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# A NUMERICAL EVALUATION ON THE UTILIZATION OF EARTH TO AIR HEAT EXCHANGERS IN ARID REGIONS ALGERIA

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## ABSTRACT

In this paper, the numerical results of the study on geothermal-air heat exchanger in dry areas of Algeria (Ghardaia region) were presented. Computational fluid dynamics equations were solved using our specific code compilated with Fortran. The outputs of the numerical calculations were compared and validated with the experimental results and the outputs of a commercial CFD code. In these conditions, our results present good agreements with an error not exceeding 2%. By using our numerical model, we have calculated the optimum length, the internal diameter, the air velocity of the pipe in winter and summer periods and have determined the optimum depth at different depths. The comparison of two types of pipes making material (PVC and PEHD) has taken into account the characteristics of the Ghardaia-Algeria region (specific heat capacity, density, thermal conductivity and temperature) of the soil. The obtained results proved that the chosen model gives a satisfactory agreement in all the studied variables.

***Keywords:*** *Arid climate, Earth to air heat exchanger, Heat exchanger, Mathematical model, Temperature.*



## INTRODUCTION

Today, specialists are doing research to find alternatives to the classic cooling and heating systems, and improve ventilation and air conditioning as well, so they are interested in developing and exploiting renewable energies to solve this problem. Energy resources are produced naturally and rapidly from sun, wind, waves, tides, biomass, rain and geothermal energy. Today, renewable energy has become the ideal solution to operate cooling and heating systems because it is clean, continuous, renewable, permanent, and free of charge, compared to classical energies [1-6]. The most used ground connected systems are Earth-to-Air Heat Exchangers (EAHEs) and Ground Source Heat Pumps (GSHPs). In GSHP, a pipe is buried in the ground, and the heat transfer fluid circulates through it, since the earth temperature is higher than the temperature of the heat transfer fluid in winter, and vice versa in summer [1, 7-10].

EAHE systems work on the principle of heat exchange. The heat transfer fluid, usually air and initially at outdoor temperature, is blown into the tubes buried into the earth, and through the heat exchange that takes place between the heat transfer fluid and the ground, its temperature approaches the temperature of the earth. To meet the heating and cooling needs of buildings, pretreated air is sometimes used. EAHE systems can be open loop or closed loop. In an open loop system, the outside air is pumped with a continuous supply inside the buried pipe where heat exchange takes place with the soil whereas in a closed-loop system, the air in the buried pipe is recycled periodically (from the building to EAHE and back) [1]. With the increase in energy efficiency and with the decrease in its price, in the last ten years, many countries in the world have sought to develop EAHE systems, and in more than 30 countries, an increase of about 10% in installations of EAHE system is recorded. Yujiao Zhao et al. [11] compared an EAHE system with to the conventional system in Nagpur, Indian, and concluded that by employing, up to about 90% of the required energy can be saved.

Much empirical and numerical research has been done in the world, in order to enhance the performance of EAHE. Tiwari et al. [12] investigated the impact of inlet air temperature on the performance of an EAHE unit. So, they considered 5 different inlet air temperature values, flowing through a tube at 0.10 m fixed diameter and 21 m length. In the summer, they achieved a reduction of 5 to 6 °C in the temperature of the outlet air. Sobti and Singh [13] used the thermal energy of the soil and applied it as an alternative to the classical heating and cooling systems for buildings, in order to augment energy efficiency in built environments. Khabbaz et al. [14] showed

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that the EAHE with one and three tubes results in a 19.5°C and 18.3°C decrement in the outlet air temperature, respectively. In the opinion of Fazlikhani et al. [15], the EAHE system saves a great deal of energy, improves the average air temperature outlet the EAHE, and also reduces temperature fluctuations. Benhamza et al. [16] reported a significant decrease in the energy consumption by the EAHE system, an increase in the efficiency and performance factor of air conditioning, compared to direct utilization of an air conditioner. Maoz et al. [17] disclosed that the EAHE system with tube length ranging 50 to 70 m, diameter between 18 to 25 cm, and air speed between 5 to 7 m/s, can lower the temperature by about 15 to 18°C, and can be used to cool a single room. Bordoloi et al. [18] studied the influence of pipe material on the performance of an EAHE unit and concluded that pipe material had no significant influence on the outlet temperature. They also reported that EAHE technology could replace classic air conditioning systems. Hamdi et al. [19] showed that if an EAHE cooling system is used, the difference between inlet and outlet temperatures of EAHE can be up to 15°C. Demirtas et al. [20] emphasized that EAHE systems are among the most important solutions to the environment and pollution problems that the world suffers from today, and they also reduce the costs of traditional energy expenditures. Taşdelen and Dağtekin [21] numerically investigated the effect of inlet air speed on the thermal efficiency of EAHE systems and demonstrated that the smaller the air inlet velocity, the better the thermal efficiency of EAHE systems. They also showed, according to this case, a decrease in the consumption of cooling energy required in order to provide a state of thermal sufficiency for the model building. Agrawal et al. [22] conducted a 12-hour continuous study investigating the effect of tube shape (slinky-coil, U-shaped and helical) on the performance of an EAHE system. Their results exhibited that the slinky-coil tube resulted in a lower outlet air temperature and a higher heat transfer rate, compared to the U-shaped and helical-coil tubes. EAHE system efficiency of 0.80, 0.60 and 0.78 was obtained with the slinky-coil, U-shaped and helical-coil tube layout, respectively. Liu et al. [23] concluded that a smaller tube diameter in an EAHE system provides a larger heat capacity and a constant air mass flow rate whereas a larger tube diameter enhances the COP the EAHE unit. Increasing the tube depths in the soil leads to a reduction and elevation in the outlet air temperatures in summer and winter seasons, respectively. Rodríguez-Vázquez et al. [24] concluded that in climates with low humidity, such as a Chihuahua, the potential for ventilation with EAHE is higher, whereas in high humidity climates such as Villahermosa, EAHE ventilation potential is lower. Cuny et al. [25] demonstrated that the most significant parameters that control the performance of EAHEs are pipe diameter, pipe length, burial depth, inlet air velocity, and soil nature.

In this work, we present a numerical study on the performance of a surface-to-air heat exchanger in desert arid regions of Algeria. For this, we have used a specific code compiled with Fortran to determine the outlet air temperature. In the first step, we check the coupling of the simulation model with the experimental data reported by Bansal et al. [26] with the same values and under the same conditions. In the second step, the mathematical model is used to consider four main factors: the length, burial depth and diameter of the pipe along with the velocity of the inlet air. Taking into account the soil characteristics of the Ghardaia-Algeria region like density, specific heat capacity, thermal conductivity and temperature of the soil, we determine the adequate length, depth and diameter of the pipe with the examined velocity of the inlet air.



## SYSTEM DESCRIPTION

EAHE systems are utilized to meet the heating and cooling needs of buildings. The heat exchanger is a tube, usually made of PVC, that is buried underground. The principle of operation of the EAHE system is as follows: The outside air is blown with a continuous supply into the buried pipe, and its temperature becomes very close to the temperature of the earth due to the heat exchange taking place between it and the earth, and then it is pumped into space as shown in Figure 1.

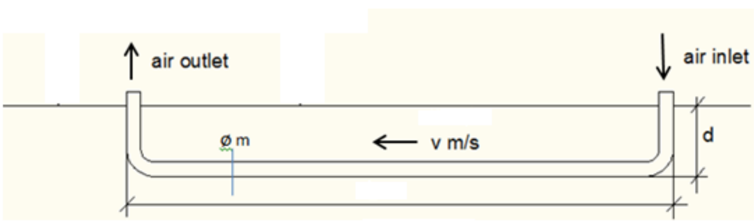



**Fig. 1.** Geometrical arrangement of EAHE

The system under consideration is applied in Ghardaia city, which is located in the north of the Algerian desert with a latitude of 32°36’N and a longitude of 3°48’E, as shown in Figure 2. Its total area is 19729 km$^2$ and it has a dry desert climate. The temperature ranges between 18 to 48 °C in summer and between 1 to 25 °C in winter. It is sunny most of the year and the weather is almost moderate in spring and autumn seasons. The city of Ghardaia is distinguished by an excellent insolation rate due to its privileged location. In fact, the duration of the sun's brightness is more than 3000 hours/year, and the annual solar radiation measured at a horizontal level exceeds 6000 W/m$^2$.

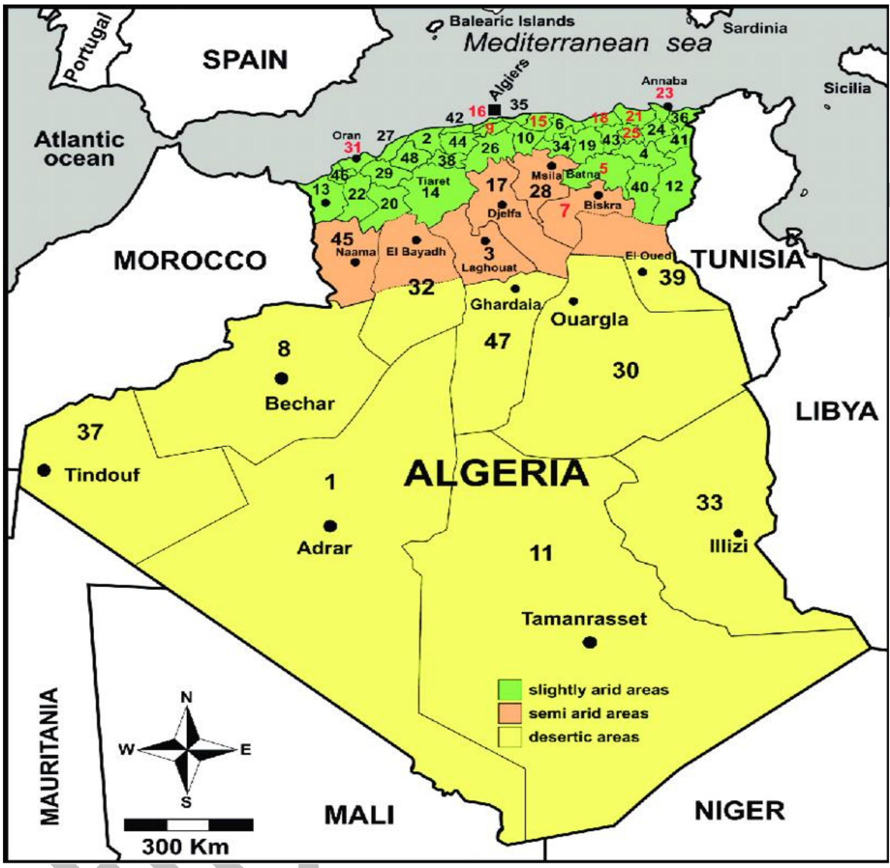



**Fig. 2.** Map of Ghardaia city

## MATHEMATICAL MODELLING

Starting from the general heat diffusion equation, assumptions are considered to simplify governing equation together with boundary and initial conditions. Constant soil temperature enables the model to solve energy balance equations. The model considers the following pertinent parameters, which alter the temperature along the heat exchanger:

- Outdoor temperature (incoming air temperature).
- Thermophysical properties of the soil area (soil temperature at each depth).
- Geometry (length and diameter) and tube material
- Inlet air velocity.

### Soil Temperature Modeling

The theory of one-dimensional transient heat conduction applied to a semi-infinite medium given below is used to mathematically model the soil temperature:

$$\frac{\partial^2 T}{\partial z^2} - \frac{1}{\alpha}\frac{\partial T}{\partial t} = 0 \tag{1}$$

$$T(0,t) = T_{mean} + A_a \cos\big(\omega(t - t_0)\big) \tag{2}$$

$$T(\infty,t) = T_{mean} \tag{3}$$

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

$$T(z,t) = T_{mean} + A_s \left( Exp - (z)\sqrt{\frac{\pi}{365\,\alpha}} \cos\left\{\frac{2\pi}{365}(t - t_0) - (z/2)\sqrt{\frac{\pi}{365\,\alpha}}\right\}\right) \tag{4}$$

At the outlet of EAHE, the air temperature is predicted as follows:

$$T_s = T_{amb} + \left(T(z,t) - T_{amb}\right) \times \left(1 - e^{-\frac{G_{Tot}}{\dot{m}\, C_{Pf}}\, x}\right) \tag{5}$$

The average seasonal thermal efficiency of the EAHE can be expressed as follows:

$$\eta_{mean} = \frac{\sum_{i=1}^{24}(T_{amb}(i) - T_{out}(i))}{\sum_{i=1}^{24}(T_{amb}(i) - T_{soil})} \tag{6}$$

**Modeling of EAHE**

The EAHE which is 50 m in length is divided into 25 elements, each is 2 m. It is presumed that the soil temperature is more altered by the air flow. The coefficient of heat transfer by convection in a tube is defined by:

$$h_{conv} = \frac{Nu\,\lambda}{D} \tag{7}$$

The number of Nusselt was expressed by the following correlation [27]:

$$Nu = 0.0214\,(Re^{0.8} - 100)\ Pr^{0.4} \tag{8}$$

The Reynolds and Prandtl numbers inside the tube are calculated by:

$$Re = \frac{V_{air}\, D_i}{\upsilon} \tag{9}$$

$$Pr = \frac{\upsilon\,\rho\, cp}{\lambda} \tag{10}$$

The heat transfer along the buried pipe can be calculated by:

$$\phi = \dot{m}\, C_{Pf}\, dT(x) = \frac{dx}{R_{conv} + R_{pipe} + R_{soil}}\big(T(z,t) - T(x)\big) \tag{11}$$

The thermal resistance of the pipe is expressed by:

$$R_{pipe} = \frac{1}{\lambda_{pipe}\, 2\,\pi}\ ln(r_e/r_i) \tag{12}$$

The convective thermal resistance on the inner surface of the pipe is:

$$R_{conv} = \frac{1}{r_i\, h_{conv}\, 2\,\pi} \tag{13}$$

The thermal resistance of the soil is calculated by:

$$R_{soil} = \frac{1}{\lambda\, 2\,\pi}\ ln\big(R_{(z,t)}/r_e\big) \tag{14}$$

Then, the total heat transfer coefficient of the EAHE is given as:

$$G_{Tot} = \frac{1}{(R_{conv}+R_{pipe}+R_{soil})} \tag{15}$$

By combining equations (11) to (15), the energy balance reads as follows:

$$\frac{dT(x)}{T(z,t)-T(x)} = \frac{G_{Tot}}{\dot{m}\, C_{Pf}}\, dx \tag{16}$$

Integrating equation (16) is then:

$$-ln\big(T(z,t) - T(x)\big) = \frac{G_{Tot}}{\dot{m}\, C_{Pf}}\, x + Cte \tag{17}$$

The boundary equation at the ground surface is:

$$T(0) = T_{amb} \tag{18}$$

The following equation is obtained when the constant in equation (17) is replaced by its expression deduced from equation (18):

$$ln\big(T(x) - T(z,t)/(T_{amb} - T(z,t)\big) = \frac{-G_{Tot}}{\dot{m}\, C_{Pf}}\, x \tag{19}$$

Finally, the air temperature can be calculated at the outlet (x = L) as follows:

$$T_s = T_{amb} + \ (T(z,t) - T_{amb})\left(1 - e^{-\frac{G_{Tot}}{\dot{m}\, C_{Pf}} x}\right) \tag{20}$$

The equations given above are sequentially solved for each section of the EAHE, from the inlet to the exit, via a program written in Fortran software (see Figure 3).

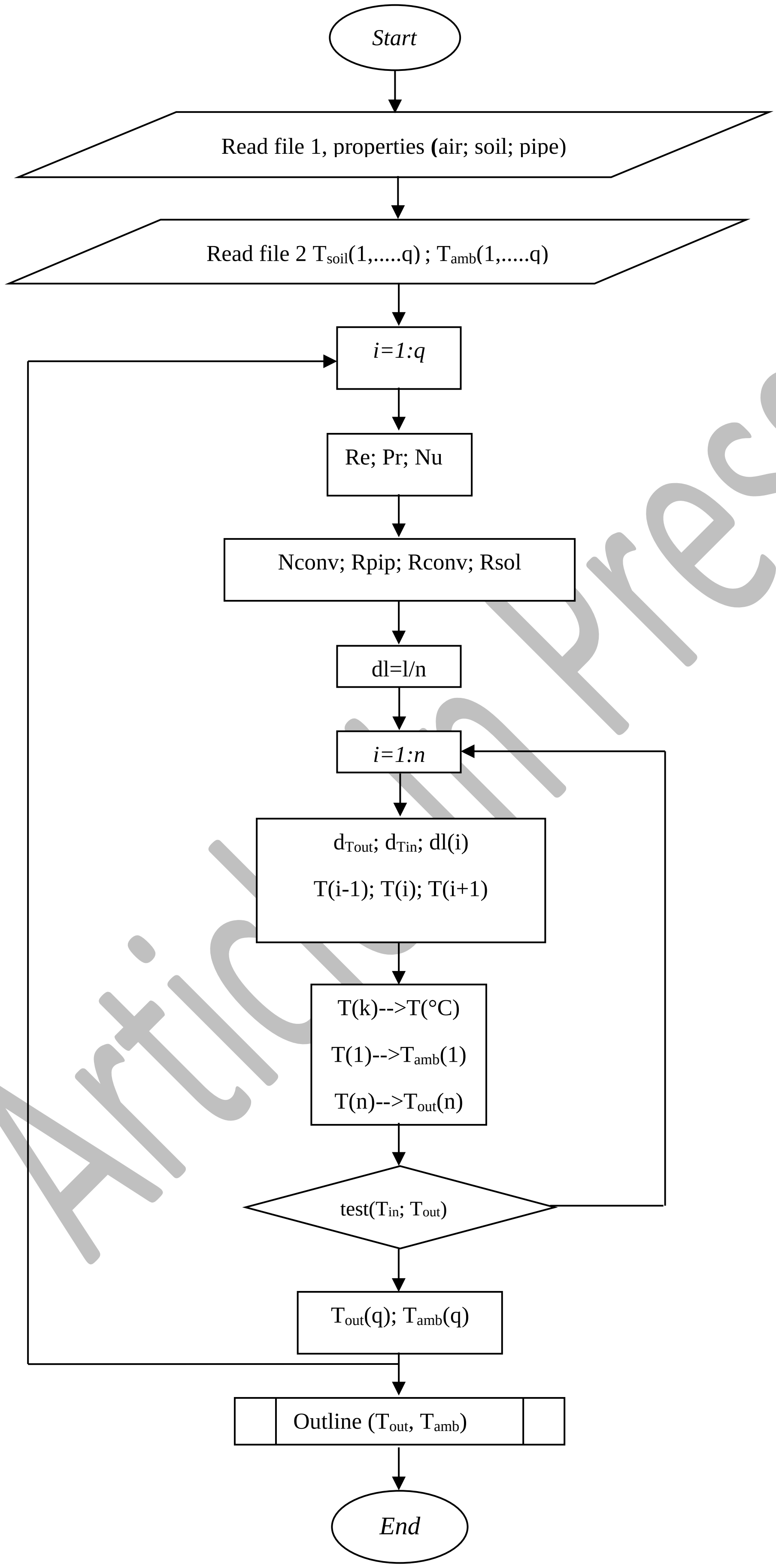



**Fig.3.** Flowchart of numerical model

## MODEL VALIDATION

The established model has been verified using the experimental outputs reported by Bansal et al. (2012) before developing our parametric analysis. The used parameters for the experimental validation are given in Table 1.

**Table 1.** Input parameters for the validation study

| Parameters | Values |
|---|---|
| Pipe diameter (m) | 0.15 |
| Pipe length (m) | 23.42 |
| Soil temperature (°C) | 26.7 |
| Soil density (kg/m$^3$) | 2050 |
| Soil specific heat capacity (J/kg.K) | 1840 |
| Soil thermal conductivity (W/m.K) | 0.52 |

Under these conditions, the air is circulated inside the pipe made of PVC with a 23.42 m of length and 0.15 m of inner diameter. The soil temperature is 26.7 °C and the air inlet velocity is 3 m/s. Inspecting the comparison between our outputs and the experimental results of Bansal et al. [26], it has been observed that the absolute relative difference is less than 2.8 %. Compared to the CFD data of Bansal et al. [26] reaching 12% as an absolute error rate, our new model presents a significantly lower value. It can be therefore confirmed that the established model can be considered to study the thermal performance of EAHE units (see Table 2).

**Table 2.** Comparison of Bansal et al. [26]'s results with our results

| **EAHE parameters** | Pipe material PVC, $D_i$ = 0.15 m, L = 23.42 m, $T_{soil}$ = 26.7 °C | | | | | |
|---|---|---|---|---|---|---|
| | **Outlet air temperature** | | | | | |
| **Air velocity inlet** | **Air temperature inlet** | **Experimental results of Bansal et al. [26]** | **CFD results [26]** | | **Current model results** | |
| $V_{inlet}$ (m/s) | $T_{inlet}$ (°C) | $T_{out}$ (°C) | $T_{out}$ (°C) | Relative error % | $T_{out}$ (°C) | Relative error % |
| 2 | 43.4 | 33.1 | 34.1 | 3.0 | 32.4 | 2.1 |
| 3 | 42.5 | 33.1 | 35.9 | 8.5 | 33.4 | 0.9 |
| 4 | 42.3 | 33.5 | 37.3 | 11.3 | 34.4 | 2.6 |
| 5 | 42.2 | 34.2 | 38.3 | 12.0 | 35.2 | 2.8 |



## RESULTS AND DISCUSSIONS

After successfully validating our model by considering the experimental results of Bansal et al. [26] at the same conditions, we exploited the mathematical model to study the influence of the length, the internal diameter, the air velocity of the pipe, pipe material and pipe depths on the performance of EAHE in winter and summer periods.

### Parametric Analysis of The EAHE in Ghardaia Regions, Algeria

To study the effect of different design and operation parameters on the EAHE efficiency, the thermophysical characteristics of air, pipe materials and soil for Ghardaia city, Algeria are considered in Table 3. Indeed, the parameters of the land air heat exchanger are presented in Table 4.

**Table 3.** Thermophysical properties of materials

| Material | Density ($kg/m^3$) | Thermal conductivity (W/m.K) | Specific heat capacity (J/kg.K) |
|---|---|---|---|
| Air | 1.1774 | 0.02624 | 1005.7 |
| PVC | 1380 | 0.16 | 900 |
| PEHD | 950 | 0.45-0.52 | 1900 |
| Sandy soil | 2050 | 0.52 | 1840 |

**Table 4**. Parameters used in the analysis

| Parameters | Values |
|---|---|
| Pipe length (L) | 0 to 50 m |
| Internal diameter ($D_i$) | 50 mm - 160 mm |
| Pipe thickness | 4 mm |
| Air velocity (V) | 0 to 5 m/s |
| Pipe depth | 1, 2, 3, 4 and 5 m |



**Influence of the soil depth on the tube temperature of EAHE**

The variation of soil temperature values of the Ghardaia region is plotted in Figure 4 for various depths varying from 1 to 5 m. The sine wave fluctuations in the soil temperature are shown in the four seasons of the year (8760 hours). When the underground depth is incremented, the sine wave fluctuations in the soil temperature decline. After 3 m depth, the fluctuations decrease considerably, and the temperature increases slowly due to going deeper toward the Earth core. These results confirm the importance of the use of the soil as a cold or hot heat source.

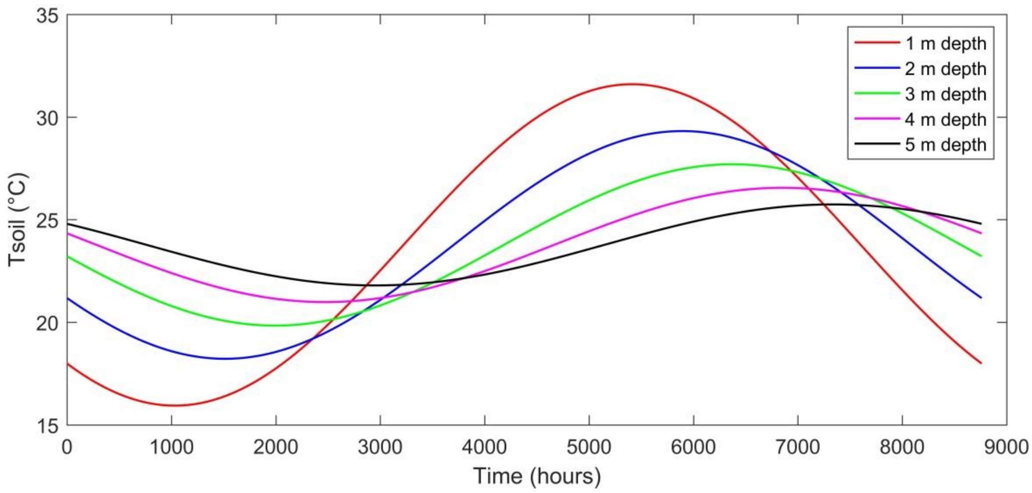



**Fig.4.** Variation of soil temperature in the Ghardaia region at various depths

**Influence of the tube length on the outlet air temperature of EAHE**

Figure 5 presents the air temperature at the outlet of the EAHE as a function of the tube length of the heat exchanger. The considered month is July when the inlet air temperature is very high reaching 45°C. It is noticed from the results that the air temperature outlet of EAHE declines significantly along the tube length and levels off at 24.5 °C after a length of about 20 m. It is also confirmed from the results that the pipe material, i.e.

Polyvinyl chloride (PVC) and Polyethylene High-Density (PEHD), has a marginal effect on the air temperature outlet of EAHE.

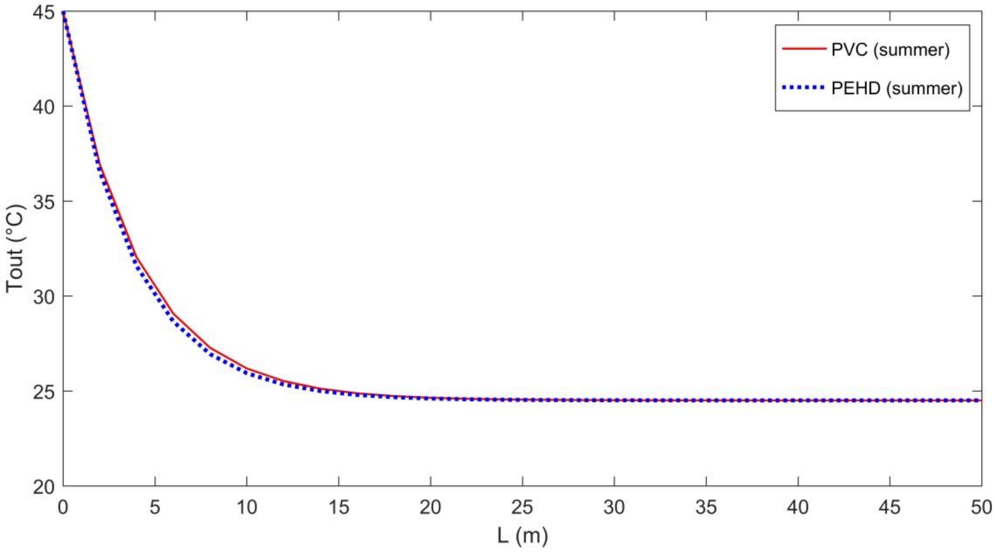



**Fig.5.** Effect of the pipe length on the outlet air temperature ($T_{amb}$=45°C)

**Influence of internal diameter on EAHE temperature outlet**

Figure 6 compares the air temperature outlet of the EAHE in summer and winter seasons for different tube lengths. In these conditions, various inner tube diameters of the heat exchanger are considered, which are namely 50, 80, 110 and 160 mm. It has been observed that the diameter of the pipes affects the air temperature outlet of the EAHE in both seasons. In the summer season when the maximum ambient temperature is equal to 45 °C, the air temperature outlet approaches about 24.5 °C for all aforementioned tube diameters, except 160 mm. However, the length where this temperature is reached depends on the tube diameter. For instance, the temperature stabilizes after a length of approximately 20 m and 35 m for the tubes with 50 mm and 80 mm inner diameter, respectively. The maximum ambient temperature is equal to 12 °C in the winter season. The outlet air temperature is approximately 20 °C in winter for all the considered pipe diameters, except 160 mm similar to the summer season. When the pipe with 50 mm inner diameter is utilized, the temperature levels off at about 20 mm, where it is around 25 m and 30 m respectively for the pipe with 80 mm and 110 mm inner diameters.

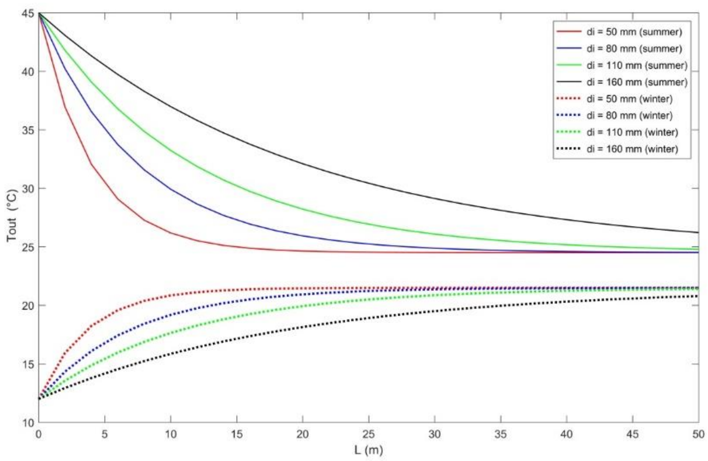
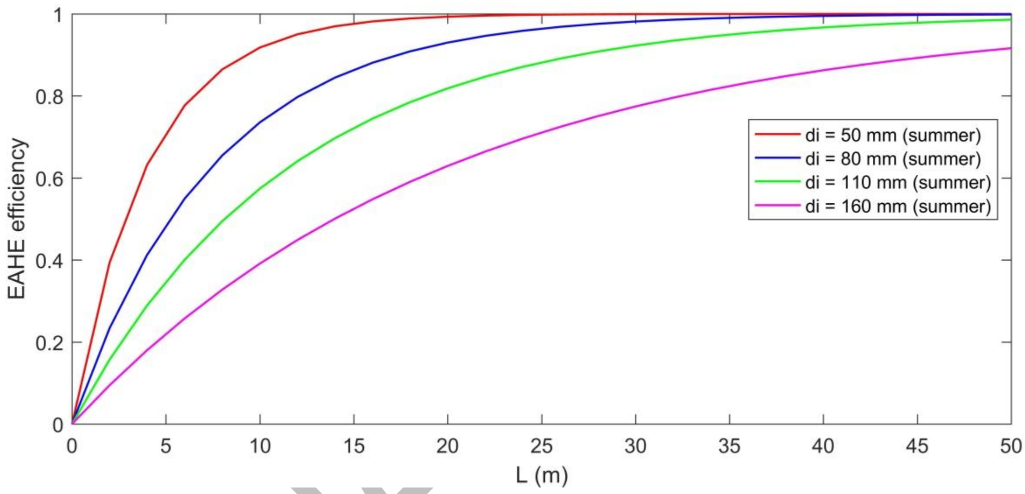



**Fig.6.** Variation of air temperature outlet versus tube length for various inner tube diameters in winter and summer seasons with V= 1.5 m/s.

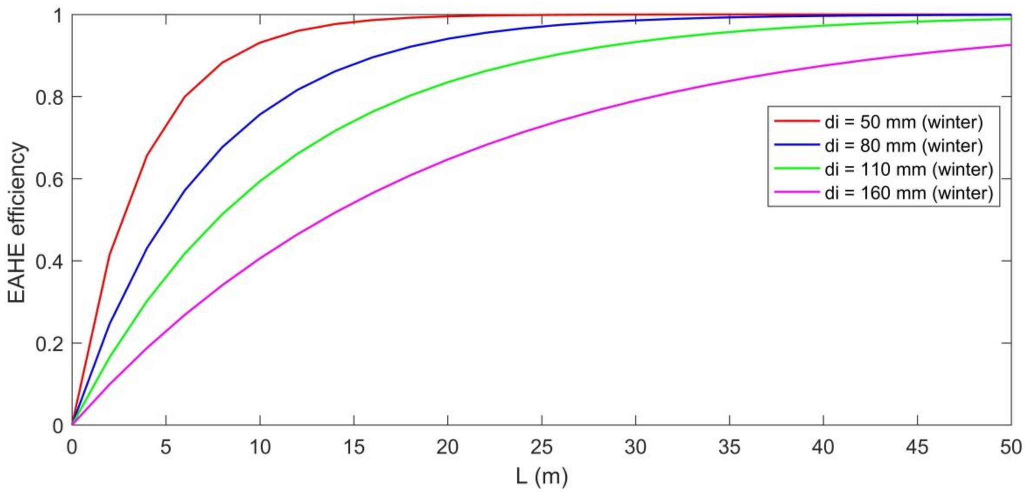
## EAHE Thermal Efficiency

### Influence of internal diameter on EAHE efficiency

Figure 7 shows the efficiency of EAHX during the winter and summer seasons as a function of the inner tube diameters equal to 50, 80, 110 and 160 mm. From these results, it has been observed that the EAHE efficiency is significantly better for smaller pipe diameters. An inverse proportion between the efficiency of the EAHX and the pipe diameter has been noted. The reason is that when the diameter of the tube is reduced, the air velocity increments which enhances the convective heat transfer coefficient, leading to higher heat transfer rate. With regard to the efficiency of EAHE in summer and winter seasons, when the inner tube diameter is equal to 50 mm, the efficiency reaches the maximum value (unity) for the pipe length larger than 20 m. For the pipe with 80 mm diameter, the required length to reach this efficiency is about 40 m in both summer and winter seasons. For larger pipe diameters, for instance, $D_i$=110 mm, the efficiency approaches the maximum efficiency while for the tube with $D_i$=160 mm, the efficiency is still around 0.99 at 50 mm length of the pipe.




(a) Summer season

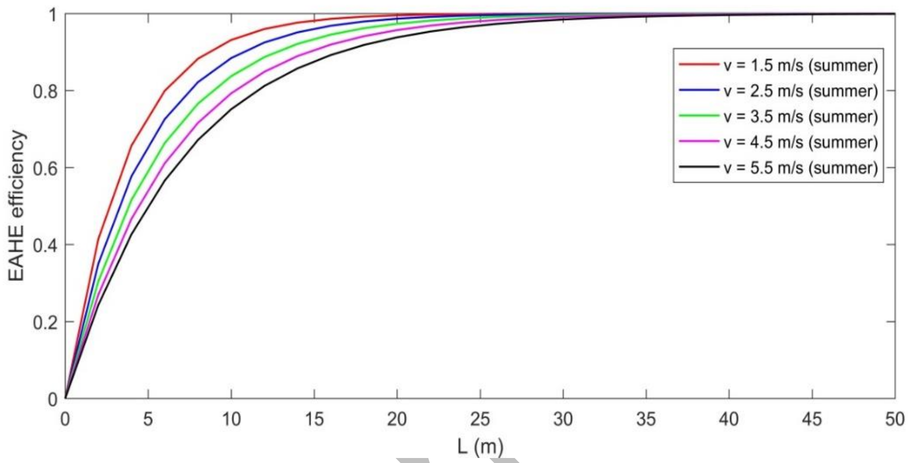



(b) Winter season

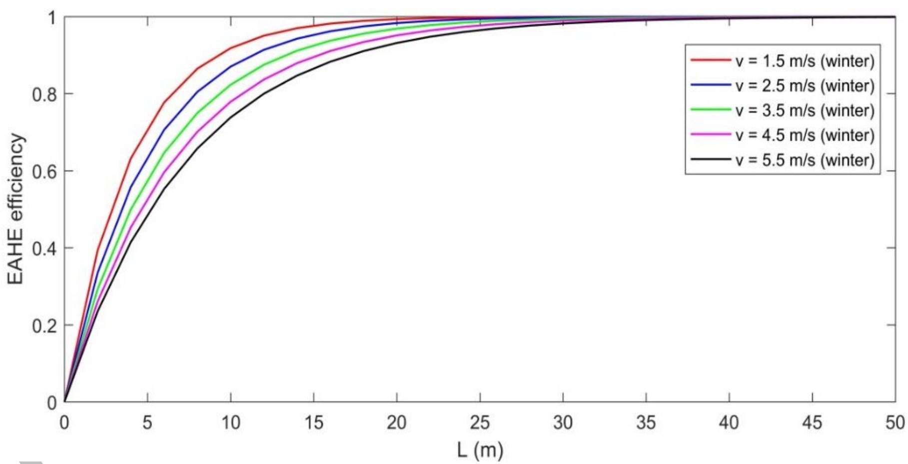
**Fig.7.** Variation of the EAHX efficiency versus the tube length for various inner tube diameters with V= 1.5 m/s

**Influence of air velocity on EAHE efficiency**

Figure 8 shows the EAHX efficiency during winter and summer seasons in function of the air velocity equal to 1.5, 2.5, 3.5, 4.5 and 5.5 m/s. From these results, it has been observed that the EAHE efficiency is significantly better for the lower air velocity. There is an inverse proportion between the performance of the EAHE and the air speed. The influence of the air speed on the efficiency of the exchanger is similar to that of internal diameter and the EAHE efficiency increases for lower air speeds. The impact of air velocity on the EAHE efficiency is significant when the pipe length is relatively short, particularly below 20 m. The EAHE efficiency reaches the maximum irrespective of the air velocity and the season when the pipe length is larger than around 35 m.




(a) Summer season




(b) Winter season

**Fig.8.** Variation of EAHE efficiency versus the tube length for different air velocities with the diameter equal to 50 mm

**CONCLUSION**

In this paper, the EAHE system was modeled by using the computational fluid dynamics equations and compiled with Fortran software. After validating the model by comparing our results with the experimental data found from literature, a parametric analysis was conducted to evaluate and examine the influence of buried pipe length, pipe internal diameter and air speed on the outlet air temperature and the heat exchange efficiency of

EAHE. In these applications, we are referred to the Ghardaia region located in the Algerian desert, which is characterized by a constant annual soil temperature. The obtained results are recapitulated in the following bullets:

- The results give a satisfactory agreement between the numerical calculations of our numerical model and the experimental data.
- An ideal depth of 3 m, length of 20 m, internal diameter of 50 mm and air velocity of 1.5 m/s was proposed for ground air heat exchangers to be utilized in air conditioning applications.
- Pipe material has a marginal effect on the outlet air temperature of EAHE.
- The heat exchange efficiency values for EAHE were very high, reaching 0.99, compared to the commonly used air-to-air heat exchangers.
- The air temperature the leaving the EAHE gradually approaches an approximate value of about 24.5 °C in summer and 20 °C in winter season and remains nearly constant thereafter.

These outputs of this study can be considered for the design and developments of the earth to air heat exchanger to be considered in different applications alternative to Heating, Ventilation and Air Conditioning (HVAC) systems in arid climates.

**Nomenclature**

| | | |
|---|---|---|
| $D$ | Pipe diameter | *m* |
| $L$ | Pipe length | *m* |
| $z$ | Depth from the earth surface | *m* |
| $x$ | Pipe length | *m* |
| $t$ | Time | *hour* |
| $V$ | Air velocity | *m/s* |
| $Cp$ | Specific heat capacity of the soil | *J/kg.K* |
| $R_e$ | Reynolds number | |
| $Nu$ | Nusselt number | |
| $Pr$ | Prandtl number | |
| $T$ | Temperature | *°C* |
| $T_s$ | Air outlet temperature of EAHE | *°C* |
| $h_{conv}$ | Coefficient of heat transfer by convection in a tube | $W/(m^2K)$ |
| $R_{pipe}$ | Thermal resistance of the pipe | *m K/W* |
| $R_{conv}$ | Convective thermal resistance | *m K/W* |
| $R_{soil}$ | Thermal resistance of the soil | *m K/W* |
| $G_{Tot}$ | Total thermal conductance of the EAHE | *W /m K* |

**Greek symbols**

| | |
|---|---|
| $\eta_{mean}$ | Efficiency of the EAHE |
| $\phi$ | Heat transfer along the pipe |

**Abbreviations**

| | |
|---|---|
| EAHE | Earth-to-Air-Heat-Exchanger |

**Statements & Declarations**

**Ethics approval**

We declare that the manuscript has not been previously published, is not currently submitted for review to any other journal, and will not be submitted elsewhere before your decision is made.

**Consent to participate**

All participates agreed to participate in this study.

**Consent to publish**

All authors agreed with the content and approved the final manuscript.

**Authors Contributions:**

AK: conceptualization, methodology, formal analysis and investigation, and writing—original draft preparation. MEHA: conceptualization, methodology, formal analysis and investigation, and writing—original draft preparation. MA: conceptualization, formal analysis, writing—review, and editing. KB: conceptualization, methodology, writing—review, and editing. ZD: conceptualization, methodology, writing—review, and editing.

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**Competing Interests**

The authors have no relevant financial or non-financial interests to disclose.

**Availability of data and materials**

Not applicable

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