3rd International Conference on Automation, Control, Engineering and Computer Science (ACECS'16)
Proceedings of Engineering & Technology (PET)
pp. 585-591

Numerical simulation of earth/air heat exchangers at arid climate operating conditions

Djamel BELATRACHE[a*], Saïd BENTOUBA[a], Mahmoud BOUROUIS[b]

[a] *Laboratory of sustainable development and Informatics (LDDI),Adrar-Algeria*
University of Adrar, Faculty of Sciences and Technology, Adrar, Algeria
[b] *Universitat RoviraiVirgili, Tarragona, Spain*
[*]Djamelbellatrach@gmail.com

***Abstract*— In Algeria, the residential and tertiary buildings are among most important sectors in terms of energy consumption.**
This paper presents the simulation modeling process of the Earth-to-air heat exchanger (EAHE) systems, as part of a simulation of the entire building in the region of Adrar. The earth tubes buried in the ground can offer considerable advantages in terms of energy and demand savings. The depth of the earthing system of the tubes was calculated and optimized to the physical conditions of the local soil using the MATLAB program. The parametric analysis includes the length of the pipe, the radius and the velocity of the air within the pipes. Performance and overall energy savings are presented.

***Keywords*— thermal comfort, Earth heat exchanger, Matlab, arid climate.**

I. INTRODUCTION

Research on earth-air heat exchangers seems to have started after peak oil 1979 and have stopped temporarily after against-shock 1985[1]. It is only since 1995 that some researchers have resumed studies on the issues of the performance of earth-air heat exchangers, thermal behavior and their integration into the building as a pre-air conditioning system.[2]

An earth-air heat exchanger (EAHE) consists of one or more tubes lying underground to cooling (in summer) or heating (in winter) to supply air in a building. This air is often outside air for ventilation, but also useful for partially or totally managing thermal loads of construction.

To understand the thermal performance of a EAHE, many mathematical models, methods and computer tools have been largely applied. **Krarti and all** considered the heat transfer problem EAHE as a passenger and have proposed an analytical model assumes the EAHE system.[8]

The physical phenomenon is simple: the ground temperature is lower than outside air in summer. Soil temperature at a depth of 1 and 5 m under the ground level, remains almost constant throughout the year; its temperature profile as a function of the depth depends on several factors such as the physical properties of soil covering the sky and the climatic conditions. [3]

Physical model to simulate the EAHE was developed and validated by **Mihalakakou et al**. [4,5]. **Benkert et al.** [6] highlighted the lack of optimization criteria In addition, they developed computer tools GAEA, based on a physical model and then experimentally validated with good results. The EAHEs are characterized by a large potential energy savings and low maintenance. Moreover, **Al-Ajmi et al**. [7] developed an analytical model of the earth-air heat exchanger (EAHE) to predict the air outlet temperature and the potential of these cooling devices in a hot, arid climate. In this model, the thickness of the disturbed soil is taken equal to the radius of the underground pipe and the thermal resistance of the pipe material is neglected. After validation with other published works mental experience, this model has been integrated into the environment TRNSYS to investigate the thermal performance of housing coupled with a kind EAHE in Kuwait weather. It was found that the EAHE can provide 30% of the cooling energy demand in summer.

A complete analytical solution for the heat diffusion of a cylindrical air/soil heat exchanger with isothermal boundary condition proposed by **Hollmuller**.[9]

Paepe and all have proposed a method to analyse one-D analysis the influence of design of the heat exchanger parameters to the thermal hydraulic performance[10].**Badescu** has developed a simple and precise model earth air heat exchanger based on a numeric transient approach two-dimensional which allows the calculation of the soil temperature at the surface and at different depths. The potential heating and cooling a system under actual climatic conditions has been studied. [11]

A factor for evaluating the thermal performance of the earth to air heat exchanger. It was determined by temperature falls obtained under the condition of steady state and transient state proposed by Bansal et al. [12]

ISSN: 2356-5608

II. **OBJECTIF**

This investigation is the evaluation of the impact of the EAHE, represented by the earth-air heat exchanger, on the summer thermal comfort in buildings and hence the comfort of individuals and demonstrating that a simple pipe placed at the inside floor connected with a building can significantly regulate indoor comfort and thus provides energy savings.

The main objective of this article is to present a survey of the earth-air heat exchanger (EAHE) used for cooling buildings in the climatic conditions of the Algerian Sahara (Adrar). This study was conducted on July in period where there is a high demand for cooling.

III. **PRESENTATION OF THE STUDIED PHYSICAL MODEL:**

The heat exchanger is formed of a PVC pipe (polyvinyl chloride) buried in the ground. The buried pipe has a length L, an inside diameter D_i and a thickness of 5 mm.

The principle of operation can be explained as follows: First, the hot outdoor air is pumped by the buried pipe with the help of adequate fan. After, during its passage, the air loses a quantity of heat exchange with the pipe and it is cooled as it progresses. Finally, the cooled air is injected into the building.

Table 1: Physical properties and thermal air, pipe and soil [13]

materials	Density (kg/m3)	Heat capacity (J/kg C)	Thermal Conductivity (w/m C)
Air	1.1774	1005.7	0.02624
Soil	2050	1840	0.52
PVC	1380	900	0.16

Table 2: Parameters of EAHE used in this simulation

Parameter	The reference values
Pipe length (L)	50m
Inside Diameter (Di)	40 mm
Pipe thickness (e)	4 mm
Air velocity (V)	2.5 m/s

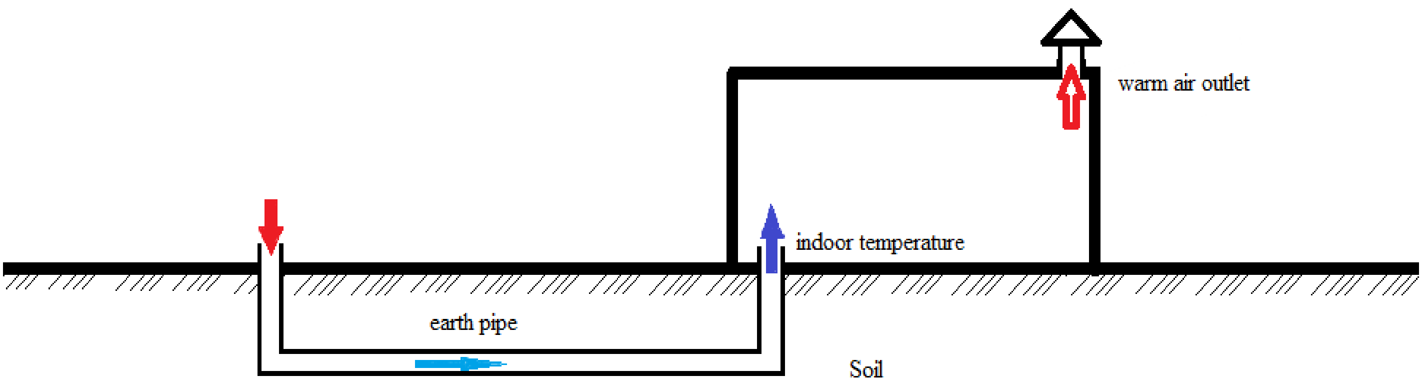

Fig. 1. Schematic of the Earth-Air Heat Exchanger system.

IV. Modeling the temperature of the air:

IV.1. Geometric hypotheses:

The earth Air Heat Exchanger that will be modeled by the following characteristics:

- A vertical air inlet located between the ground surface (z = 0) and the level of the landfill.... EAHE (z = + Z).
- One or more pipes arranged horizontally under the ground at the depth z = + Z.
- A vertical air outlet situated between the well landfill level (z = + Z) and the surface ... of the soil (z = 0).

IV.2. Thermal hypotheses:

The geometric model presented above can be further simplified as follows:

- The airflow inside is identical;
- The dimensions and physical properties are identical;
- The surrounding soil presents uniform and identical thermal properties.

IV.3. Establishment of the analytical model:

The model consists of finding from the energy balance equations considering the constant temperature of the ground, the analytical expression that reflects changes in air temperature along the exchanger according to the following parameters:

- The outdoor temperature (ambient);
- The soil temperature at the depth considered;
- The thermo physical characteristics of the soil;
- The geometry and nature of the conduit;
- The air flow.

V. Mathematical modeling of soil temperature:

The model of the soil temperature can be modeled by the equation of heat in the case of conduction in a semi-infinite medium unidirectional variable speed and without internal source, under these conditions the conduction equation with boundary conditions is given by:

$$\begin{cases} \frac{\partial T}{\partial t} = -\frac{1}{a_{sol}} \cdot \frac{\partial^2 T}{\partial z^2} \\ T(0,t) = T_m + T_0 . \cos \omega t \\ T(\infty, t) = T_m \end{cases} \qquad (1)$$

The pipes are placed nearly horizontal position, with a minor inclination to remove condensed water as possible. To begin the earth tube system simulation method it is necessary to know the optimal installation depth for underground pipes of Adrar region.

To perform the detailed thermal model soil, they physically modeled ground temperature (T_z) depending on the depth below the ground surface (z) and time (t). According to the heat transfer equation to the ground below-mentioned (equation 2) for calculating the T_z, we need to know the average surface temperature at the ground, the amplitude of the surface temperature variation of soil, constant relative phase (t_0), and the thermal diffusivity (A_{soil}) from the floor to the specific location. :

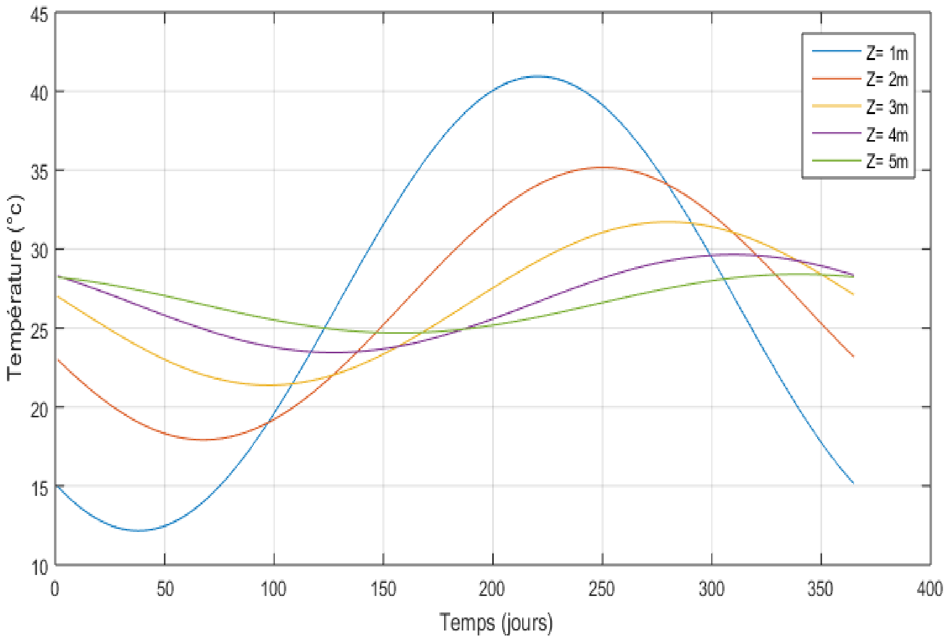

Fig. 2. Soil temperature Adrar region at different depths.

The soil temperature is calculated using the following equation:

$$T(z,t)=T_m-\times T_0\times Exp\left[-z\times\sqrt{(\pi/365\times a_{sol})}\right]\times$$
$$Cos\left\{(2\pi/365)\times\left[t-t_0-(z/2)\times\sqrt{(365/\pi\times a_{sol}}\right]\right\} \qquad (2)$$

The Fig. number 2 shows Soil models of Adrar region in different depths (5, 4, 3, 2, 1 m). With increasing depth in the ground, fluctuations of the sine wave of the soil decreases and the soil reaches a relatively consistent temperature, allowing us to use the earth as a heat source (cold / hot).

VI. AIR TEMPERATURE AT THE OUTLET OF THE EXCHANGER:

The main equations describing the heat exchange between the ground, buried pipes and crossing air are:

$$R_{conv}=\frac{1}{h_{conv}\times 2\times\pi\times r_1} \qquad (3)$$

$$R_{tube}=\frac{1}{2\times\pi\times\lambda_{tube}}\ln\left[\frac{R_e}{R_i}\right] \qquad (4)$$

$$R_{soil}=\frac{1}{2\times\pi\times\lambda_{sol}}\ln\left[\frac{R(z,t)}{R_1}\right] \qquad (5)$$

After (3), (4) and (5) the total thermal resistance is equal to:

$$U=\frac{1}{R_{conv}+R_{tube}+R_{soil}} \qquad (6)$$

There has been a drop in temperature of the air from the inlet to the outlet. It should be noted a significant deviation between the air temperature in the heat exchanger and the outside air. This gap gradually decreases until the air temperature tends to the ground temperature.

The heat balance for this tube is:

$$m\times Cp_{air}\times\left(T(x)+dT(x)-T(x)\right)=$$
$$\frac{dx}{R_{conv}+R_{tube}+R_{sol}}\times\left(T(z,t)-T(x)\right) \qquad (7)$$

Effectiveness is then equal to:

$$\varepsilon=\frac{T_S-T_{in}}{T(z,t)-T_{in}}=1-e^{\frac{-U\times L}{m\times Cp_{air}}} \qquad (8)$$

After (2), (6) and (7) the total thermal resistance is equal to:

$$T_S=T_{in}+\left(T(z,t)-T_{in}\right)\times\varepsilon=T_{in}+$$
$$\left(T(z,t)-T_{in}\right)\times\left(1-e^{\frac{-U\times L}{m\times Cp_{air}}}\right) \qquad (9)$$

VII. RESULTS OF THE OPERATION IN THE SUMMER TIME:

1- Variation Air temperature compared along the exchanger :

The simulation results are shown in the Fig. s below. There has been a drop in temperature of the air from the inlet to the outlet. It should be noted a significant deviation between the air temperature in the heat exchanger and the outside air. This gap gradually decreases until the air temperature tends to the ground temperature.

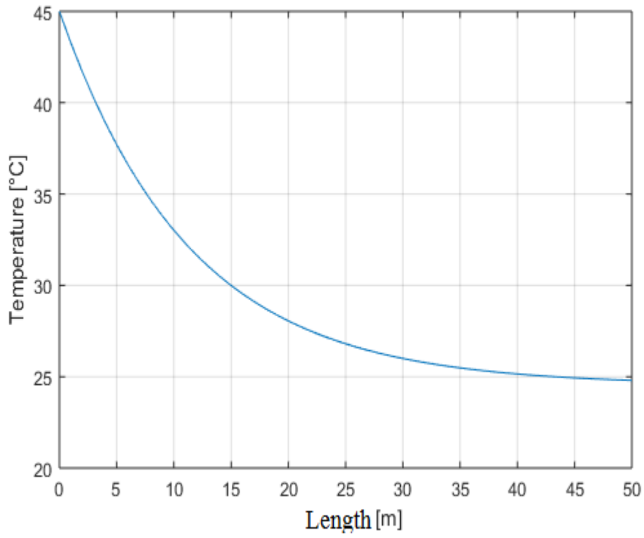

Fig. 3. Variations of the temperature of the air outlet according to the length of the exchanger.

2- Effect of depth EAHE:

Fig. 4 show the variation of the temperature output as a function of tube length for different depths of the exchanger inlet to the outlet.

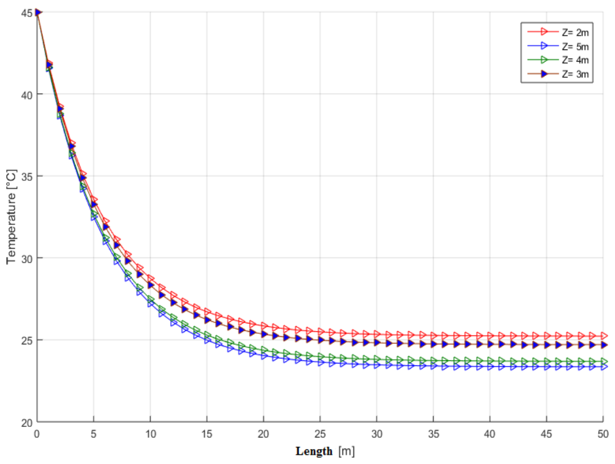

Fig. 4. Air outlet temperature variation depending on the depth of tube.

For all depths studied, it is noted that the temperature of the air decreases to the entry corresponding to the outer base temperature of Adrar city (45 ° C) until it reaches the temperature value soil (24 ° C). It is also noted that the outlet temperature of the earth-to-air heat exchanger at a constant value beyond a length L = 25 m.

However we see that from a depth Z = 2&3 m, we do not have an influence on the depth (Z = 4 and 5 m) are confused.

3- Effect of diameter:

To assess the influence of the diameter on the outlet temperature are presented in Fig. 5, changes in temperature for different diameters. The same shape is found as before, that is to say an exponential decrease of the temperature of the air for all different diameters studied.

It is noted also, that the air temperature increases as and by increasing the diameter.

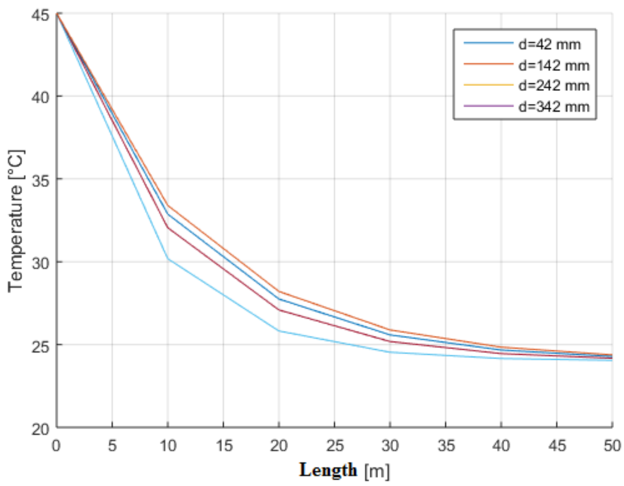

Fig. 5. Air outlet temperature variation depending on the diameter of the exchanger

This situation is explained by the fact that for large values of the flow rate becomes maximum diameter knowing the velocity of the outer air is always fixed and having the base temperature value (summer) 1 m / s, and therefore the air is not sufficiently enough time to absorb the heat stored in the soil. For economic reasons, we simulated diameters below 42 mm and thus it was found that with these, you can always reach the value of soil temperature while earning the tube length as is the case diameter 42 mm to 100 mm, the soil temperature is reached.

4- Effect of the thermal diffusivity :

To assess the influence of the thermal diffusivity on the outlet temperature presented in Fig. 06, changes in temperature for different thermal diffusivity.

The same shape is found as before, that is to say an exponential decrease of the temperature of the air for all different thermal diffusivity studied.

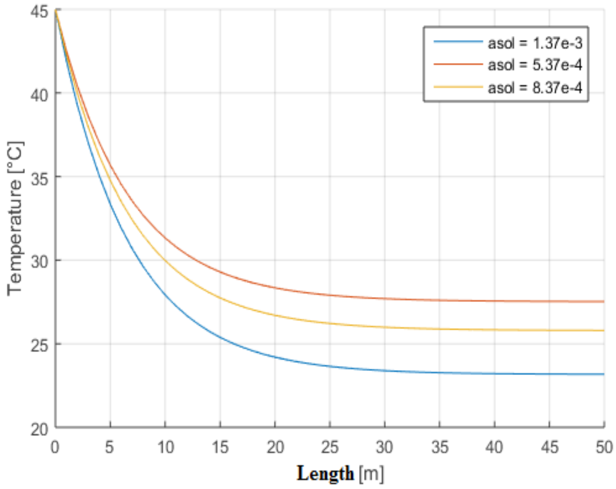

Fig. 6. Air outlet temperature variation as a function of the thermal diffusivity of soil.

VII. CONCLUSION

The installation depth of optimal pipes of earth tubes (5 m) in terms of constant annual soil temperature has been calculated using the MATLAB program as regards the physical characteristics of the soil Adrar.

The ground tube simulation process was used. A parametric analysis was performed to evaluate and confirm the effect of the length of the ground tube, the diameter and the air flow rate on the temperature of the outlet air of the ground tube.

The results of the simulation show an actual increase and decrease the temperature of the air tube outlet to earth during summer.

The results of the parametric analysis of soil tube show that longer length top and bottom radius of the air flow tube grounding to a more efficient system.

Nomenclature

z depth [m];
t Day of the year [1 ... .365];
T_m mean annual temperature [° C] gives the weather station Adrar.
T_0 Depth of surface temperature (maximum temperature of the air - Temperature ... ..Minimal air).
t_0 The day of the year corresponding to the maximum surface temperature, in our case it was . .the 17th day of July is t0 = 198 days [1 ... 365];
d Depth of penetration [m];
a_{soil} thermal diffusivity of the ground [m2 / day];
λ thermal conductivity of soil [W / m / K];
Cp specific heat capacity of the soil [J / kg / K];
ρ density of the soil [kg / m3];
R_{CONV} Thermal resistance corresponding to the convective exchange between the air and the tube [m · K / W];
R_{tube} Thermal resistance of the buried pipe [mK / W];
R_{SOiL} Thermal resistance between the tube and the cylindrical surface of adiabatic [m · K / W];

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