arid and semi-arid climatic zones. So, our use CFD modeling techniques were used to assess the impacts of the parameters of dimensioning on the performance of earth-to-air heat exchanger (EAHE). Assume that exchangers are made (polyvinyl chloride–PVC) As its length a 50 m conduct length, 80 mm diameter and 3 m burial depth). The simulation results were validated by comparison with experimental results, Results show that the specific heat exchange is used to cool in an arid zone (south-east of Algeria). When the ambient temperature varies between 36°C and 40 °C, the cooling temperature varies between 25°C and 28 °C. Temperature difference inlet and outlet air exchanger 12°C, these values are quite acceptable with minimal consumption of electrical energy***

Keywords— ***CFD modeling, performance, Heat Exchanger, Geothermal energy,***

1. Introduction

Energy consumption in arid areas is very high due to the high temperature in the summer and the low temperature in the winter. The local cooling necessities a considerable consumption of electric energy, which costs very expensive. The warm-up also consumes energy (city gas or other fossil fuels). The utilization of geothermal energy to reduce heating and cooling needs in buildings has received increasing attention during the last several years. An Earth Air Tunnel Heat Exchanger (EATHE) consists of a long underground metal or plastic pipe through which air is drawn. As air travels through the pipe, it gives up or receives some of its heat to/from the surrounding soil and enters the room as conditioned air during the cooling and heating period. Recently, many numerical and experimental studies have investigated the heat transfer mechanisms of the various types of HGHE Several research works have dealt with the exploitation of soil thermal potential for heating and cooling applications [1,2]. Two principal types of ground heat exchangers are usually exploited: Horizontal [3–4] and vertical heat exchangers [5–6].Congedo et al. [7] investigated the configuration effect of HGHE on the heat fluxes transferred to and from the ground. Various parameters such as the velocity of the fluid, installation depth, the thermal conductivity of the ground, and pitch size were considered in an investigation of the influence of heat fluxes in linear, spiral coil, and slinky-type HGHEs. These researchers determined that the depth of the HGHE installation does not play an important role in the system performance. In addition, they noted that the spiral coil-type HGHE exhibits higher heat transfer performance than line and slinky-type HGHEs. A. Atia et al [8]. Has been studied aims to give an overview of the implementation of the ground heat exchanger (GHE) for passive air conditioning As used the soil as a source of heat; These factors have the greatest influence on the performance of GHE, which must be considered from the thermal properties of the soil to the piping materials. In addition, a review of the literature on major scientific research implemented in low temperature geothermal energy such as the Algerian climate, to reduce energy needs and greenhouse gas emissions. In addition, a review of the literature on major scientific research implemented in low temperature geothermal energy such as the Algerian climate, to reduce energy needs and greenhouse gas emissions. PV. Kabashnikov et al [9] developed a mathematical model for calculating the temperature of the soil and air in a soil heat exchanger for ventilation systems. N. Moummi et al [10] have established theoretical and experimental study on refreshing by geothermal energy in Biskra area. M. Benhammou et al [11] presented study on simulation and characterization of a geothermal air exchanger for refreshing buildings operating in the climatic conditions of southern Algeria (Adrar) A. Trombe et al. [12] proposed a numerical model to evaluate the performance of this system when it is coupled with an individual house; the results were compared with experimental model. They also proved that this system can be used to save 10% of house energy consumption by preheating fresh air in winter, and to improve comfort conditions in summer. Several experimental and numerical studies, which deal with EAHE system, have been done to predict the airflow behavior inside the buildings. P. Hollmuller et al [13] developed an analytical model and a 3D model in finite elements of air-to ground exchanger. The analytical model is intended to dimension and provide a better understanding of air-to-ground exchangers, but is not very flexible to represent systems with complex geometry.G. Mihalakakou et al. [14] proposed a parametrical model in order to evaluate the impact of design parameters (pipe length, pipe radius, the velocity of the air inside the tube and depth of the buried pipe below earth surface) on the performance of the EPAHE. P.Cui et al [15] addressed the ground heat exchanger for ground coupled heat pump applications in alternative operation modes over a short time period. They developed a finite element numerical model to simulate the ground heat exchanger. V. Bansal et al [16, 17] developed a CFD model to determine the effect of air velocity and buried pipe material on the performance of EAHE system. M. Bojic et al [18] presented a technical and economic studies of an EAHE coupled to the system for heating or cooling of a building. An analytical model was compared with the experimental results and the use of a spiral heat exchanger form. The numerical results were obtained with the Fluent program. There is a good agreement between the analytical results and the experimental results. The numerical results show that there is a significant difference in temperature between the ambient temperature obtained at the outlet of the exchanger. Heat in all cases studied, which offers the possibility of planting this system in desert areas in Algeria [20]. The objective of the present paper is to influence extern temperature on earth air heat exchangers in summer. This work aims to demonstrate that a simple pipe placed underground and connected to a building can significantly regulate indoor thermal comfort and thus help in energy savings in hot arid climate conditions. The modeling on heat Exchanger study was conducted in the summer, in which the highest cooling demand and the climatic conditions were those of the region of El Oued in the Algerian Sahara.

2. Modeling Of The Soil Temperature

An earth air heat exchanger (EAHE) consists mainly of a PVC (polyvinyl chloride) pipe buried in the ground. The geometric parameters of the buried pipe used in the thermal analysis are: length, inside diameter and thickness which is usually 4 mm. The principle of operation of an earth-air heat exchanger (EAHE) is such that the hot outdoor air is pumped into the underground buried pipe with the help of an adequate fan. The air is cooled by transferring heat to the soil which is at a lower temperature (Fig. 1). The cooled air is then injected into the building. The thermal and physical properties of air, soil and pipe used in this simulation are represented in Table1, while the parameters of the earth air heat exchanger are summarized in Table 2. Then configuration described above can be further simplified by considering a uniform airflow inside the pipe. The surrounding soil is considered to have uniform and constant thermal properties, the dimensions and physical properties of the pipe are considered constant. The monthly maximum and minimum temperatures used in the simulation of the site under study are shown in Fig.2 [21].

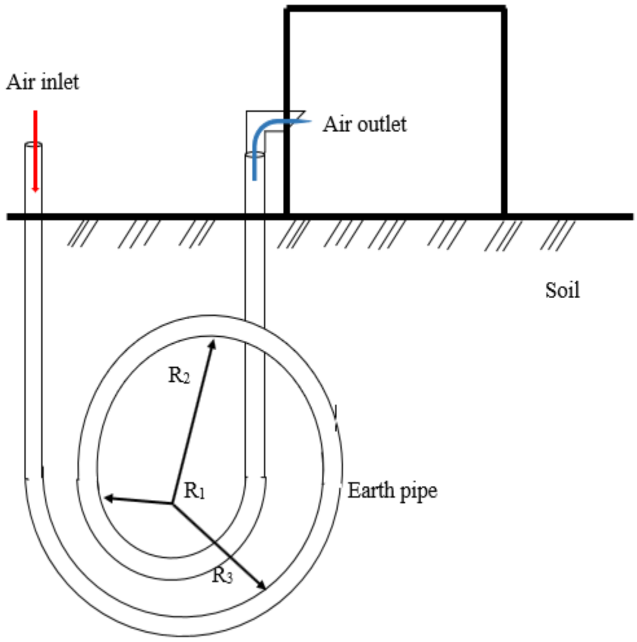


Fig.1 diagram representing an Exchanger (EAHE)

Table 1. Thermal and physical properties of air

Density	Heat capacity	Thermal conductivity
(kg/m^3)	**(J/kg. K)**	**(W/m. K)**
1.225	**1006.43**	**0.0242**

Table 2. Parameters of the earth air heat exchanger used in the simulation.

Parameter	Reference valuer
Pipe depth	3 m
Pipe Length (L)	45 m
Air velocity (V)	10 m/s
Pipe thickness €	4 mm
Pipe Diameter	80 mm

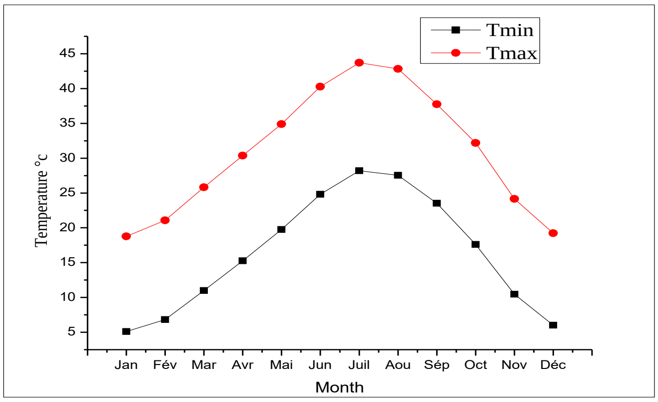


Fig.2; Maximum average and minimum annual temperature

3. Modeling The System

To select the optimal dimensions of a heat exchanger Which is able to cool the buildings of the indoor environment in Summer Climate to the wadi, the soil temperature of different depths and the outside temperature were measured in May 2018 in the city of el Oued using a thermocouple type K. These measured temperatures were used as input data for simulation model. Figure 2 shows the variation of the average soil temperature as a function of depth. The results show that soil temperature decreases as one moves away from the soil surface. This study concerns southeast regions located in southeastern Algeria. It is one of the arid regions (Saharan) that are characterized by the hot and dry climate. This region is characterized by long periods of overheating and thermal discomfort is felt strongly. The climate of El Oued is one of the hardest in the northeastern Sahara. The simplified method of analysis was applied for the climatic conditions of regions in regions mean annual temperature is 16 °C, with 36°C for warmer months (July) and 12°C for the colder month (January). The highest temperature ignited 49.6 ° C on July 15.

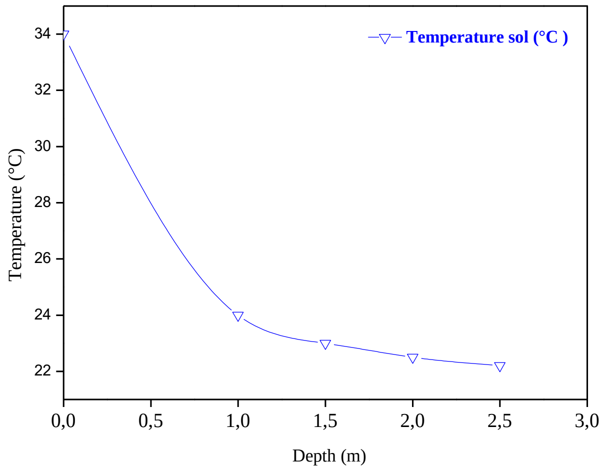


Fig 3; Soil temperature as a function of depth

4. Mathematical Procedures

A. *Computational domain*

hows the physical domain configuration considered in this study. The EAHE system contains four parts with a total length of 45 m. It has tubes inner diameter of 80 mm. The assembly is fixed at a depth of 2.5 m at a slope of 2%, while the tubes are arranged and spaced from each other by a center distance of 50cm.Table2 shows some other important physical properties of PVC tube. The physical description of EAHE system becomes very complicated. Figure 3 shows the schematic diagram of the EAHE system. Therefore, it is appropriate to make a number of assumptions for arriving at a correct calculation time and also without losing too much information. The choice was therefore focused on a two-dimensional field and the assumptions used in this work are;

B. Hypothesis

The physical description of EAHE system becomes very complicated. Therefore, it is appropriate to make a number of assumptions for arriving at a correct calculation time and without losing too much information. The choice was therefore focused on a two dimensional field, and the assumptions used in this work are:

- Soil is considered homogeneous;
- A uniform temperature is assumed along the perimeter of the face of pipe;
- The temperature of the inlet air exchanger is the temperature of the outside air;
- The fluid is assumed viscous "and Newtonian;
- The flow in steady state.

A CFD (Computational Fluid Dynamics) model was used to simulate the studied phenomena. The choice of the required mesh is based on the geometry of the study domain. The cylindrical co-ordinates with two-dimensional flow seem to be the best choice for our study. We present the results of the numerical simulation obtained by the code FLUENT; considering the following thermo-physical properties of air[20];

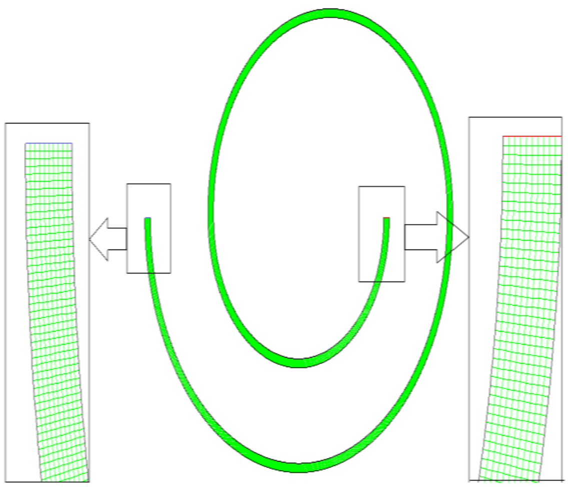


Fig 3: Schematic of the EAHE system.

On the one hand, the Fluent CFD was used to bring us the influence of the length and position of the exchanger in the ground, on the efficiency of our system. the speed is set at 10 m / s. on the other hand, real experience has been established to validate this study.

5. Results And Discussion

Figure1 shows the relationship between the outlet temperature (°C) as a function of the length of the exchanger (m). Each time the length increases, the output temperature decreases. Note that this temperature is constant when the length exceeds 45 meters. Figure 2 shows the spiral shape of the exchanger made by CFD Fluent. Figure 5 shows the relationship between the outlet temperatures (°C) as a function of the length of the exchanger (m) with a constant speed of 10 m / s. the result obtained is validated by real experience. We note that the two graphs are almost the same. Which have 45 m long and at velocity of 10 m/s shows as described in resultant. We chose a summer simulation period in June to compare the temperature of buried pipes. The pipe has the same engineering characteristics. Note that the effect of the ambient temperature in the summer ranges between 35 and 45, the air temperature at the exit outlet of the buried pipes is between 24 °C and 27 °C (Fig. 6). Low average temperature is about 11 °C. For ambient temperature in the valley ranging from 35 °C to 45 °C, the air temperature in the air outlet tube ranges between 27 °C and 25 °C. (Fig.5) The air temperature in the exchange port develops as a function of the length, We found that the differences in the corresponding temperature between the ambient air and the cooled air at the exchanger outlet to the temperature of the air inside of 42 ° C and 33.4 ° C. Are respectively 13.9 ° C and 7.6 ° C. This is due to the fact that when the ambient air temperature is greater than that in the exchange port, this confirms simulations have shown that the energy supplied by the cooling exchanger (EAHE) is more significant in the south of the country than in the north.

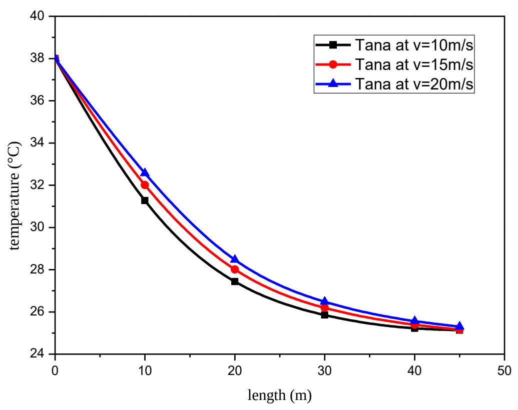


Fig 4. *Variation of the air temperature versus*

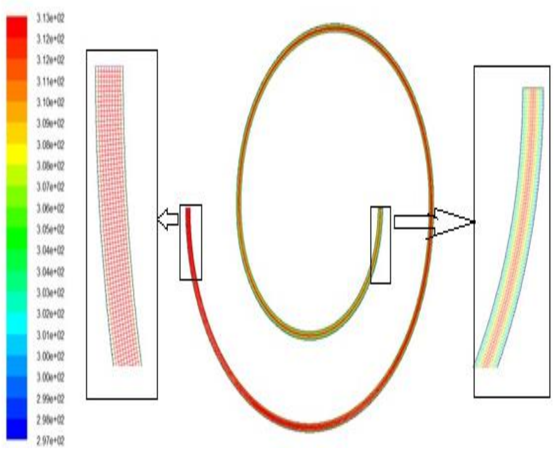
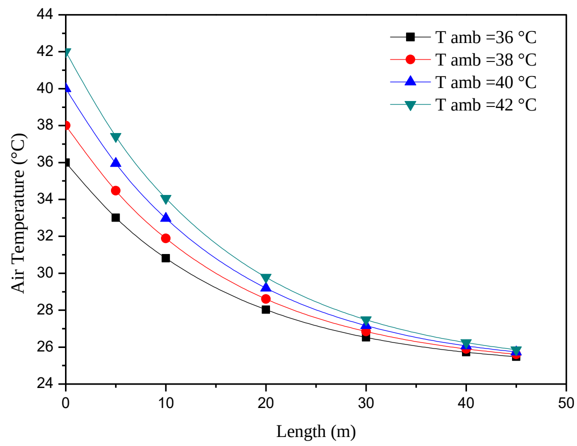


Fig 5. *Temperature distribution in the exchanger the exchanger length and velocity 10m/s.*



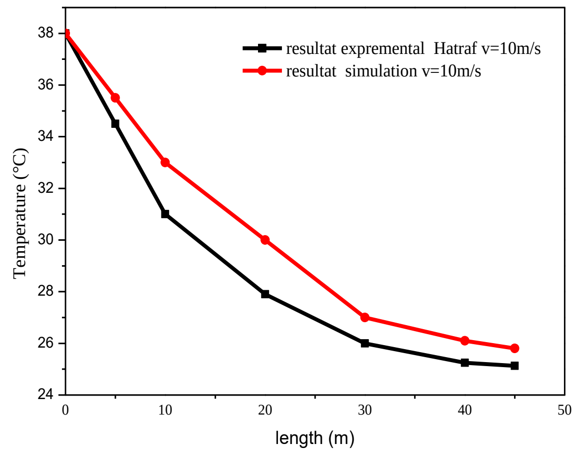


Fig 6. Validation With the experience.

6. Conclusion

Based on our work, we should not exceed the length of 50 meters for the exchanger and not to exceed the depth of 3 meters in the ground. The simulations resultant carried out on this CBGHE, The recommendations can be recapitulation as follows:

1) The length of the well must be between 40 and 45 m. Below 40 m, the exchanger it is not possible for the exchanger to obtain an outlet temperature close to that of the ground, because the general conclusion exchange efficiency is average ; beyond 45 m, the yield no longer increases significantly;
2) The diameter of the pipe and the air flow are related to the speed of the air flowing through the well; The diameter is between 16 and 25 cm;
3) The outlet temperature is directly related to the soil temperature. Its amplitude decreases sharply with depth. For example, we obtained a temperature drop of 9.5°C to 2.5 m and from 6°C to 1 m. As a result, the well must be buried as deeply as possible, so as to best benefit from the inertia of the soil.
4) This simulations have shown that the energy supplied by the cooling exchanger (EAHE) is more significant in the south of the country than in the north.

7. References

1) N. Aranzaba, J. Martos, Á. Montero, L. Monreal, J. Soret, J. Torres, R. GarcíaOlcina, Extraction of thermal characteristics of surrounding geological layers of a geothermal heat exchanger by 3D numerical simulations, Appl.Therm.Eng.99(2016)92–102.
2) P.M. Congedo, G. Colangelo, G. Starace, CFD simulations of horizontal ground heat exchangers: a comparison among different configurations, Appl. Therm. Eng. 33–34 (2012) 24–32.
3) Nabiha Naili, Issam Attar, Majdi Hazami, Abdelhamid Farhat, First in situ operation performance test of ground source heat pump in Tunisia, Energy Convers. Manage. 75 (2013) 292–301.
4) Nabiha Naili, Majdi Hazami, Sami Kooli, Abdelhamid Farhat, Energy and exergy analysis of horizontal ground heat exchanger for hot climatic condition of northern Tunisia, Geothermics 53 (2015) 270–280
5) M. Philippe, Development and Experimental Validation of Horizontal and Vertical Geothermal Heat Exchangers for Heating Residential Buildings (PhD thesis), Ecole des Mines de Paris, France, 2010 (in French).
6) W. Zhang, H. Yang, L. Lu, Z. Fang, Investigation on heat transfer around buried coils of pile foundation heat exchangers for ground-coupled heat pump applications, Int. J. Heat Mass Transf. 55 (21–22) (2012) 6023–6031.
7) Congedo PM, Colangelo G, Starace G. CFD simulations of horizontal ground heat exchangers: a compassion among different configurations. Appl Therm Eng 2012;33e34:24e32.
8) Atia, A., Hadjadj, A., Benhaoua, B., Lebbihiat, N., Brima, A., 2017. A Review of Studies on Geothermal Energy System Applied on Sub-Saharan Climate Regions. Water and Energy International 60, 63-68
9) Kabashnikov VP, Danielevskii LN, Nekrasov VP, et al. Analytical and numerical investigation of the characteristics of a soil heat exchanger for ventilation systems. International Journal of Heat and Mass Transfer 45: 2407–2418. (2002).
10) N. Moummi, H. Benfatah, N. Hatraf, A. Moummi, and S. Y. Ali, "Le rafraîchissement par la géothermie : étude théorique et expérimentale dans le site de Biskra," Revue des Energies Renouvelables, vol. 13, pp. 399-406, 2010.
11) M. Benhammou and B. Draoui, "Simulation and characterization of a geothermal air exchanger intended for the cooling of buildings operating in the climatic conditions of southern Algeria, " Renewable Energy Review, vol.15, pp. 275-284, 2012.
12) A.Trombe, L. Serres, Air-Earth Exchanger Study In Real Site Experimentation and Simulation, vol. 21 Energy and Buildings,1994,pp. 155-162
13) Hollmuller P, Lachal BM (2014), Air-soil heat exchangers for heating and cooling of buildings: Design guidelines, potentials and constraints, system integration and global energy balance, Int. J. Appl. Energy. 119: 476-487.
14) Mihalakakou G, Santamouris M, Asimakopoulos D, Tselepidaki I. Parametric prediction of the buried pipes cooling potential for passive cooling applications. Sol Energy 1995;55(3):163–73
15) Cui P, Li X, Man Y, Fang Z. Heat transfer analysis of pile geothermal heat exchangers with spiral coils. Applied Energy. 2011;88(11):4113-9
16) V. Bansal , R. Misra, G. D. Agrawal, J. Mathur, Performance analysis of earth–pipe–air heat exchanger for winter heating , vol. 41. Energy and Buildings ,2009, pp. 1151–1154 .
17) V. Bansal , R. Misra, G. D. Agrawal, J. Mathur, Performance analysis of earth–pipe–air heat exchanger for summer cooling" , vol. 42 Energy and Buildings ,2010,pp. 645–948
18) M. Bojic, T.N. Trifunovic, T.G. Papadakis , S. Kyritsis ,Numerical simulation, technical and economic evaluation of air-to-earth heat exchanger coupled to a building, vol. 22, Energy , 1997, pp. 1151- 1158
19) Hatraf N, Chabane F, Brima A, Moummi N, Moummi A (2014). Parametric Study of to Design an Earth to Air Heat Exchanger with Experimental Validation. Int. J. Eng. 18(2): 41-54. ISSN 0125-8281
20) M.A.ATTIA, B. Bendjenidi, B.Addoun, Simulation d'un échangeur de chaleur air /sol de forme spiral, Mémoire de master ,université Kasdi Merbah Ouargla, (2017).
21) Algerian National Weather Office