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The Effect of Soil Depth on the Performance of Earth Air Heat Exchanger for Climatic Condition of Baghdad, Iraq: Mathematical and Numerical Study

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Abstract

Geothermal energy is one of the important sources of renewable energy, so researchers are greatly interested in this type of energy. One of the advantages of this type of energy is its use to heat or cool buildings because the ground temperature is fairly constant throughout the year. The research focuses on understanding how soil depth affects the temperature difference, the rate of heat transfer, and the overall performance of the system in Baghdad, Iraq, throughout the year by conducting a mathematical test for the ground heat exchanger and determining the number of appropriate requirements during the study to reach an equation that simulates the distribution of temperatures at depth and time. The software package (CFD ANSYS FLUENT) version 17 was used for numerical analysis. The results showed that the heat transfer rate from air to soil for cooling purposes reached its highest value of -1375 watts during July at a depth of 6 m. As for heating purposes, the maximum value during January reached 579 watts at a depth of 10 m and 499 watts at a depth of 6m. Earth air heat exchanger effectiveness was highest possible at depths of 4 and 5 m, ranging from 0.9 to 0.92 over the year. The highest value of 0.98 for the exchanger effectiveness appeared during March. The results showed good agreement between the mathematical and numerical analysis and comparison with other studies, as the percentage of deviation ranged from 1.7% to 3.6% for depths from 1 m to 10 m.

Keywords: *Heat Exchanger, Mathematical Model, Renewable Energy, Ground Temperature, Ansys Fluent.*

1. Introduction

An earth-to-air heat exchanger (EAHE) consists of one or more tubes buried underground to obtain cooling for the air prepared for the building in the summer and heating in the winter. The explanation of the physical phenomenon of this application is simple: the earth's temperature in the winter is higher than in the open air, and vice versa in the summer, so this feature is the earth as a cold or warm exchanger. The earth's temperature at 5 to 8 meters deep is almost constant. It also depends on many factors, including the type of soil in terms of physical characteristics and climatic conditions. This exchanger is a concrete, metal, or plastic pipe buried underground at a certain depth. Heat exchange between air and soil occurs across the tube surface of the exchanger. Considering all design considerations while designing these systems leads to obtaining good performance and efficiency. Many factors affect the efficiency of these systems, including air velocity, type of exchanger tube material, soil type, and others. These systems are considered clean energies, as they reduce energy consumption and pollution compared to traditional methods. There are also two types of these systems, one of which is the open system (in this system, the treated outside air inside this exchanger enters the building, and the path stops) or, in the case of the closed system(which enters the treated air inside the exchanger to the building and then is recycled to the exchanger, i.e., In this case, the outside air is not used every time). This type can increase the system's efficiency for cooling or heating according to the purpose used. Manjul et al., focused on summer cooling using an air heat exchanger and different summer climate temperatures at LNCT Energy Park Raisen Road Bhopal M.P. This study was carried out practically to evaluate the performance efficiency of the air-ground tube heat exchanger. The ground-air heat exchanger was studied for its experimental performance. The experimental results of this study indicated that the COP ranged from (0.85 - 2.12) in April and March and ranged from (1.28 -2.12). The highest COP in the summer, at 4:00 pm in March and April. The maximum and minimum heat transfer achieved by this study in the summer is 265.65 and 106.38 Watts, respectively [1]. Barakat et al., used a new method of cooling the incoming air for gas turbines. This method must first be examined by knowing or estimating the soil temperature for different depths throughout the year and determining the appropriate soil depth for better performance and a low cost. The factors that led to this study were a lower air temperature than the exit, the use of a long and deep ground tube, a low speed of air entry, and a smaller diameter of the tube [2]. Bisoniya, developed a one-dimensional model of EAHE systems using many simplified design equations. It was used in calculating the non-turbulent temperature of the earth and matters related to friction calculations that were recently developed; the Nusselt number is used to ensure the highest accuracy in estimating a value heat transfer. The equations developed by the researcher help designers calculate the heat transfer coefficient, pressure drop, heat transfer rate, and tube length of the EAHE system. This study also found that using a pipe with a smaller diameter, a greater length, and a greater depth, and also that the air flows at a low speed leads to improvement in the performance of the EAHE system [3]. Khot, focused on the different design parameters of the geothermal heat exchanger system. In this study, the possibility of using the EATHE hybrid evaporative cooling method was demonstrated to obtain the best result and performance by reducing the diameter and increasing the length of the pipe and the depth of the soil to more than 4 meters, in addition to reducing the airflow velocity inside the buried pipe EATHE is used better and more efficient in summer [4]. Ascione et al., developed geothermal exchangers for Italian climates. The study focused on several factors (such as the type of pipe material, soil classification, length and depth of the pipe, airflow velocity, and control modes). This study showed that the heat exchanger has the highest performance and efficiency in places with cold climates, such as summer and winter. This exchange was developed to relate to the use of the building. It has been found that the most convenient and optimal solution for office buildings that work 15 hours a day is to use EAHE. When the inlet's outside temperature is 15-22°C, the system can be controlled by the outside air temperature or the mass [5]. Ozgener, used analytical and empirical analysis of EAHE systems. This study focused on EAHE systems comprising pipelines in different combinations: closed-loop and open-loop buried. Using a fan of adequate capacity and size, the air is drawn through the buried pipes [6]. Liu et al., used a comprehensive numerical method on mass coupling and heat transfer. The heat exchanger (EAHE) analysis is performed using a self-compliance program based on the finite volume method. He also studied the moisture present in the vicinity of the pipe, the thermal properties, and their effect on the evaluation of EAHE's performance using a two-dimensional simulation model to perform the analysis. And also building an actual model to verify EAHE by taking empirical data, which showed good convergence as a result of comparing them. The results of the numerical study showed that the moisture distribution is radial and that this peak gradually decreases away from the tube. The researchers also concluded that thermal conduction performance in the soil is better than pure conduction [7]. Qi et al., developed to evaluate the effect of condensation and humidity on thermal performance, and this study developed three-dimensional fluid dynamic (3D-CFD) computational models adopted in this study. The effect of the relative humidity of the incoming air in each tube was studied. Flow volume and average temperature were analyzed. According to the results reached in this study, condensation has few effects on the rate of uniformity of airflow distribution of the geothermal heat exchanger to air, while it affects thermal performance. Also, small-diameter tubes can Condensate more easily [8]. Mohammed et al., used a solar chimney (SC) with a geothermal heat exchanger (EAHE); this method was used to remove unwanted heat inside the building during the hot season. This study was conducted using the numerical program "FLUENT" to analyze the Earth-to-air heat exchanger (EAHE) model to determine the possibility of cooling devices and the temperature of the outside air in the Basra climate. The study was conducted using theoretical analyses. We also verify the feasibility of cooling ground pipes for thermal comfort in Basra. Searching for a passive cooling alternative to air conditioning. The earth's soil was used as a heat sink to produce cooler air. A working soil temperature model was adapted using Basrah climatic conditions, and its outputs were compared with the CFD model. Earth Pipe's ability to obtain a lower output temperature of the air inlet to the room [9]. Ginestet et al. used ground air heat exchangers, considered one of the modern ways to solve the problems of energy consumption and comfort problems in buildings. This study aims for the thermal performance to be checked and done. The solution uses the numerical model and an empirical ocean climate [10]. Pfafferott, developed with performance analysis. Three EAHXs for office buildings in central European climatic conditions, the study aimed to describe the efficiency, compare the results with the practical case, describe the temperature behavior over time, and determine the rate of energy consumption reduction [11]. Liu et al., developed the thermal performance of EAHE in summer, winter, and cold winter regions. An experimental model for EAHE has been studied in Changsha, China. The focus was on several variables, including air temperature, soil, and outdoor air, and those values were taken for one week. The thermal performance was known through an analysis of these data. The results of this study showed that the inlet air temperature reached the soil temperature for a 20-meter-long pipe. The heat transfer rate increased as the tube length increased and decreased with the increased temperature of the supplied air [12]. Raczkowski et al., presented a numerical simulation of a model, which was done by solving the partial differential equations of a three-dimensional heat transfer model. This simulation was done using CFD technology. The modelling was done by taking several temperature values in the winter season, ranging from -24 to -8 degrees Celsius). This study found a linear relationship with EAHC calculations according to the Polish National Standards Agency for Energy Conservation (NAPE). The temperature divergence rate from the NAPE standards was calculated using the CFD model, which was equal to 0.59. This showed that the efficiency of the exchanger was less [13]. Yu etal., presented a geothermal cooling system with a geothermal heat exchanger and a solar collector. Experiments were conducted using a model and tested in the summer to show the system's performance in terms of heat capacity. In 43 days in a series, three different tests were performed, from passive cooling mode to active and then back to passive mode. The results showed that providing the necessary cooling for the building without electricity is possible. The solar collector provided more airflow to the system during the day. As for the results in terms of thermal sensation, they depended on the percentage between the total vote and the dissatisfied people. It showed that thermal comfort was more acceptable when the airflow was natural than forced flow. The results also showed a decrease in the efficiency of cooling coupled quickly after a week due to the increase in soil temperature. The soil also needed two weeks to return to its natural state and remove the heat. The study also showed that the horizontal direction disperses heat at a higher level than the vertical [14]. Niu et al., developed a comprehensive performance analysis, and a one-dimensional model was built and used to simulate the performance of EAHE. This study combined heat and mass transfer between tube and air. These models and their results were compared with experimental results from the existing renewable energy testing facility. Six factors that have been focused on in terms of their impact on performance are air temperature and air velocity Inlet EAHE, relative humidity, tube length and diameter, and tube surface temperature, and the study concluded to obtain capacitances including total, latent, and reasonable cooling capacity with high accuracy [15]. Al-Ajmi et al. developed a theoretical ground-air heat exchanger (EAHE) model to know the temperature of the air leaving the model, the cooling performance, and the capacity of these devices in hot and dry climates. The results of the model presented in this study were compared with the published models and showed great agreement. This model is made in Kuwait conditions. A typical Kuwaiti housing model was built, and the models were applied. They were encrypted in a TRNSYS-IIISIBAT environment. A typical meteorological year for Kuwait was also relied upon. The results of this study showed that a decrease of 1700 W operates at a higher cooling load, as well as a decrease in the internal temperature of 2.8 °C in summer at peak hours in mid-July. It also reduced the demand for cooling in a typical home to 30% [16]. D. J. Harris, provided an overview of the cyclical variations in subsurface temperature with depth for soil conditions in Kuwait. Based on the Lab's equation for geothermal temperatures, create the profile. This considers the soil's thermal and physical qualities [17]. Lattieff et al. evaluated the performance and efficacy of an EHX design in a sandy soil location in Baghdad, Iraq. The climate in the region is subtropical semi-humid. Temperatures in the air and soil were measured. During the months of 2021.The EHX was discovered to be functional and effective, with potential energy savings for cooling and heating equipment under various weather situations [18]. M. Y. Taib et al., The wide use of GHE for greenhouse cooling and comfort is covered in the paper. This report also reviews the geothermal variation employed in various studies as a crucial step in identifying prospective GHE applications. The GHE's design and performance elements were also examined. This study summarizes the advantages and possibilities of using GHE for cooling applications in Malaysia's climate to lower building energy usage and greenhouse gas emissions [19]. Peretti et al., conducted literature research to examine the design and features of earth-to-air heat exchangers and if they might be combined with HVAC systems. Various projects were evaluated to collect and synthesize design recommendations [20]. Puri et al., suggested an unstable model of two differential equations displaying the coupled and simultaneous transfer of moisture and heat in the soil for a single EAHE, assuming that soil moisture and temperature around the tube were initially constant. In contrast, the tube's presence at a large axial distance boundary unaffected ground temperature distribution and moisture content. These researchers discovered that soil temperature profiles change quicker than moisture content profiles [21]. Bojic et al., created a set of linear equations characterizing the thermal efficiency of an EAHE system for cooling and heating a building. The EAHE system's mathematical model comprises steady-state heat balance equations applied to each soil layer, assuming the soil is separated into layers with homogeneous temperature values. It estimated its energy requirements and the part of the EAHE system to these requirements [22]. Abdula, estimated the geothermal temperature of various parts of Iraq [23] and [24], based on the estimation of the geothermal temperature in the center of Iraq, represented by the city of Baghdad, the subject of this study. R. Molina et al., presented an experimental study of the thermal performance of an earth-to-air heat exchanger of the "U" type. The apparatus is vertically configured and serially coupled. With an installation area of 3 m 2, the wells where tubes were placed are spaced 1.5 m apart and have a depth of less than 3 m. In March, when the temperature outside hits 35 °C throughout the day, the experiment was conducted in Morelos, Mexico. To replicate the space constraints present in urbanized regions, the device's performance was assessed and compared to the specifications of an office for cooling purposes within a university campus. The gadget reached a maximum efficiency of 88.4% and COP of 12.8. These findings concluded that the system can cool spaces with limited space. This work was interesting because it compares the thermal requirements of an office with the dimensions that can be installed in metropolitan areas. Moreover, no documented works utilizing vertical heat exchangers joined in series have been found [25]. M.H. Ali etal., used MATLAB/Simulink model to efficiently build Earth-to-Air Heat Exchangers (EAHEs) and anticipate the spread of soil temperatures. Four EAHE setups are compared: systems with single-pipe, multipipe, multiple-single pipes (MS-pipes), and twisted-single pipes (TS-pipes). The suggested model is simple to modify to get the final design and has been validated with trustworthy outcomes. According to the results, the MS pipe EAHE has superior cooling potential and better pressure losses. With a cooling potential of 1626 W in August and 129.8 W in March, the study demonstrates the great efficiency of the EAHE installation in Kufa, Iraq. Furthermore, by providing an equation, the paper illustrates how the geometric arrangement of EAHEs affects their flow behavior and thermal efficiency [26]. A. Aranda et al., studied parametrically using numerical models based on CFD and the finite volume approach. The analysis of the geometric factors to identify those that have the biggest influence on the application potential of GAHE comes after the numerical code created using published experimental data has been validated. The analysis included climatological factors, including relative humidity, airflow velocity, and inlet air temperature, in addition to the rise in soil thermal conductivity caused by dampness.

Furthermore, investigated the ideal installation depth and the length of the thermal insulation in the GAHE output pipe [27]. According to a thorough review of the literature, the EAHE is affected by a variety of factors, including inlet air temperature, moisture, soil temperature, the diameter of pipe and length, burial pipe depth, soil thermal conductivity, air flow velocity, and so on Many studies use various strategies to improve these characteristics. The diameter and length of the pipe, as well as the air velocity, were fixed in this investigation. The variation in inlet air temperature was determined based on the time of year, with a study of different pipe depths in the soil throughout the year to determine the maximum heat transfer rate to cool the buildings and reduce the cooling load. And, especially in the summer, the best temperature drops for the outside air. The results of this research can be used in designing the heating, ventilation, and air conditioning (HVAC) system by focusing on the best depth of study and thus enhancing the efficiency of overall performance and heat transfer in various buildings. Implementing it in buildings makes them energy efficient through concentration that reduces operating costs and energy consumption for building owners. It invests in sustainable construction operations through infrastructure development, urban planning, and creating sustainable and environmentally friendly cities, including all industrial, residential, and commercial complexes. In addition, existing buildings can be rehabilitated by addressing the development and upgrade of heating, ventilation, and air conditioning (HVAC) systems to reduce operating costs without modifying extensive structures.

2. Mathematical modeling

Implementing ground heat exchangers demands knowledge of temperature variation with different depths. Also, the properties of the soil. The major benefit of soil is keeping it at a constant temperature throughout the year. This feature can be used and hosted to reduce energy use. As shown in the figure. 1, an earth-air heat exchanger (EAHE) concept is fairly basic. Soil can be classified into three zones depending on depth [19].

- Depth about 1m.
- Depth from 1m to 8m.
- Very large depth of 8 to 20m.

Niu et al., (2014) investigated a mathematical model depending on the conduction of heat theory. The final equation at a certain depth and time $T(z,t)$ can be given in the following [15].

$$\mathbf{T(z,t) = T_m - [A_s * e^{\left(-z\left(\frac{\pi}{365*\alpha}\right)^{0.5}\right)}] * \cos\{\left(\frac{2\pi}{365}\right)[(t - t_o) - \left(\frac{z}{2}\right) * \left(\frac{365}{\pi\alpha}\right)^{0.5}]\}} \quad (1)$$

Thermal diffusivity of the ground ranges from 0.042 to 0.1 (m^2 / day) as Typical thermal properties of selected soils and rocks [28]. T_m, A_s, and t_o can be determined from a city weather station. In the present study, the local ambient temperature obtained from (The Meteorological Service of Iraqi for the city of Baghdad) showed that the mean temperature of the soil surface (Tm) and amplitude of surface temperature variation (A_s) will be (28), and (14). So, from the above requirements, the resulting equation to determine the ground temperature at a certain depth and time (Tz,t) for Baghdad in Iraq is expressed below.

$$\mathbf{T(z,t) = 28 - [14 * e^{(-za)}] * \cos[\left(\frac{2\pi}{365}\right)(t - 33) - za} \quad (2)$$

Where

$$\mathbf{a = \left(\frac{\pi}{365 * \alpha}\right)^{0.5} = 0.415} \quad (3)$$

The quantity of heat energy exchanged between the air inside the EAHE and the soil is also represented by the rate of heat transfer in the EAHE. This amount must be determined to evaluate the building's heating and cooling requirements. The heat transfer rate in the EAHE tubes is estimated using the following formula [3];

$$\mathbf{Q = \dot{m}\, cp(T_{out} - T_{in})} \quad (4)$$

The temperature differential between the air entrance and exit is a significant element in enhancing the heat transfer rate and, consequently the efficacy of the EAHE since it impacts the amount of heat that can be transported between the air and the soil. The rate of heat transfer of the ground exchanger is affected by several factors, including the exchanger's design, the rate of fluid flow, and the type of soil (thermal properties), so it is necessary to know that the system contains a rate of heat transfer to meet the required needs of the building. The effectiveness of the EAHE is determined by some parameters, including system design, climate, and soil type (in terms of moisture and pollutant presence). Compared to HVAC systems, the EAHE saves significant energy, especially in places with a substantial temperature variation between seasons and day and night. The equation used to calculate the effectiveness of EAHE under the premise that the temperature of the soil in contact with the exchanger's surface is constant and that the heat transfer coefficient is constant is expressed as follows [3];

$$\in = \mathbf{\frac{T_{out} - T_{in}}{T_s - T_{in}}} \quad (5)$$

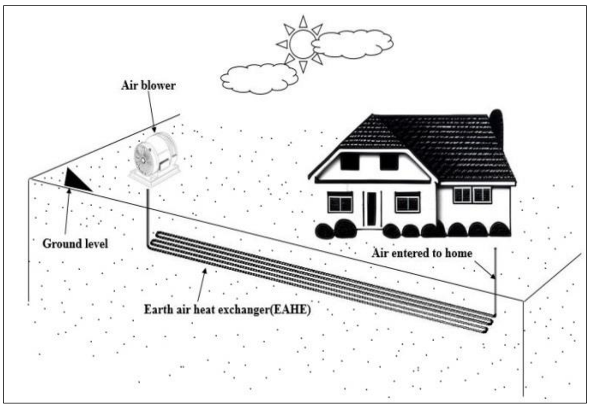


Figure 1. Schematic Diagram of the Process by EAHE

3. Numerical model

Numerical analysis was done using Ansys Fluent software. In the beginning, the model was created.

Then, several mesh tests were conducted to obtain high accuracy in the results for less time and cost of analysis using the computer. The three-dimensional analysis of the heat exchanger was used. The governing equations, which are the continuity, momentum, and energy equations, were adopted for the analysis [29].
Conservation of a mass can be expressed as:

$$\nabla.\vec{v} = 0 \quad (6)$$

The energy equation can be written as follows;

$$P(\frac{\partial e}{\partial t}+(\vec{v}\cdot\nabla)E)=-\nabla\cdot(P\vec{v})+\nabla\cdot(K\nabla T)+Q+P\vec{v}\cdot G+\vec{v}\cdot F \quad (7)$$

Momentum equation can be written in the form;

$$\rho\left(\frac{\partial\vec{v}}{\partial t}+\vec{v}.\nabla\vec{v}\right) = -\rho g - \nabla p + \mu\nabla^2\vec{v} \quad (8)$$

Air is modelled using the viscous k-epsilon (k-∈) [30] realizable turbulence model and is regarded as an incompressible ideal gas. Two equations were solved for the type used in this study, turbulent kinetic energy k;

$$\frac{\partial(\rho k)}{\partial t} +\nabla\cdot(PK\vec{v})= \nabla\cdot[(M+\frac{\mu_t}{\sigma_k})\nabla K] +P_k - E \quad (9)$$

And for turbulent dissipation rate ε;

$$\frac{\partial(\rho\varepsilon)}{\partial t} +\nabla\cdot(PE\vec{v})=\nabla\cdot[(M+\frac{\mu_t}{\sigma_\varepsilon})\nabla E]+C_{\varepsilon 1}P_k-C_{\varepsilon 2}\,\rho\,\frac{\epsilon^2}{k} \quad (10)$$

The analyzed physical model is a coil-design heat exchanger with polyvinyl chloride (PVC), with other important specifications listed in table 1. Due to the very thin pipe utilized in the EAHE, the material's minimal thermal resistance is caused by this. The distribution of soil temperature at different depths was found numerically by fixing the upper surface of the soil with the temperature for each month of the year being studied, as well as determining the temperature of the lower surface of the soil, which is represented by the geothermal temperature, which is determined according to the study site. In this study, due to the lack of specific information for the region, it was estimated based on different studies listed in table 2, which determined the mean of the highest geothermal temperature for different locations in Iraq. Therefore, through these values, the groundwater temperature was estimated for the central regions of Iraq, represented by Baghdad, by taking the highest values among the values mentioned for study and analysis. The temperature around the pipe's surface was described as equal to the undisturbed temperature calculated of the earth and varied with soil depth in Baghdad. In this study, the average surrounding temperature during 2021 and 2022 for Baghdad city in Iraq of the air was taken from [32] for all months in the year. Figure 2 shows the variation in the surrounding temperature over the year under Baghdad's climatic conditions. The outside temperature varies between 20 to 50°C, indicating a large variance in air temperature. Furthermore, the highest and coldest months for air temperature were noted in Aug. and January, respectively. Inlet temperatures in the city of Baghdad vary according to seasons in Iraq. The thermal and physical properties of different materials used in this numerical simulation are listed in table 3 [31].

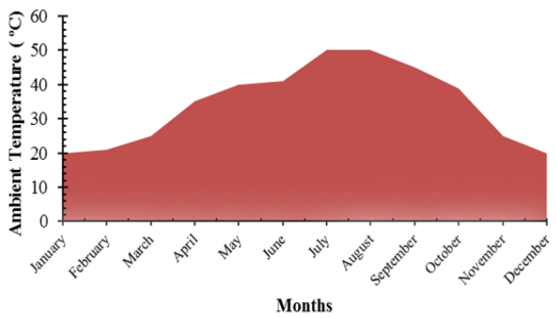


Figure 2. Ambient Temperature for Baghdad City in Iraq [32].

Table 1: EAHE system specifications

Variable	Symbol	Value (Units)
Tube length	L	50 m
Tube diameter	D	2 Inch
Tube depth	Z	0 m to10 m, increasing by 1m
Volume flow rate	Q	200 m^3/hr

Table 2: Geothermal temperature at different locations

Geothermal temperature		
Location	**Value (Units)**	**Reference**
Northern Iraq	29.2 °C/km	[23]
The western desert of Iraq	26°C/km	[24]
Mosul	28°C/km	[23]
Kirkuk	25°C/km	[23]

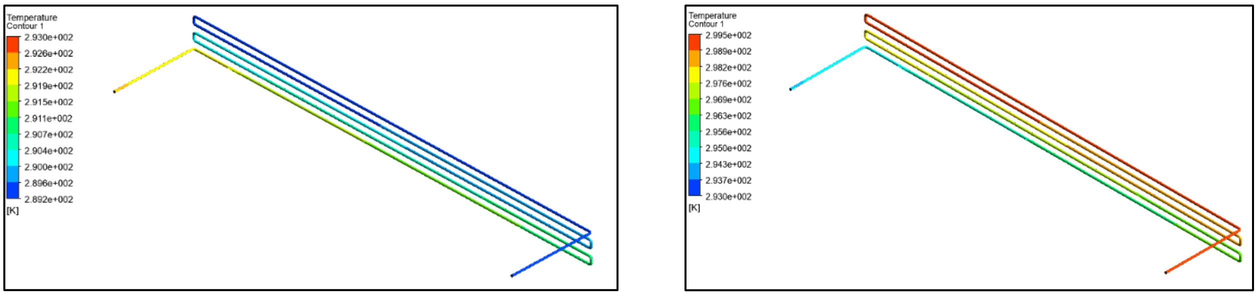
Table 3: Thermal and physical properties used in the model [31]

Material	Density (Kg/m^3)	Specific heat capacity(J/kg.K)	Thermal conductivity(W/m.K)
Air	1.225	1006	0.024
PVC	1380	900	0.16
Soil	2050	1840	2.806

4. Results and discussions

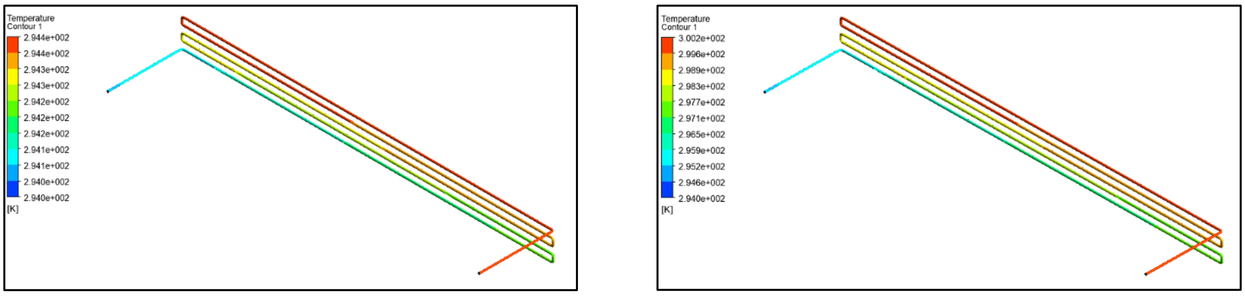
Discuss the results obtained theoretically from equations in mathematical models and numerically. A Microsoft Excel spreadsheet has been used to facilitate theoretical calculations. Outlet air temperatures at different depths were calculated for all seasons, with ambient air temperature for each month numerically. The samples of simulation results are shown in figures 3 to 11, showing temperature distribution along the pipe with the depths for different months.

Figure 3(a) shows the air temperature distribution inside the earth air heat exchanger tube at a depth of 0 m from the ground surface during January. The temperature of the inlet air is 20ºC. The temperature at the soil surface is lower than the temperature of the air entering the exchanger due to weather factors such as humidity, rain, etc. This causes the surface of the soil to have a lower temperature. As the air passes through the pipe, its temperature decreases. Figure 3(b): At a depth of 5 m, a large heat transfer is observed as a result of the difference between the soil temperature at this depth, which is higher than the temperature of the inlet air, leading to an increase in the air temperature by about 6.5ºC at the pipe outlet of the EAHE. Figure 4(a) shows the air temperature distribution inside the EAHE tube at a depth of 2 m from the ground surface during February. The inlet air temperature is 21ºC. It was noted that the heat transfer rate is low due to the small difference between the temperature of the inlet air and the soil at this depth, with an increase of 0.4ºC for the air coming out of the ground exchanger. Figure 4(b), in the same month and at a depth of 7 m, there is an increase in the heat transfer rate between the soil and the incoming air due to the difference in temperature, with an increase of 6.2ºC for the air leaving the ground heat exchanger. Figure 5(a) shows the air temperature distribution inside the heat exchanger tube at a depth of 1 m from the ground surface during March, and the inlet air temperature is 25ºC. It is noted that the temperature of the outlet air decreases by 0.5ºC. The reason is due to the nature of the soil and its influence on humidity, rain, and other factors at this depth. At a depth of 9 m, as in figure 5(b), there is a slight increase in the temperature of the outlet air by 3.7ºC, and this is due to the relatively small difference between the soil temperature and the air temperature entering the exchanger during this month. It is clear from the previous figures that the efficiency of the exchanger at different depths in raising the temperature of the air leaving the exchanger is very low during the first three months of the year. Figure 6(a) shows the air temperature distribution inside the exchanger tube during April. The inlet air temperature is approximately 35ºC at a depth of 3 m from the ground surface. The heat transfer rate from the incoming air to the soil is rather large due to the temperature difference between them, which decreased the air temperature by 8.7ºC between the outgoing air and the inlet air into the exchanger. Figure 6(b) shows the thermal distribution at a depth of 10 m, which led to a decrease in the temperature of the air leaving the exchanger by about 6.4ºC. When comparing these two depths, it is noted that the soil temperature increases with increasing depth, and the cooling efficiency decreases when the soil depth increases significantly. Figure 7(a) shows the temperature distribution inside the tube of the ground heat exchanger. At a depth of 4 m for May, the inlet air temperature is about 40ºC. It is observed that the temperature of the air leaving the exchanger is lower by 12.1ºC than the air entering the exchanger. This is due to the large difference in air temperature from the soil, leading to a higher heat transfer rate. At a depth of 7 m, as shown in figure 7(b), there is stability in the rate of temperature difference compared to depth 4. Here, it indicates the stability of the soil temperature, and the difference in soil temperature at different depths becomes small due to the increase in temperature due to heat storage in Those depths. Therefore, a depth of 4 m is sufficient for this case. Figure 8(a) shows the temperature distribution inside the tube of the heat exchanger at a depth of 0 m from the ground surface for June, and the inlet air temperature is 41ºC. The temperature of the air decreases as it passes through the exchanger by a rate of 0.9ºC at the outlet of the exchanger because the temperature of the soil surface is lower than the temperature of the entering air. At a depth of 4 m, as in figure 8(b), a temperature decrease of 11.4ºC is observed as a result of the rate of heat transfer between the incoming air and the soil being relatively large due to the temperature difference. It is also noted from the results that at a depth of 4 m and for May and June, respectively, the temperature reduction rate is very similar. This is due to several factors, including the stability of the soil temperature at this depth as well as the small difference in temperature of the incoming air between these two months. Figure 9 (a & b) shows the temperature distribution inside the ground heat exchanger tube during August and at a depth of 1 and 8 m, respectively. The inlet air temperature is 50ºC, and the outlet air temperature decreases by 12.8ºC and 20.2ºC, respectively. This is due to soil and air's relatively large heat transfer rate. Figure 10 (a & b) shows the temperature distribution inside the EAHE during September, at a depth of 3 m and 8 m, respectively, with an inlet air temperature of 45ºC. It showed a decrease in the temperature of the air leaving the exchanger by 11.5ºC and 15.2ºC, respectively. Figure 11 (a & b) shows the temperature distribution inside the EAHE tube and the temperature of the inlet air at 39ºC and at a depth of 1m and 10 m, respectively, with a decrease in the temperature of the air, leaving the exchanger by 10.9ºC and 10ºC. The difference is small as the temperature decreases and at different depths due to storing heat in the soil during the summer because the soil has the advantage of storing and releasing heat slowly. Hence, the soil at a certain depth needs a longer time to be affected by the outside air temperature. It is also observed from the previous forms that during the hot months of the year, the temperature of the outside air decreases compared to the inside. This means that there is an increase in cooling efficiency. It was also noted that the heat transfer rate between air and soil at the beginning of the pipe is very large and then gradually decreases throughout the length of the pipe.



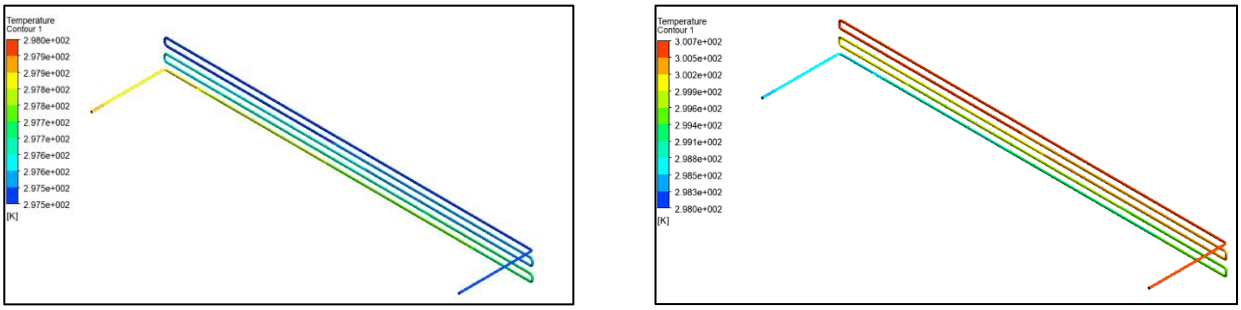
(a) **(b)**

Figure 3. Temperature variation for Jan. month (a) 0 m depth (b) 5m depth



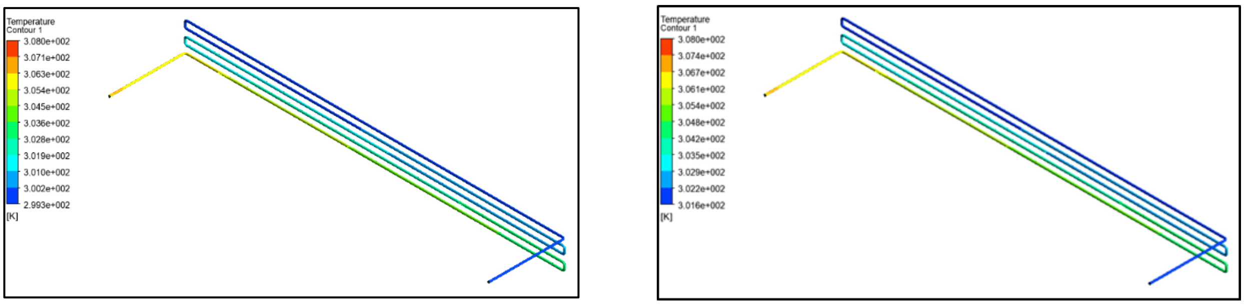
(a) **(b)**

Figure 4. Temperature variation for Feb. month (a) 2 m depth (b) 7 m depth



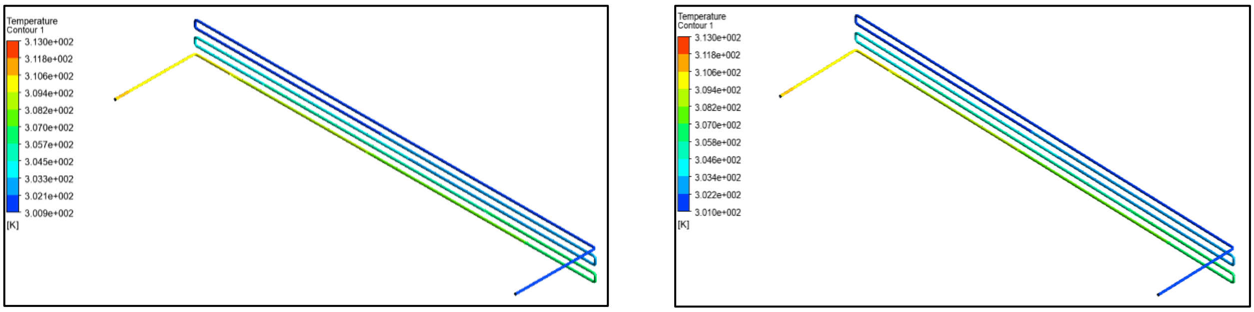
(a) **(b)**

Figure 5. Temperature variation for March month (a) 1 m depth (b) 9 m depth



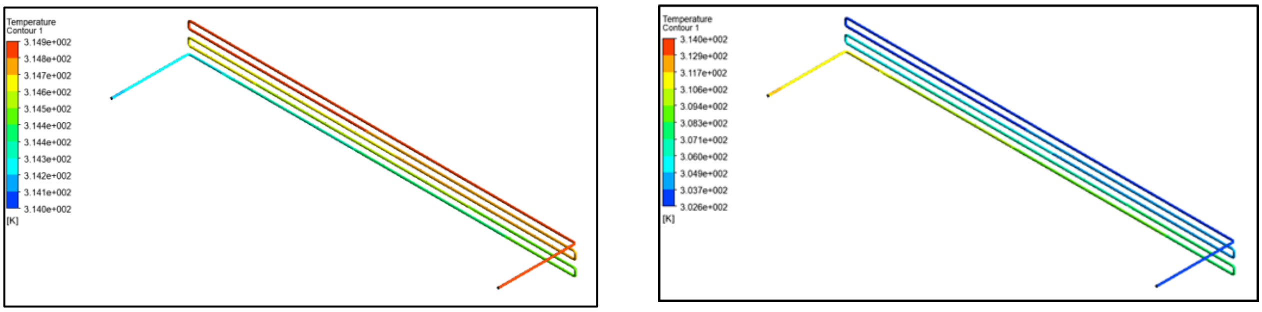
(a) **(b)**

Figure 6. Temperature variation for Apr. month (a) 3 m depth (b) 10 m depth



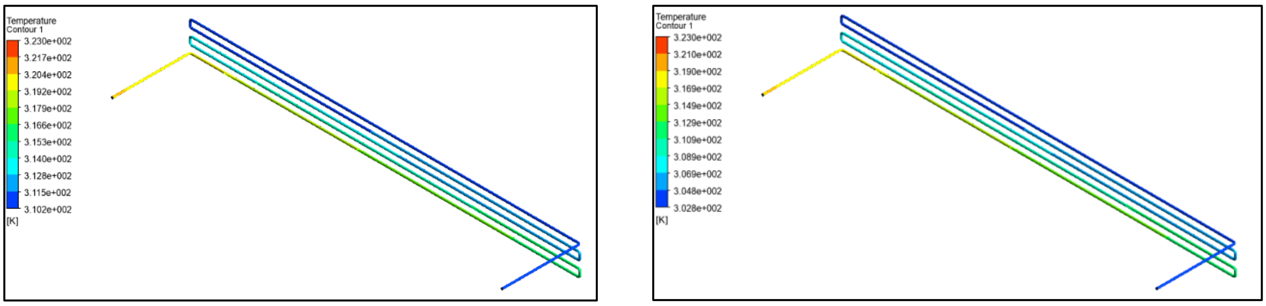
(a) **(b)**

Figure 7. Temperature variation for May. Month (a) 4 m depth (b)7 m depth



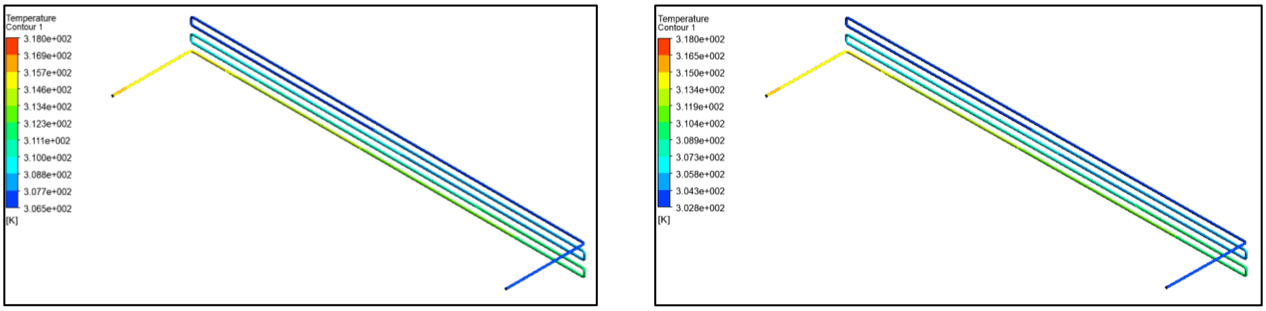
(a) **(b)**

Figure 8. Temperature variation for Jun. month (a) 0 m depth (b) 4 m depth



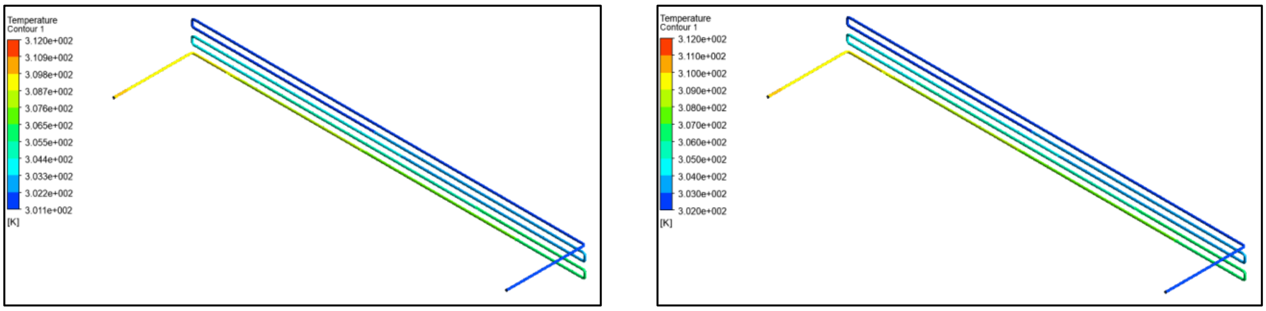
(a) **(b)**

Figure 9. Temperature variation for Aug. month (a) 1 m depth (b) 8 m depth



(a) **(b)**

Figure 10. Temperature variation for Sep. month (a) 3 m depth (b) 8 m depth



(a) **(b)**

Figure 11. Temperature variation for Oct. month (a) 1 m depth (b) 10 m depth

Figure 12 shows that the outlet temperature changed from 15 ºC to 42 ºC at the earth's surface along the year and became constant at a depth equal to 7 m. The greatest ambient air temperature is recorded in the July and August months, reaching 50ºC; at a soil depth of 6 m, the outlet air temperature from EAHE drops and reaches around 30ºC. Similarly, the temperature of the air departing the exchanger is greater than that of the air entering it for the first three months and the last two months of the year. Figure. 13 shows the earth's temperature distribution over the year for different depths from 0 m to 10 m. The greatest soil temperature was recorded at a depth of 10m in January, February, March, November, and December, respectively, while the lowest temperature begins at a depth of 6 to 10m in April, May, June, July, August, and September. It has been found that the surface temperature substantially impacts the temperature of the top layer of the ground at a depth of about 1 to 3 m. Still, that impact decreases as ground depth increases. Starting at a depth of 6 meters, the change is essentially consistent and extremely small.

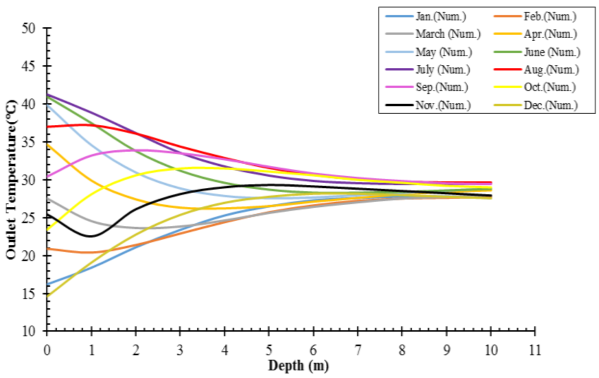


Figure 12. Outlet Temperature for Different Depths and Time

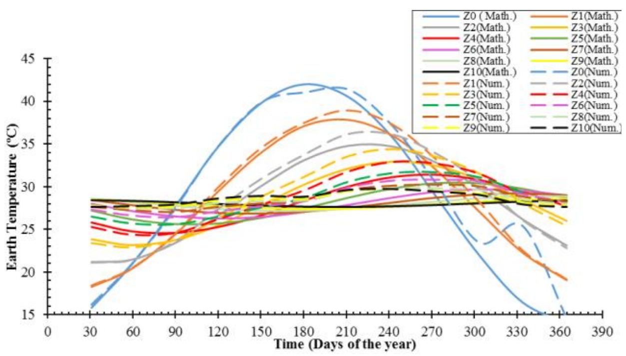


Figure 13. Earth Temperature for Different Depths and Time

Figure 14 shows the heating rate throughout the year for different depths from 1m to 10m. The fact that the heat transfer rate is negative indicates that the air moving through the system is hotter than the earth around the EAHE. It is employed for cooling purposes in this_period because heat is transferred from warmer air to colder soil, acquiring air outside the system at a lower temperature and using it for cooling. When the positive sign of the heat transfer rate illustrated in the figure is present, the reverse occurs. Furthermore, the 4 and 5 m depths yield the best results for the heat transmission rate for such a design and the climatic and soil conditions, after which it stabilizes at higher depths. The heat transfer rate from the air to the soil for cooling purposes was maximum during the year's warm months: Apr., May, Jun., Jul., Aug., and Sep. The value began to settle at a depth of 6 m, with the greatest value recorded in July at -1375 watts. The maximum heat transfer rate from the earth to the air for heating purposes was discovered during the cold months of January, and it amounted to around 579 watts at a depth of 10 m and 499 watts at a depth of 6 m. Figure. 15 shows the effectiveness of EEHE along the year with different depths. The effectiveness of the EAHE varies throughout the year and at the same depth under the ground due to changes in the air and soil temperature. The system's effectiveness is greatest at depths of 4 and 5 meters. It is also mentioned that the system's effectiveness varies dramatically depending on the depth in the early months of the year, roughly during the first 120 days and the last 60 days. In addition, the system's effectiveness is stable during the remaining days of the year and at different depths of the exchanger pipes. Furthermore, the two previously indicated depths are appropriate for minimizing cooling demands from the remainder of the system. At a depth of 4 m, an increase in EAHE effectiveness of 0.98 was demonstrated on the 90th day of the year. This appears due to the slight difference between the temperature of the incoming air and the soil during the spring. This is due to several reasons, soil can release and store heat slowly, this results in a delay in the heat transfer process, as the soil at a certain depth takes longer to be affected by the change in air temperature. There is also a change in weather factors, including sunlight, temperature, and rain; the surface soil layers are greatly affected. Moreover, due to the seasonal shift, the ground retains some heat accumulated at this depth, and the difference is very small in this season. This lead the actual temperature difference achieved by EAHE asymptotic to the maximum possible temperature change in this season, resulting in the exchanger performing as high as possible.

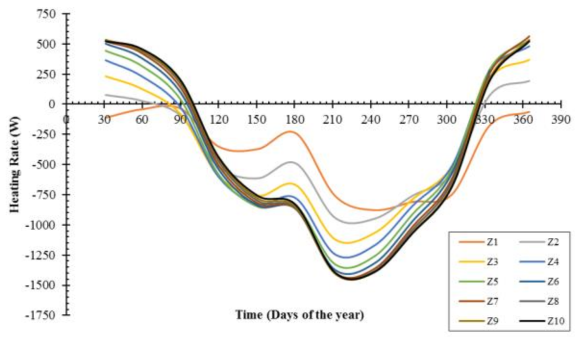


Figure 14. Heating Rate for Different Depths and Time

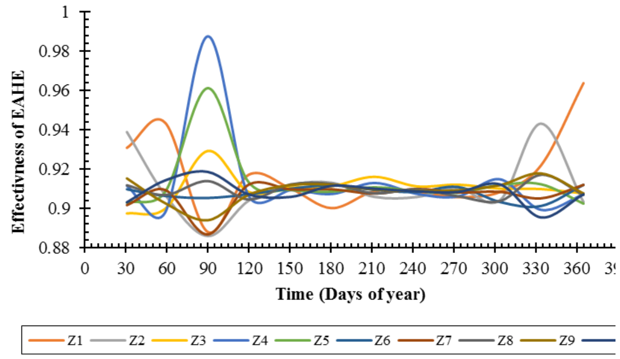


Figure 15. Effectiveness of EAHE for different Depths and Time

5. Verification of results

The numerical solution developed was verified using CFD, and the results showed good accuracy for the mathematical model and numerical analysis; the mean percentage deviation ranged between 1.3 -3.6% for depths from 1m to 10 m. At a depth of 0 m, the results showed a large deviation of up to 6.3%. This is due to several reasons, including the difference in the properties of the soil near the surface compared to the deeper layers and that the mathematical solution relied on values measured by the Meteorological Authority, while the numerical solution, to simplify it, was assumed The soil properties are constant at all depths. Also, the measured values are likely affected by the thermal convection on the surface. At the same time, this was neglected in the numerical solution, thus resulting in this difference in surface temperature, as shown in the figure. 16. The numerical and mathematical EAHE model presented in this investigation was validated against two studies: one theoretical (D. J. Harris, [17]) for three depths 2, 4, and 6 m. and other experimental (F. A. Lattieff, [18]) for 4m depth only. Figure 17. shows the comparison of the models and the difference between the predicted subsurface temperature.

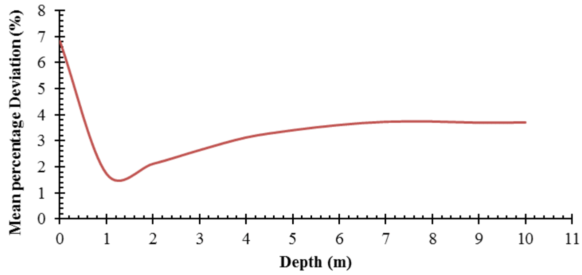


Figure 16. Mean Percentage Deviation for Different Depths

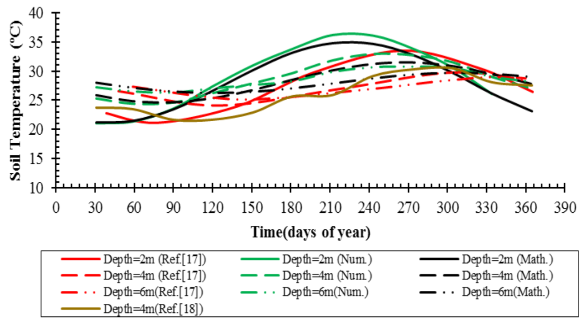


Figure 17. EAHE models presented Vs. D. J. Harris, [17] and F. A. Lattieff, [18]

6. Conclusions

A numerical and mathematical study was conducted to determine the effect of soil depth on the performance of the heat exchanger in hot and dry climates and for hot and cold months throughout the year in Baghdad, Iraq. After analyzing the results, it was noted that, for January, Feb., March, April, Aug., Sep., Oct., and Dec. months, the best outlet air temperature from EAHE were 300, 299.6, 299.4, 300, 303.6, 303.7, 304.7, 301.2, ^{o}k respectively, at a depth of 6m when the ambient temperature were 293, 294, 298, 308, 323, 318, 312, and 293 ^{o}k respectively. Also, for May, June, July, and November months, the best outlet temperatures were 300.6, 300.7, 303.6, and 302.3 ^{o}k, respectively, at a depth of 5 m when ambient temperatures were 313, 314, 323, and 298 ^{o}k, respectively. This was reached to conclude that the optimum depth that gives the constant temperature at all months along the year for Baghdad city in Iraq at different ambient temperatures is 6 m. At 6 m, the average temperature calculated numerically and theoretically is 27 ºC throughout the year. In July, the maximum heat transfer rate for cooling purposes was -1375 watts at a depth of 6 m. In January, the maximum heat transfer rate for heating purposes was 579 watts at a depth of 10m, followed by 499 watts at a depth of 6m. The maximum value of ground heat exchanger effectiveness was found at depths of 4 and 5 m in January, February, March, November, and

December. It was between 0.96 and 0.98. Furthermore, the EAHE effectiveness value is consistent over April, May, June, July, August, and September, ranging from 0.88 to 0.91.

7. Nomenclature

$T(z,t)$	the Earth temperature (°C) at soil depth (z) after t days from 1 January
T_m	average temperature of the soil surface (°C).
A_s	the amplitude of surface temperature variation (°C).
z	depth of soil (m).
α	thermal diffusivity
t	time elapsed from the beginning of the year(day)
t_o	A phase constant (day) since the beginning of the year of the lowest average ground temperature (day).
$\dot{m}$	mass flow rate of air in kg/s
cp	specific heat in J/kg.k.
T_{out} ,T_{in}, and T_s	are the outgoing temperature, the temperature of the incoming air, and the temperature of the soil surrounding EAHE, respectively.
ρ .	density
t	time
∇,	del operator
$\vec{v}$	velocity vector
P	pressure
μ	dynamic viscosity of the air
∇^2	laplacian operator
g	acceleration due to gravity
F	external forces
e	total energy per unit mass of the air, including internal energy, kinetic energy, and potential energy
K	thermal conductivity
T	temperature
∇T	gradient of temperature
q	heat source or sink term
k	turbulent kinetic energy,
σ_k	turbulent Prandtl number for turbulent kinetic energy
P_k	Production of turbulent kinetic energy
ε	turbulent dissipation rate
σ_ε	model constant related to the turbulence Prandtl number
$C_{\varepsilon1}, C_{\varepsilon2}$	Constants turbulence model

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