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Numerical study of a new earth-air heat exchanger configuration designed for Sahara climates

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Abstract – *Thermal performance for cooling and heating in the building can be achieved by the novel shape of the earth–air heat exchanger (EAHE). In a heavily populated area such as City, Due to the limited ground space. EAHE systems are rarely used, for most residential andcommercial utilization.This paper presents a numerical investigation of the thermal performance of a spiral-shaped configuration Spiral Earth to Air Heat Exchanger SEAHE intended for the summer cooling inhot and arid regions of Algeria. A parametric analysis of the SEAHE has been performed toinvestigate the effect of diameter, depth, pipe length and of airflow rate on the outlet air in theexchanger. 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 40°C and 45 °C, the coolingtemperature varies between 25°C and 29 °C. Temperature difference inlet and outlet airexchanger 18°C, these values are quite acceptable with for cooling the building.*

Keywords: *CFD modeling, Spiral, Heat Exchanger, Geothermal energy, Thermal performance*
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I. 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 needs 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 a building or greenhouse has received increasing attention during the last several years [1-4]. Geothermal energy is considered among renewable energy resources which allow easy access to low thermal supply energy without environmental harm. It was considered as a promising space-cooling and heating solution [5-10]. A Ground Heat Exchanger (GHE) is a long underground metal or plastic pipe which draws air through. As air passes through the pipe, during the cooling and heating process, it gives up or receives some of its heat from/to the surrounding soil, and enters the room as cooled or heated air [11-13].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 building [14-19]. A GHE system's energy performance is mainly influenced by air temperature, air velocity, geometric dimension, pipe materials, burial lengths of the pipe, soil temperature, and soil type [20]. Study on Calculation Models of Earth-Air Heat Exchanger Systems. have been performed to investigate the effect of pitch, depth, pipe length and of the flow velocity on the outlet air temperature and the EAHE mean efficiency [21,22]. A study developed a CFD model to determine the effect of air velocity and buried pipe material on the performance of EAHE system [23]. Another project presented a technical and economic studies of an EAHE coupled to the system for heating or cooling of a building [24]. 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 [25]. 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 Ouargla in the Algerian.

II. Computational modeling

The theoretical model used to research the EAHE contains two main parts: the first is correlated to the bare soil for the measurement of initial conditions, and the second is devoted to the ground heat exchanger. For both sections the resolution of the equations together is based on an iterative mathematical method. A spiral earth air heat exchanger (SEAHE) consists primarily of a pipe buried in the ground made of PVC. The geometric parameters of the used pipe used in the thermal analysis are: length, inside diameter and thickness which is normally 4 mm. SEAHE is such that the hot outdoor air is drawn into the underground buried pipe with the help of an adequate blower the airs is cooling by transporting heat to the low-temperature soil in Figure 1 then inject the cooled air into the house. Table 1 represented the thermal and physical properties of air, soil, and pipe used in this simulation, while the parameters of the earth air heat exchanger are presented in Table 2.

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

Parameter	Reference value
Pipe depth	2.5 m
Pipe Length	54 m
Air flow rate	50, 80, 100 m^3/h
Pipe Diameter	110, 200, 250 mm

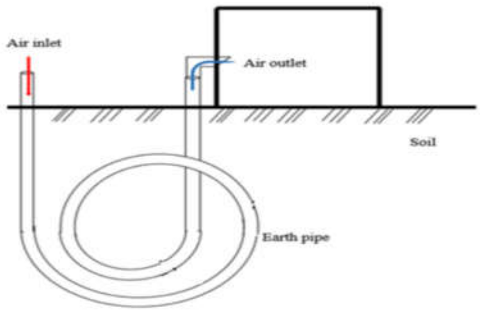

Figure.1. Diagram representing an SEAHE

Table .1. Physical and thermal properties

Material	**Density ($kg\ m^{-3}$)**	**Thermal Capacity ($J\ kg^{-1}\ K^{-1}$)**	**Thermal Conductivity ($W\ m^{-1}K^{-1}$)**
Air	1.225	1006	0.0262
Soil	1758	1000	0,58
PVC	1380	900	0,16

The maximum and minimum monthly temperatures used in site understudy simulation are presented in Figure 2.

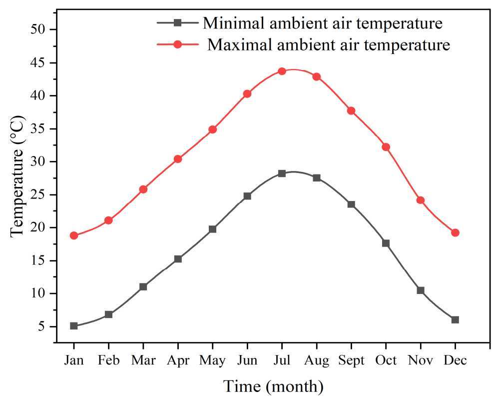

Figure .2. Monthly maximum and minimum temperatures of the site in Ouargla

II.1. Soil modeling

The soil temperature mathematical model is based upon the principle of heat conduction applied to a semi-infinite homogenous solid. Ref gives heat conductions in soil [26, 27].

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\alpha_s \frac{\partial T}{\partial z}\right) \quad (1)$$

where T is the soil temperature (°C).

where the soil thermal diffusivity is given by: $\alpha = \frac{\lambda}{\rho \times Cp}$

$$T(Z,t)=T_{moy}+A_s\times(Exp\text{-}(z)\sqrt{\pi/8760}\times\cos\left\{\frac{2\pi}{8760}\times(t\text{-}t_0)\text{-}\frac{z}{2}\times\sqrt{8760/\pi\alpha}\right\} \quad (2)$$

II.2. Earth-air heat exchanger modeling

Computational fluid dynamics (CFD) methods are quite known for their ability to analyze the fluid flow in depth heat transfer, mass transfer and many other problems. Numerical simulations have been conducted using CFD research software. The physical geometry system was utilized to develop a model for numerical analysis in Figure 3. The material properties of SEAHE pipe and surrounding soil were used in the model developed on ANSYS's workbench platform i.e. ANSYS's DESIGN MODELER [19]. Material properties of SEAHE pipe and surrounding soil worked in the simulations are measured values or as specified by the manufacturer. Developed physical model of SEAHE system was meshed using 2D. The numerical studies were based on the following hypotheses:

a) Thermo-physical properties of soil are homogeneous;
b) Uniform temperature is assumed along the perimeter of the face of pipe;
c) Thermal contact among soil and buried pipe is ideal;
d) The temperature of the inlet air exchanger is the temperature of the outside air;
e) The fluid is assumed viscous "and Newtonian;
f) The flow in steady state.

The definitive differential equations are the mass equation, the equation of momentum, the equation of energy and the standard k -ε model used to close the systems. The standard model k- ε model is a semi-empirical turbulence model based on the kinetic energy turbulence (k) and its dissipation rate (ε).

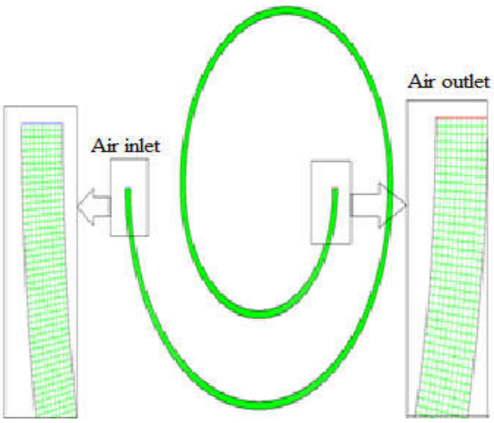

Figure.3. Physical geometry of straight SEAHE

III. Result and discussions

Figure 4 different depths (1-5 m). As the depth of the subsoil increases, fluctuations in the sine wave of the soil temperature decrease until the temperature reaches a relatively constant value at 5 m depth, allowing us to use the soil as a heat source (cold/hot).

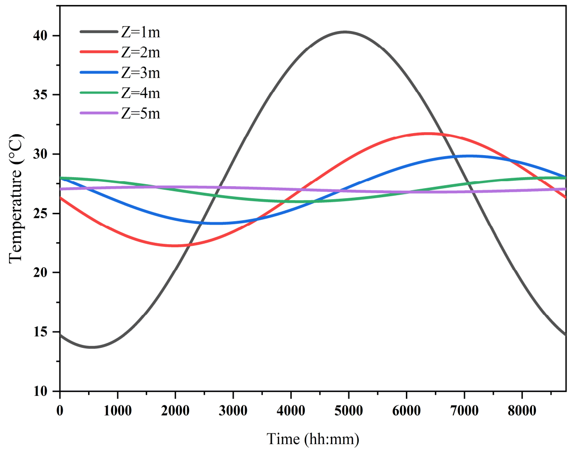

Figure .4. Soil temperature as a function of depth

Figure 5 represents to evaluate the influence of the air volume flow rate on the outlet air temperature, but in this case the length, diameter and depth are kept constant (For Tin=320.15 K, D=200 mm, Z = 2.5 m, and L=54m). The SEAHE efficiency decreased with the increase of the airflow rate. The outlet temperature of the heat exchanger was obtained to be 310.8 k,309 K and 306.2 K for the average airflow rate value of 50, 80 and 100 m^3/h.

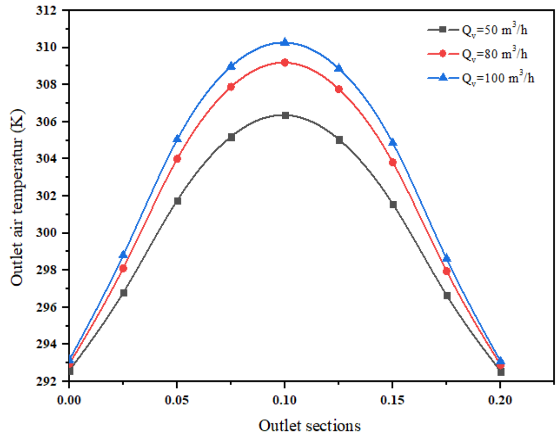

Figure.5. Temperature profiles at the outlet of the tube for different airflow rate

At varied airflow rate, Figure 6 shows the evaluated air temperature at the exchanger. In Figure 6, there are three different airflow rates of 50, 80 and 100 m^3/h respectively have been considered to study the effect of air flow rate on the SEAHE thermal performance. It was observed that the increased airflow velocity causes a decrease in air temperature drops, because of the decreasing residence duration of the flowing air inside the SEAHE. Therefore, the thermal performance deteriorates proportionally with air flow rate increases.

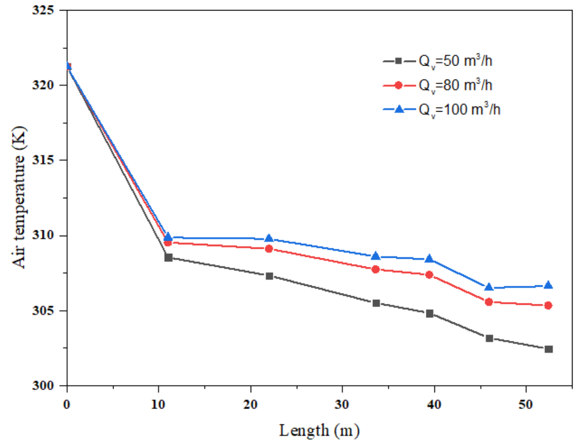

Figure. 6. Outlet air temperature versus exchanger length and air flow rate

To highlight the effect of the exchanger diameter, the air temperature the exchanger variations according to the exchanger length for three diameters were represented in Figure.7. As seen in Figure. 7. It was also observed the increase of the exchanger diameter causes a decrease in the air temperature because of the decreasing residence time of the flowing air inside the SEAHE.

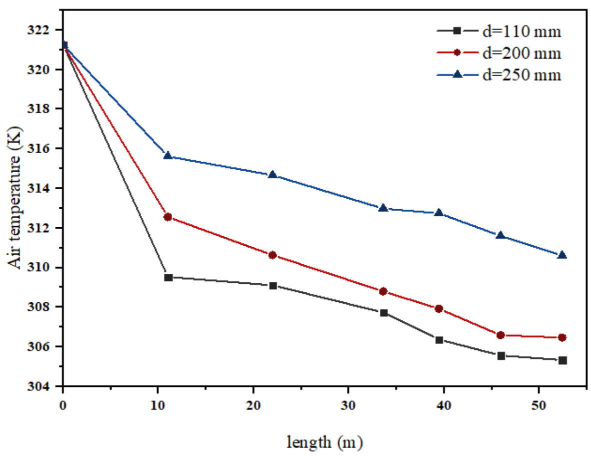

Figure .7. Outlet air temperature according to the pipe diameter and the exchanger length

IV. Conclusion

The main interest of our study related to the reality that the SEAHE system is able to decrease a building indoor temperature in arid climate. To achieve efficient SEAHE, the recommendations can be summarized as follows:

- At a depth of 2,5 m, the air temperature decreases from the maximum ambient temperature of 45 °C reaches the soil temperature at about 25 °C.
- A maximum gap temperature difference of about 18.7 °C between the Inlet temperature and outlet temperature at the exchanger.
- The inlet airflow rate effect on the outlet air temperature. Increasing the airflow rate from 50 to 100 m^3/h leads to an increase in the outlet air temperature of the exchanger.
- The diameter SEAHE effect on the outlet air temperature. Increasing the airflow rate from 110 to 250 mm leads to an increase in the outlet air temperature of the SEAHE by two times.

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