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Investigating the Effects of Disturbed Soil Thickness on the Performance of Earth-Air Heat Exchanger

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ABSTRACT

The heat exchanger, which connects the Earth with the air, dramatically streamlines the process of heating and cooling buildings while conserving energy. This study quantitatively examines an Earth-Air Heat Exchanger (EAHE) natural ventilation system that serves the dual purpose of heating and cooling. The study's objective was to investigate the potential impact of varying thicknesses of disturbed soil on the efficiency of (EAHE) under varied pipe lengths and flow velocities. The study was conducted at Nasiriya, a city in southern Iraq, utilizing computational fluid dynamics (CFD) to analyze the meteorological conditions. The study findings revealed that, about the pipe diameter, if it exceeds a specific threshold, variations in wall temperature do not have any additional impact on it. While at 0D thickness, it was found that at high speeds with varying lengths, the air temperature inside the pipe increases due to the lack of sufficient time to exchange heat with the undisturbed soil. However, at low speeds, the air temperature inside the pipe begins to decrease as the length of the pipe increases due to the longer period of air remaining inside the pipe. The wall temperature remains constant at low speeds regardless of variations in flow velocity and pipe length at the soil thickness from 1D to 6D Due to the increased thickness of the soil, which is considered disturbed soil, affected by the ocean temperature. The wall temperature equals the soil temperature, but the higher speed amplifies the differential and causes the wall temperature to deviate from the soil temperature. Although the soil on the wall is shallow, the temperatures in such locations correspond to the temperature of the soil.

1. INTRODUCTION

The problem that the research aims to solve is to find an environmentally friendly alternative method for generating cooling through the development of an environmentally friendly ground heat exchanger at a lower economic cost, which reflects positively on reducing electricity consumption as a result of current methods and the fact that these methods have high economic costs, as the research included the continuous effect of soil thickness on the heat exchanger and its extent. Its effect on changing air speed and pipe lengths.

Geothermal energy, being an applaudable renewable energy source, can help attain the goal of reducing energy consumption and carbon emissions by the buildings. AIR EAHEs are active solar systems that can be cheaply maintained during summer and winter, decreasing energy costs [1]. They have a very compact footprint and are primarily designed to keep heat exchange with air and land. The EAHE technology transfers the thermal energy from the above-ground pipes to underground heat exchanger pipes. In winter, the pipes strip off cold air heated by the Earth's temperature. In summer, the soil heats up, cooling the warm air before entering the structure and undergoing circulation. The EAHEs can be set up to work correctly with different types of architectures and during all-weather occasions. Moreover, the realm finds its best roles in places that are the champions of the extreme winter and efficient summer seasons.

Earth-air heat exchangers are conditions induced by the air entering a building for ventilation using a stable temperature from the Earth [2]. This system is often buried in the ground and connected to a blower with yet another end exposed to the open air. However, as their functions may vary, Earth-Air Heat Exchangers can effectively lower the energy consumption in buildings, improve air quality, and de-condition the air. Nevertheless, since different ground conditions, climate, and building usage apply to every situation, installation must be carried out smoothly. Leaving the application of EAHEs alone, the one that offers the most effective and non-active energy source for providing the required conditions within a building can promote energy savings. Doing this will help to cut the amount of energy consumed, enhance the air quality of the inhabitants, and represent the best alternative for the regions with a more significant difference between the day and night temperature. Practical allocation and installation are mandatory to ensure the system operates as this is designed to consider factors like soil type, buried pipe depth, and the system size in the building concerning heating and cooling demands.

Numerous scholars have explored the effective utilization of (EAHE) in combination with buildings, demonstrating its proficiency in utilizing passive energy to regulate the indoor climate of towers such as:

Rosa et al. [3] presented a numerical assessment of the impact of design parameters on the performance of an open-loop residential buildings in warm-summer Mediterranean environment can benefit from the implementation of an Earth-Air Heat Exchanger (EAHE) system. study focuses on the spacing between pipes, pipe diameter, and airflow velocity. ANSYS-CFX® is used to simulate the system's transient behavior during heating and cooling operation modes. The accuracy of their numerical findings is verified through comparison with experimental data and juxtaposed with previously acquired analytical outcomes. findings indicate that higher airflow velocity reduces the thermal performance of the system, particularly for cooling. Additionally, reducing the distance between pipes from 1m to 0.5m does not compromise the EAHE performance and allows for a 50% reduction in the land area needed for the pipes. The results of their study provide valuable insights into optimizing the design of EAHE systems for energy-efficient residential buildings in warm-summer Mediterranean climate.

Bisoniya et al. [4] presented a quasi-steady state, three-dimensional model developed using computational fluid dynamics (CFD) for simulating an Earth-Air Heat Exchanger (EAHE) system. Thier model was validated against experimental results and used for parametric analysis to investigate the performance of the EAHE system for summer cooling is influenced by the pipe length, pipe radius, air flow velocity and depth of burial. Thier results show that the thermal performance of the EAHE system is mostly influenced by the depth of pipe burial and air flow velocity, rather than the pipe diameter and length. Extending the pipe length beyond 20-30 m did not result in any substantial improvement in performance. Thier authors conclude that EAHE is a powerful passive heating and cooling system technique for buildings and industries. The CFD model can be used to determine the operating parameters and their optimum combinations for a particular application. suggested that the analysis presented this study will provide valuable insights for academics and researchers working in the field of passive building heating and cooling, particularly in relation to the utilization of EAHE systems. Future work includes embodied energy analysis of EAHE systems and calculation of carbon credits earned by them.

Misra et al. [5] analyzed the performance of the (EATHE) and found that those units operated with higher heat efficiencies and consumed less energy than storage systems. "CFD modeling with FLUENT software" gives a micro-level analysis of the EATHE's heat endurance, including the effect of soil properties. One of the main differences between intermittent and continuous operations is that intermittent operations may be the preferred means of generating higher system performance.

Al-Ajmi et al. [6] introduced a theoretical framework of EAHE (Earth-Air Heat Exchanger) and a custom-designed sub-soil temperature model for Kuwait. The conducting EAHE simulation can reduce the cooling needs by 1700W and 30% energy requirements for an average home in Kuwait compared to the traditional way of building. The EAHE cannot cater to air conditioning comfort. Still, it may contribute to energy conservation when used with an air conditioning system, making it a potential energy provider in Kuwait's climatic environment and similar climates, especially in deserts.

One of the standards pointed out the possibility of exploiting the undisturbed Earth's temperature as a natural source for heating and cooling buildings via applying EAHE systems [7]. The compilation of studies from some countries forms the basis of the work, emphasizing those conducted in Indian universities as of 2012. Lastly, they conclude that implementing EAHE systems would help reduce the power used for essential services and the output of CFC and HCFC. This, in turn, may lead to climate change reduction. The ecologically high current system can be integrated with other green energy sources, as shown in this paper. Renewable sources using efficient equipment and technologies will play a huge role here. Energy conservation and the environment will benefit nationally and globally, surpassing India.

Sakhri et al.'s study [8] perfectly illustrated the practicability of outdoor-indoor heat trading with turbo fans in arid areas such as southern Algeria. Heating efficiency was estimated at 7℃ while temperature drop varied between 7℃ and cold days but relied on the local climate. The fact that the EAHE discharges the water with a constant temperature interval even in the winter season, when the temperature is below freezing, highlights the potential of this system. In addition, there is research about two thermal regimes induced by the hygrometric regime and their apparent dependency on external conditions. The total heat output was between 9.1 and 9.8 (W), and the maximum values were between 10:12:00 and 4:00.

Gauthier et al. [9] explored the feasibility of a soil-based heat exchanger-storage system (SHESS) using a 3D heat transfer model, which was validated with collected experimental details. Test results indicated that HVACS are efficient if designed and operated correctly. The key performance factors are air velocity, length, insulation, spacing, and soil moisture. Having pipes buried deeper cranked up daytime energy storage but significantly hampered nighttime recovery. Such a setup needs constant (daytime) charging to store energy that will serve at night. The study suggests that so-called dense streets could effectively decrease energy consumption in greenhouses.

Niu et al. [10] the multiple regressions model for the cooling capacity assessment of the air-to-water heat exchanger (EAHE), a new environmental approach. Air temperature, tube velocity, tube surface temperature, length, and diameter of the EAHE are the six concepts under consideration for the tuning of the model. The second-order polynomial function with the same high level of accuracy is also created and used to forecast and sensibly address the latent cooling capacities. These equations provide comprehensible and practical models for installing and operating efficient EAHE systems, which finally help sustain energy efficiency and stability of the environment.

This study aimed to find out about the EATHE (Earth Air Tunnel Heat Exchange) performance after ground it had been working for 12 hours using different soils. The study explored the promoting effect, heat flux transmission, and the COP of the selected system. As the research outcome demonstrated, a pretty diverse pattern of heat distributions increases or lowers EATHE effectiveness. If the heat is convected through the EATHE pipes into the soil, which is subsequently conducted to the upper subsoil layer, the soil thermal conductivity is highly correlated with the heat transfer effect. This means that soils with a high proportion of sand and gravel conduct more heat from the deeper soil layers to the surface, where temperatures become colder.

Hasan and Noori [11] implemented an EAHE system to lower the energy required for heating or cooling a residential building in Nasiriya, a city in southern Iraq. Three different EAHE systems were studied, and the argument for fuel and energy bill reductions was given. The essay emphasizes the need to calculate the length and number of pipes to ensure optimal sewage operation throughout winter. Since the expenses might be covered in two years, the researchers demonstrated the effectiveness of dual EAHE layers for this small cemetery area.

In the study of Hasan and Noori [12], this study aimed to investigate the impact of input material and Wall thickness on the overall efficiency of Ground-Coupled Heat Exchangers (GCHE) in passive cooling and heating systems for buildings. Computational simulations were conducted for PVC and steel materials using three layers and four different thicknesses (2, 3, and 6) in the climate of Nasiriyah, a city in southern Iraq. The study was conducted using the provided findings, which indicated that while steel had somewhat inferior thermal performance compared to glazing, the price difference made it an acceptable choice. The previous simulation of the EAHE demonstrated that this system could surpass the traditional system's performance when employed for cooling with elevated inlet air temperatures and heating with reduced inlet air temperatures. The investigation concluded that wall thickness is not reliable in determining overall performance. PVC pipes are deemed more suitable due to their cost-effectiveness and resistance to corrosion. This analysis confirmed the accuracy of the numerical model by comparing it with the experimental model. A strong link has been shown between the two variables.

Congedo et al. [13] discuss the possibilities of utilizing an inclined exchanger to provide the needed heat-air conditioning for buildings to comply with the regulations for a zero-energy building. HAGHE, through its use of thermal energy stored underground, utilizes pre-heat/cooling to air ventilation systems in commercial, educational, and industrial buildings, cutting energy bills drastically. Their study utilized observing data and numerical modeling to show that thermokarst lakes profoundly strengthen ventilation effectiveness in the summer and provide several degrees of offset in heating water in the winter. The horizontal supply of pipes allows better heat exchange between ground and air, with steadiness of air temperature, and surpasses vertical structures. They unanimously agreed that applying tube and plate ground-air heat exchangers will incur energy savings and be cost-effective in terms of ventilation energy cost.

Ahmad and Prakash [14] performed a laboratory-scale experiment of an earth-to-air heat exchanger (EAHE) as a heating device in the Patna region of India. Experiments were performed in the controlled indoor space under the experimental test rig, which consisted of three horizontal PVC pipes of various diameters. The most probable rise in outlet temperature was observed at the lowest speed for the smaller tubes, and the efficiency of about 0.83 was observed at 2 m/s for the smallest pipe. Research showed a linear temperature growth as the airflow progressed through the pipe. Still, at the end of the pipe, the temperature gain dropped due to heat losses, and these temperature rises were higher in small-diameter pipes than in large-diameter pipes. As the velocity of the airflow augments, the heat exchange and performance of the EAHE drop. The effectiveness degradation is more significant in small-diameter pipes than in big ones. After analysis of the results, developing the research rig for the various diameters was considered feasible to understand the thermal performance of earth-to-air heat exchangers.

Misra et al. [15] studied the thermal performance of an Earth Air Tunnel Heat Exchanger (EATHE) during the operation of a warm-dry climate in Ajmer, India, in reality, and by computational fluid dynamics model. The study looked into the effect of the length of continuous operation, soil thermal conductivity, pipe diameter, and flow velocity on the EATHE thermal efficiency. Data interpretation showed that the EATHE's transient thermal performance was highly reliant on the thermal conductivity of the soil as well as the continuous run time of its operation. From 0% of derating to 64%, the cases were analyzed, and the extent of the range was made evident. The study finds out that the main aim should be to optimize the length of the pipe EATHE and include the derating factor (factor of limiting power output of the solar system) so that the device could keep its thermal performance for a longer time under transient conditions. The study also discovered that EATHE's thermal performance with a larger pipe was more reduced than that with a smaller one since the smaller area of the air flowing through the pipe leads to decreased amounts of turbulence and, consequently, the reduction of heat transfer. Moreover, uplifting the flow rate of the cooling system at EATHE had a negative relationship to the thermic functions.

This work presents a numerical analysis that examines the impact of soil thickness on various factors, such as pipe length, wall temperature, and air velocity. The weather conditions in Nasiriya, located in southern Iraq, are known for their consistently high temperatures throughout the year.

2. PROBLEM DESCRIPTION

This paper examines a 3D model of an EAHE (Earth-to-Air Heat Exchanger) system installed 3 meters below the surface, with pipe lengths of 30 meters, 50 meters, and 70 meters, with different values of disturbed soil thickness to varying air velocity values. Figure 1 illustrates the EAHE pipe and the depth of the disturbed soil.

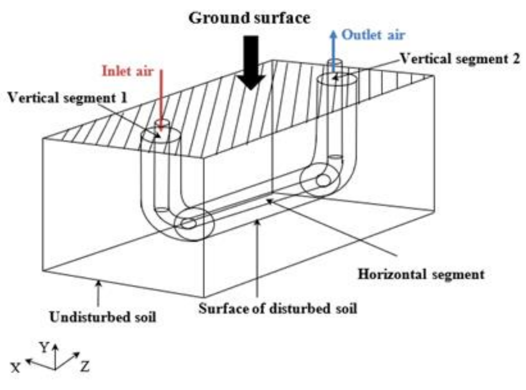

Figure 1. Schematic of EAHE system

2.1 Disturbed soil

The way that section titles and other headings are displayed the uppermost layer of soil in the region of the EAHE channel receives heat transmission, leading to a condition referred to as thermally changed soil. Currently, there are no recognized rules for estimating the thickness of this disturbed soil layer. Previous research has suggested various values for this thickness, including the pipe radius [6] and double the pipe diameter [8], Quadruple the radius of the pipe [5], and increase the size by a factor of 10 compared to the pipe diameter [10]. Additionally, studies have indicated that the impact of disturbed soil on EAHE system.

Table 1. The EAHE pipe sizes and disturbed soil thickness

Diameter of Pipe (in)	Diameter of Pipe (m)	Thickness of Disturbed Soil (m)
		0 (neglect disturbed soil)
		0.0254
		0.0508
		0.0762
4	0.1016	0.1016
		0.2032
		0.3048
		0.4064
		0.508
		0.6096

It is possible to reduce performance by utilizing the system only during the summer and winter [16]. This study focuses on the soil thickness effect when different values of disturbed soil thickness (ranging from 0D to 6D in increments of 0.25D) the pipe diameter is selected based on their availability in local markets (with a diameter of 4 inches). The disturbed soil layer thicknesses are presented in Table 1 and Figure 2.

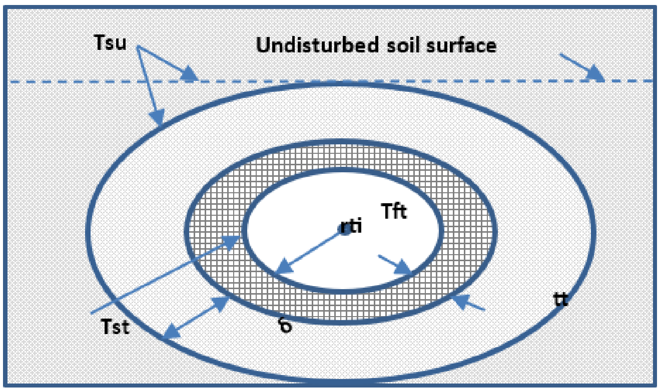

Figure 2. Cross sections of EAHE pipe with thickness of disturbed soil

3. MATHEMATICAL MODELING

The following assumptions were made during the development of the mathematical model [10]:
Steady-state turbulent flow.

1- The soil exhibits homogeneity, with its physical qualities being consistent.

2- The fluid cannot be compressed and possesses consistent values for specific heat, density, and thermal conductivity.

3- The tube and the Earth are in complete and continuous contact.

4- The EAHE pipe wall is skinny, resulting in low heat resistance.

This analysis utilizes the following fluid flow and heat transfer equations [12, 17, 18].

The equations that govern the flow of air inside EAHE, considering steadiness, incompressibility, and three-dimensional aspects, are depicted as follows:

Continuity equation:

$$\mathrm{div}\,\overline{V} = 0 \tag{1}$$

Momentum equations:

X dir:

$$\frac{\partial \bar{u}}{\partial t} + div\,(\bar{u}\bar{V}) + div\left(\overline{u'V'}\right) = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial x} + v\, div\,(grad\,((\bar{u})) \tag{2}$$

Y dir:

$$\frac{\partial \bar{u}}{\partial t} + div\,(\bar{u}\bar{V}) + div\left(\overline{u'V'}\right) = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial x} + v\, div\,(grad\,((\bar{v})) \tag{3}$$

Z dir:

$$\frac{\partial \bar{w}}{\partial t} + div\,(\bar{w}\bar{V}) + div\left(\overline{w'V'}\right) = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial w} + v\, div\,(grad\,((\bar{w})) \tag{4}$$

Energy equation:

$$\frac{\partial U\tilde{T}}{\partial t} + \frac{\partial V\tilde{T}}{\partial y} + \frac{\partial W\tilde{T}}{\partial z} = \frac{k}{\rho cp}\left(\frac{\partial}{\partial x}\left(\frac{\partial \tilde{T}}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{\partial \tilde{T}}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{\partial \tilde{T}}{\partial z}\right)\right) \tag{5}$$

Reynolds number represented by Nashee and Hmood [19].

The Reynolds number (Re), which signifies the relationship between internal forces and viscous forces, has been computed to determine whether a flow is in a laminar or turbulent state.

$$Re = \frac{\rho\, w\, D}{\mu} \tag{6}$$

where:

Dh is the hydraulic diameter.

To assess the overall efficiency with regards to an Earth-to-Air Heat Exchanger (EAHE) system, the performance factor (η*) is employed. This factor signifies the thermal conductivity ratio between the air and the soil to the energy expended for pumping [20-22].

$$\eta * = Q\,/\,p.p \tag{7}$$

where:

Q: It symbolizes the rate of heat transfer between the air and the soil. (In an Earth-to-Air Heat Exchanger, the heat exchange process is primarily sensible, with negligible latent heat exchange).

$$Q = m \cdot Cp\, \Delta T \quad (8)$$

P.P: is the pumping power and calculated from:

$$P.P = \dot{V} \Delta P \quad (9)$$

V: is the volume flow rate.

Pressure drop: refers to the complete variation in pressure from the entry point to the exit point within the channel of an Earth-to-Air Heat Exchanger (EAHE).

$$\Delta P = Pi - Po \quad (10)$$

3.1 Boundary conditions

The model was supplemented with the subsequent boundary conditions:

3.1.1 Inlet boundary condition

In both turbulent and subsonic flow scenarios, the beginning section of the EAHE pipe maintained a constant air velocity and a steady dry-bulb temperature (Ti) at the entry point. The choice of (Ti) values as boundary conditions was determined by the climatic parameters of Nasiriya city in southern Iraq, considering both summer and winter conditions.

3.1.2 Outlet boundary conditions

At the outlet, the relative pressure was equal to zero atmospheric pressure.

3.1.3 wall

The horizontal section of the EAHE pipe is thermally linked to the modified soil layer with a specific thickness, as shown in Figure 1. Consequently, the boundary condition facilitates the conjugate heat transfer process. Ts = 26.1℃ is the constant temperature maintained outside the disturbed soil at a distance (t) from the pipe wall. This temperature corresponds to the recorded temperature of unaltered soil at a depth of (3-4) meters in the southern region of Iraq, as ascertained in the empirical investigation [23]. We hypothesized that thermally insulating barriers separated the two vertical parts. Based on the references, this decision was made since it was discovered that the air temperature difference between the two vertical segments (inlet and outflow) is the same and stable [7, 8, 11].

4. NUMERICAL SOLUTION

The governing equations and boundary conditions are solved numerically using the finite volume technique. The flow is in a transition state, and computational fluid dynamics (CFD) modeling is used to solve the 3D continuity and 3D Navier-Stokes equations.

4.1 CFD modeling

Currently, (CFD) has gained significant popularity for modeling and assessing the performance of EAHE systems [24]. CFD analyzes the airflow inside the EAHE (Earth-to-Air Heat Exchanger) pipe under well-defined boundary conditions. The pipe turbulence simulation employs a direct k-ε model with the standard wall treatment. In addition, the energy equation is solved by including the heat transfer process. CFD modeling allows for determining airflow characteristics at multiple locations within the EAHE system, usually connected through a numerical grid or mesh. Both the momentum and energy equations are subject to a convergence requirement $1*10^{6}$.

4.2 Grid independence test

A test for grid independence was performed to assess the precision of the created CFD model. The solution is regarded as when the outcomes remain consistent even when the mesh is refined, which involves reducing cell size and increasing the cell count. in Figure 3, the results indicate that the solution is insensitive to grid size changes, with little to no impact on air temperature as the grid transitions from mesh 1 to mesh 2 to mesh 3.

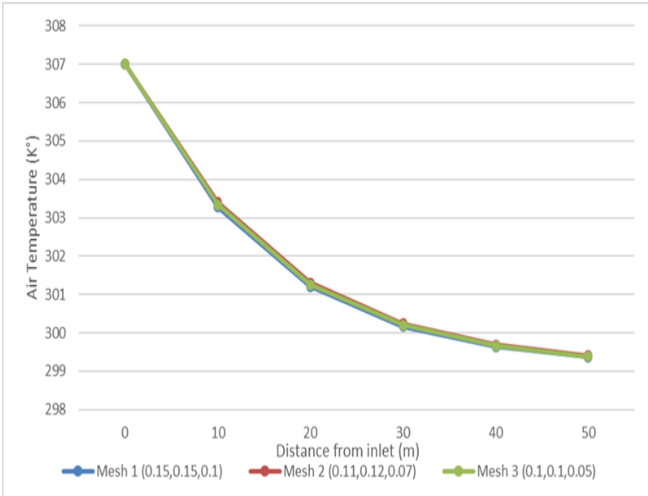

Figure 3. Grid independent test

5. RESULT AND DISCUSSION

To confirm the accuracy of the created numerical model, a verification process has been conducted by solving the numerical model introduced in a published study [25]. The EAHE system described in the previous study consisted of a 50 m long pipe with a diameter of 0.1016 m. The temperature profile along the EAHE pipe's length was assessed at varying air speeds (1, 3, 5, 7, and 9 m/s), with an inlet air temperature of 50℃ and a uniform pipe surface temperature that matched the undisturbed soil temperature of 26.3℃. Figure 4 illustrates a comparison between the temperature distribution along the EAHE pipe as simulated by our current model and the results from a prior study by Hasan et al. [25]. The graph indicates a reasonable agreement between the two sets of simulation results, with an average error of 0.5%. Consequently, it can be inferred that our numerical model is dependable and can be employed with appropriate accuracy to investigate the overall performance of the EAHE system.

The model was numerically solved for Nasiriya city in southern Iraq under both summer and winter climatic conditions. We operated under the assumption that the thermal and physical characteristics of both air and soil remained consistent, and their respective values, as cited in the study of Nashee [26], were employed as reference.

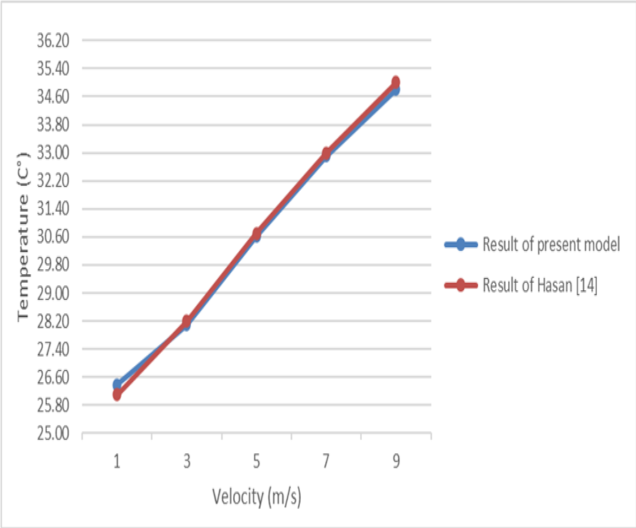

Figure 4. Distribution of outlet temperature with velocity for EAHE pipe as a comparison between present model with numerical model results of the previous study [23]

Figure 5 and 6 illustrate the simulation results of the Earth-to-air heat exchanger (EAHE) system when functioning as a cooling and heating system.

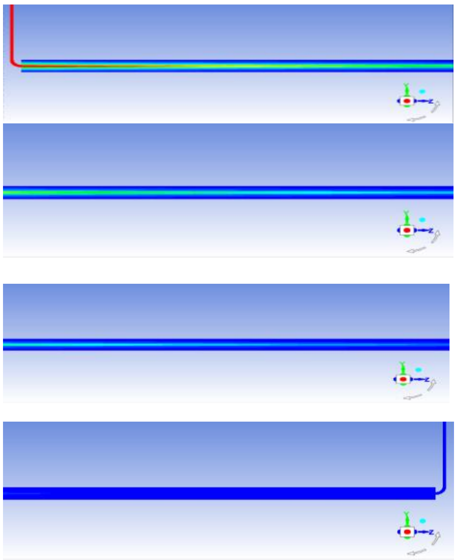

Figure 5. Temperature contour (K°) of EAHE pipe and disturbed soil at air velocity of 5

Figure 5 displays the temperature distribution on the longitudinal (y-z) plane at the center of the pipe (x=0 m) with an air velocity of 5 m/s and an initial air temperature of 32℃ at the intake. The contour has been divided into four portions to enhance the visibility of the entire pipe length. The graphic illustrates that transferring heat from the pipe to the soil results in a decrease in air temperature and an increase in soil temperature in the flow direction. The initial portion of the channel undergoes the most significant temperature variation, whereas the latter exhibits a more moderate variation. The initial few meters of the channel exhibit a significant difference in air and soil temperatures, gradually decreasing as the channel length increases.

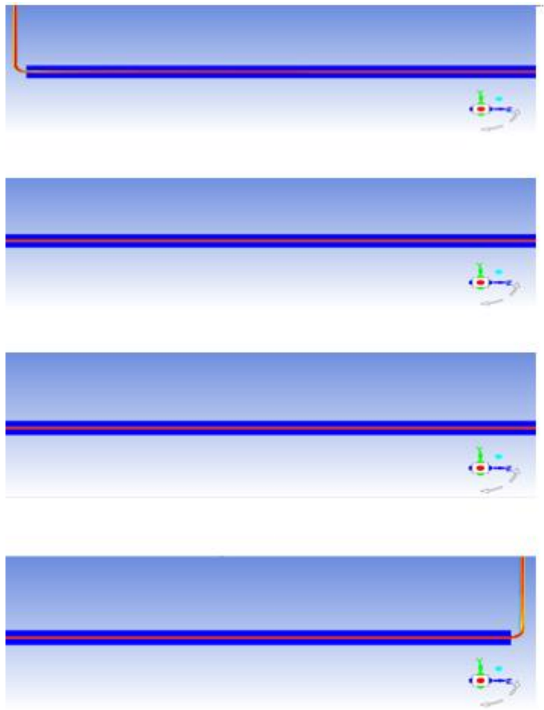

Figure 6. Temperature contour (K°) of airflow through EAHE pipe at air velocity of 300 m/s

Figure 6 illustrates the temperature pattern within the pipe's central axis (x=0 m) and the (y-z) plane in an EAHE setup with a soil layer thickness equivalent to 1D, considering an air velocity of 300 m/s and an initial air temperature of 32℃ at the inlet. It should be noted that there is no significant change in air temperature where the outlet temperature matches the inlet air temperature. The soil temperature does not impact the outlet temperature at high velocities since the heat does not have sufficient time to interact with the soil due to the high velocity.

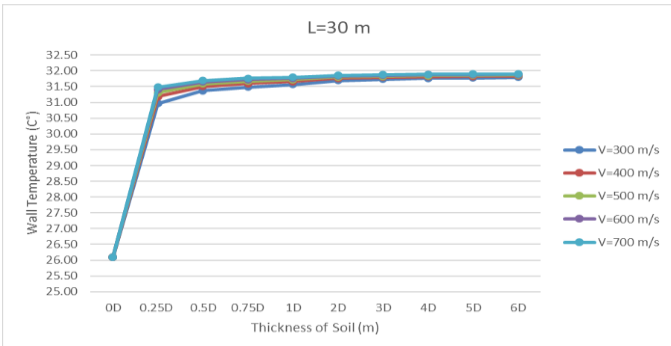

Figure 7. EAHE system pipe wall temperature change with soil thickness for all high air velocities with constant length (30 m)

Figure 7 displays the relation between soil thickness and pipe wall temperature under different velocities for 30 m. The value of 0D represents pipe without disturbed soil Because of the temperature of the wall in direct contact with the soil and at a certain depth from the surface of the earth, we note that the temperature of the wall is not affected by the level of the soil above it because it is considered undisturbed soil. It is worth noting from this figure that as the soil thickness increases, the wall temperature increases until it reaches 0.25D and becomes nearly constant independent of soil thickness.

The wall temperature is roughly equivalent to the entry temperature of 32°C under high velocities for soil thicknesses higher than 0.25D. Therefore, the wall's temperature mainly relies on the entry temperature rather than the temperature of the soil at higher velocities due to an inefficient heat transfer process that decreases the time inside the pipe and because of the disturbed soil in contact with it.

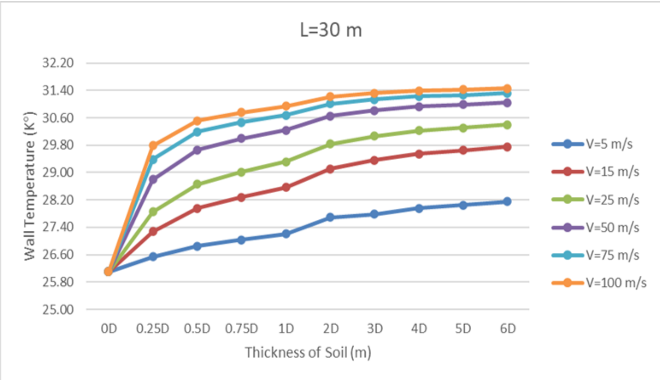

Figure 8. The temperature of the EAHE system's pipe walls varies with soil thickness for all low air velocities investigated, with a constant length of 30 meters

Figure 8 illustrates how soil thicknesses and velocities affect the temperature of a wall over a 30 m length at low velocities. The value of 0D indicates a pipe without soil disturbance. The figure shows that as the thickness of the soil surrounding the pipe increases, the wall's temperature rises until it reaches 1D. After that, the rate of increase in the wall temperature decreases. When the soil thickness is more significant than 1D, and the velocity is low, the wall's temperature becomes very similar to the temperature of the surrounding soil due to the longer time taken for heat exchange between the soil and the air. This behavior differs from the higher velocities indicated in Figure 7, where at higher velocities, the wall temperature becomes mainly dependent on the entry temperature rather than the soil temperature due to the inefficient heat transfer process caused by reduced time inside the pipe.

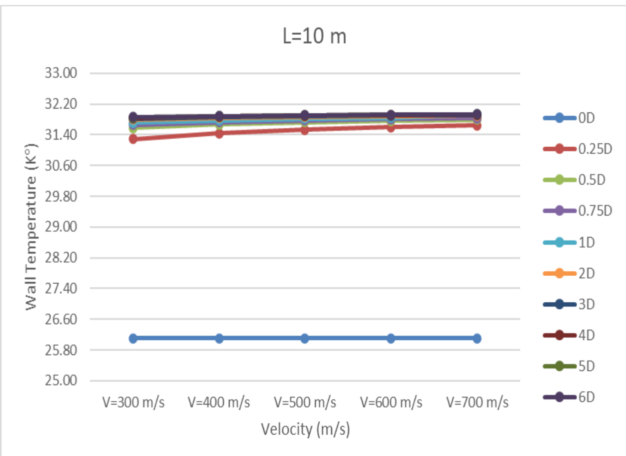

Figure 9. Variation of the wall temperature of EAHEsystem with high air velocities for soil thickness with constant length (10 m)

Figure 9 displays how the pipe wall temperature and air velocities are related for different soil thicknesses with a fixed length of 10 m. It is observed that when the soil thickness is at 0D, the wall temperature remains constant as the velocity increases, similar to the soil temperature. However, when the soil thickness reaches 0.25D or higher, the wall temperature becomes identical to the entry temperature and remains steady as the velocity increases. This suggests there is no impact on soil thickness when the soil thickness increases from 1D or higher. Moreover, due to the high velocities that do not provide enough time for heat exchange with the soil, the wall temperature is higher than the soil temperature.

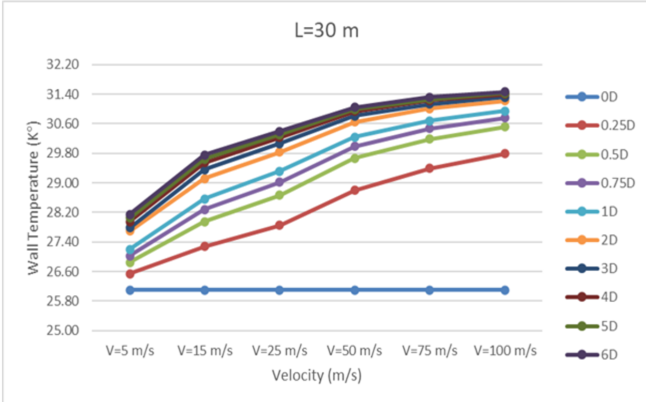

Figure 10. EAHE system wall temperature change with air velocities for all soil thicknesses with constant length (30 m)

The data presented in Figure 10 depicts the relation between the wall's temperature and the air's velocity for different soil thicknesses. The chart shows the variation in wall temperature at different air velocities ranging from 5-100 m/s for different soil thicknesses while keeping the length constant. Notably, when the soil thickness is 0D, the wall temperature remains constant regardless of the velocity Due to the low speeds and the undisturbed soil surrounding the tube, it allows heat exchange between the air inside the tube and the soil; the wall temperature varies between 0.25D and 6D. With an increase in air velocity, there is a corresponding increase in wall temperature until the velocity reaches 100 m/s, where the wall temperature becomes close to the entry temperature. Hence, it has been confirmed that at high velocities of any length, the wall temperature is nearly the same as the entry temperature.

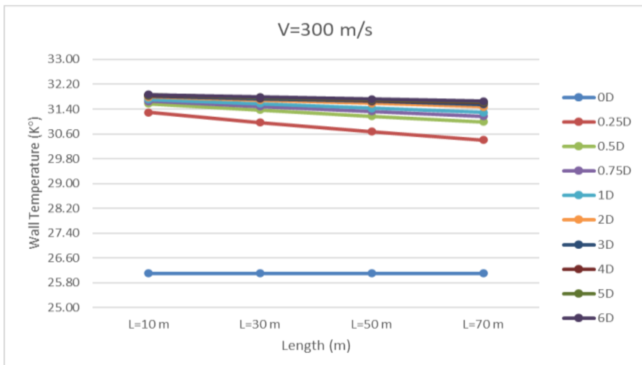

Figure 11. Variation of the wall temperature of EAHE system with different lengths for all studied soil thickness with constant air velocity (300 m/s)

Figure 11 illustrates the relationship between wall temperature (Tw) and various lengths for different soil thicknesses at an inlet air temperature of 32°C and velocity of

300 m/s. For soil thickness of 0D, lengths have no significant impact on wall temperature as the curve slope is minimal. Similarly, increasing lengths do not cause a noticeable change in wall temperature for other soil thicknesses. But it's clear that soil thickness significantly affects wall temperature; as soil thickness grows, so does the temperature. This is because air is heated more efficiently, and the temperature range is closer to the soil temperature in pipes with thinner soil layers.

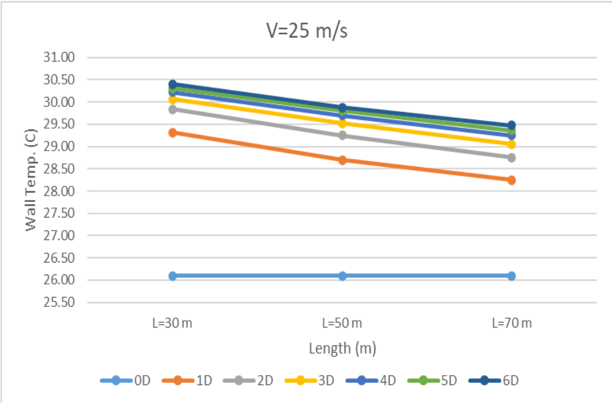

Figure 12. Variation in the wall temperature of the EAHE system with different lengths for all studied soil thicknesses with constant velocity (25 m/s)

Figure 12 demonstrates the change in wall temperature concerning length at low velocity for all the investigated soil thicknesses. The figure reveals an apparent decline in wall temperature as length increases at soil thickness (1D to 6D), except for soil thickness (0D). Moreover, it is evident from the figure that wall temperature is not significantly affected by soil thickness (0D) at high lengths. In contrast, the maximum wall temperature is associated with the thicker soil (6D). The minimum wall temperature is associated with thinner soil (1D), which can be attributed to the variation in soil thickness.

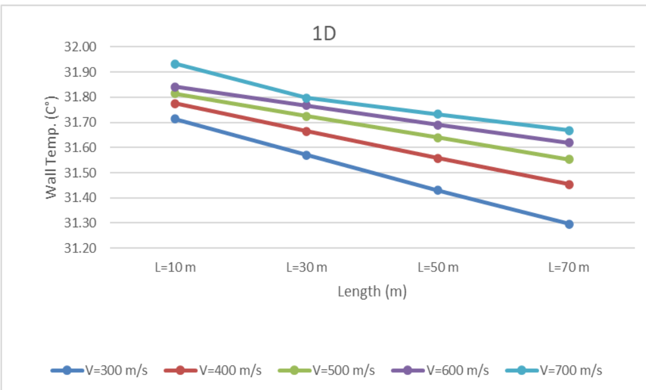

Figure 13. Variation of the wall temperature of EAHE system with different length for high air velocity with constant soil thickness (1D)

Figure 13 depicts the wall temperature and pipe lengths at high air velocities ranging from 300-700 m/s. The thickness of the wall is fixed at 1D. Upon analyzing the data, it is observed that at a length of 10m, the wall temperature for all air velocities remains near the entry temperature of 32℃ due to the high velocities that hinder heat exchange with the soil. As the length increases, the wall temperature experiences a slight decline across all velocities until it reaches the maximum selected length of 70 m. There is no considerable change in wall temperature for all lengths due to the high velocities that do not provide enough time for heat exchange with the soil and Due to adding thickness to the soil around the pipe, we notice that no matter how much the length or speed changes, they are not affected by the thickness of the soil, which is considered disturbed soil, meaning its temperature is affected by the surroundings.

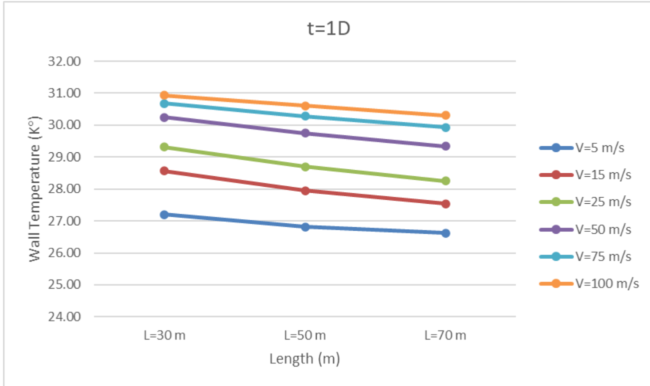

Figure 14. Wall temperature of EAHE system under different length for low air velocities with constant soil thickness (1D)

Figure 14 illustrates how the wall temperature varies with the length, so its thickness is 1D for low velocities; a slight decrease in Wall temperature can be observed as size increases. However, as velocity increases, the wall temperature increases significantly regardless of the length. This suggests that increasing length will have little effect on wall temperature.

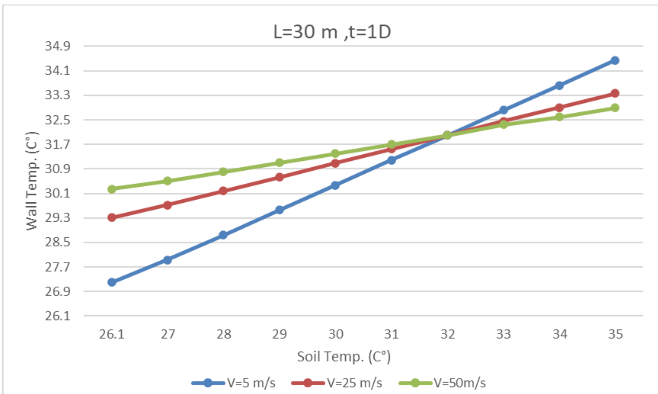

Figure 15. The variation of wall temperature with soil temperature for all studied low air velocities at length of EAHE (30 m) and the soil thickness (1D)

Figure 15 illustrates the relation between the wall temperature and soil temperature variations along a 30 m length of EAHE, with a soil thickness of 1D, for different values of air velocities. The results indicated that the wall temperature consistently increased as the soil temperature increased across all air velocities (5, 25, and 50 m/s). This trend persisted until the soil temperature reached 32℃, the same entry temperature beyond which the wall temperature continued to increase with reverse behavior due to the process becoming heating instead of cooling Due to the effect of soil thickness on the wall temperature.

In Figure 16 the relationship between soil temperature and wall temperature changes along a 30 m EAHE is demonstrated, where the soil thickness is 1D and various air velocities are examined (300 to 700 m/s). The wall temperature rises slightly in conjunction with the soil temperature because of high air velocity, with the soil temperature increasing until it reaches the entry temperature of 32℃. Following that, the soil temperature continued to rise, and the wall temperature slowly grew with behavior becoming heating instead of cooling.

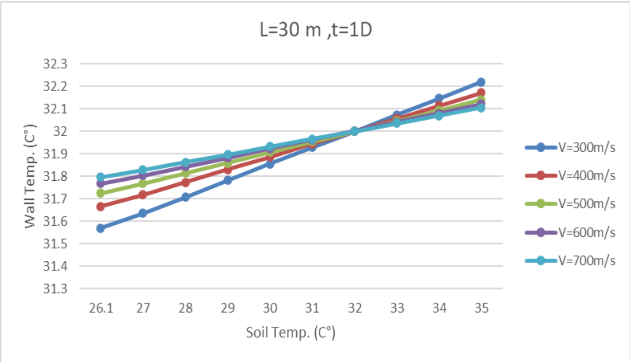

Figure 16. EAHE system wall temperature under varying soil temperatures for all examined high air velocities at 30 m length and 1D soil thickness

Figure 17 presents the change in the exit air temperature concerning different air velocities for varying soil depths while maintaining a constant length of 30 m and an inlet temperature of 29℃. At high velocities, the temperature at the outlet is similar to the temperature at the inlet when soil thickness is added. Adding a small amount of soil thickness results in a lower outlet temperature than adding a more significant amount. This suggests that the outlet temperature becomes closer to the inlet temperature as the thickness of the soil surrounding the tube increases and the velocity increases. Additionally, due to the high velocities and short time, there is negligible heat exchange inside the tube.

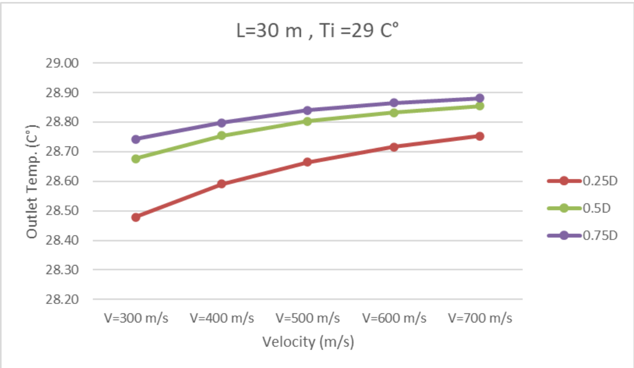

Figure 17. High air velocity and exit air temperature variation for all soil thickness at EAHE (30 m) and intake air temperature (29℃)

6. CONCLUSIONS

The use of (EAHE) for heating and cooling buildings is facilitated by the soil's consistent temperature at a specific depth under the surface. This research paper focuses on a numerical study that examines the influence of EAHE pipe's soil thickness (0D, 0.25D, 0.5D, 0.75D, 1D, 2D, 3D, 4D, 5D, and 6D) In the weather conditions found in the southern region of Iraq's Nasiriya city. Based on the simulation results, the following conclusions can be drawn:

1- For soil thicknesses ranging from 1D to 6D, the wall temperature remains unchanged as the air velocity and pipe length increase. This is observed at high velocities of 300, 400, 500, 600, and 700 m/s while maintaining the same inlet temperature Because of the disturbed soil that is affected by the external environment and is not in contact with the pipe, the temperature of the disturbed soil is higher than the temperature of the undisturbed soil that is not affected by the external environment and that is at a certain depth from the surface of the earth.

2- For all chosen soil thicknesses ranging from 1D to 6D, an increase in air velocity from 5 to 100 m/s resulted in a corresponding increase in wall temperature. The wall temperature even reached the inlet air temperature at specific air velocities Because of the disturbed soil that is affected by the external.

3- At low air velocities, the (EAHE) wall temperature decreased as the pipe length increased Only in the case of soil thickness of 0D due to the undisturbed soil surrounding the pipe.

4- When the soil thickness is minimal and located near the outlet's wall, the temperatures of both the wall and outlet will be near the soil temperature. This behavior is accompanied by an increase in air velocity and a decrease in pipe length.

5- It is preferable to bury the heat exchanger pipes at a depth (3-4 m) of the city of Nasiriyah because at this depth it is considered saturated soil, i.e. undisturbed soil, thus obtaining the best results.

6- We suggest that when burying the pipes, they should be spaced apart to allow heat exchange between the soil and the air inside the pipe without being affected by the temperature of the adjacent pipe.

REFERENCES

[1] Dubey, H., Kosthi, B., Choudhary, K. (2016). Performance analysis of earth tube heat exchanger. International Journal of Engineering Sciences and Research Technology, 5(7): 323-331. https://doi.org/10.5281/zenodo.56979

[2] Mathur, A., Surana, A.K., Mathur, S. (2016). Numerical investigation of the performance and soil temperature recovery of an EATHE system under intermittent operations. Renewable Energy, 95: 510-521. https://doi.org/10.1016/j.renene.2016.04.037

[3] Rosa, N., Soares, N., Costa, J.J., Santos, P., Gervásio, H. (2020). Assessment of an Earth-Air Heat Exchanger (EAHE) system for residential buildings in warm-summer Mediterranean climate. Sustainable Energy Technologies and Assessments, 38: 100649. https://doi.org/10.1016/j.seta.2020.100649

[4] Bisoniya, T.S., Kumar, A., Baredar, P. (2014). Parametric analysis of Earth-Air Heat Exchanger system based on CFD modelling. International Journal of Power and Renewable Energy Systems, 1: 36-46.

[5] Misra, R., Vikasbansal, Agarwal, A. (2016). Investigation of thermal performance of EATHE system under intermittent operation: A CFD approach. International Journal of Engineering Technology, Management and Applied Sciences, 4(4): 340-349.

[6] Al-Ajmi, F., Loveday, D.L., Hanby, V.I. (2006). The

cooling potential of earth–air heat exchangers for domestic buildings in a desert climate. Building and Environment, 41(3): 235-244. https://doi.org/10.1016/j.buildenv.2005.01.027
[7] C33-78, A. Standard Specification for Concrete Aggregates 1. ASTM International West Conshohocken, 2010.
[8] Sakhri, N., Menni, Y., Chamkha, A.J. (2022). Heating capacity of an earth to air heat exchanger in arid regions-experimental investigation. Journal of Applied and Computational Mechanics, 8(2): 429-437. https://doi.org/10.22055/jacm.2020.31237.1843
[9] Gauthier, C., Lacroix, M., Bernier, H. (1997). Numerical simulation of soil heat exchanger-storage systems for greenhouses. Solar Energy, 60(6): 333-346. https://doi.org/10.1016/S0038-092X(97)00022-4
[10] Niu, F.X., Yu, Y.B., Yu, D.H., Li, H.R. (2015). Heat and mass transfer performance analysis and cooling capacity prediction of earth to air heat exchanger. Applied Energy, 137: 211-221. http://doi.org/10.1016/j.apenergy.2014.10.008
[11] Hasan, M.I., Noori, S.W. (2019). A study of the potential of using the Earth to air heat exchanger for cooling and heating of residential buildings in Iraq. Heat Transfer—Asian Research, 48(8): 3902-3927. http://doi.org/10.1002/htj.21574
[12] Hasan, M.I., Noori, S.W. (2018). Numerical investigation of earth to air heat exchanger for cooling and heating applications. In 3rd International Scientific Conference of Southren Technical University, Southrn Technical University, Basra, Iraq.
[13] Congedo, P.M., Lorusso, C., Giorgi, M.G.D., Laforgia, D. (2014). Computational fluid dynamic modeling of horizontal air-ground heat exchangers (HAGHE) for HVAC systems. Energies, 7(12): 8465-8482. https://doi.org/10.3390/en7128465
[14] Ahmad, S.N., Prakash, O. (2022). Thermal performance evaluation of an earth-to-air heat exchanger for the heating mode applications using an experimental test rig. Archives of Thermodynamics, 43(1): 185-207. http://dx.doi.org/10.24425/ather.2022.140931
[15] Misra, R., Bansal, V., Agrawal, G.D., Mathur, J., Aseri, T.K. (2013). CFD analysis based parametric study of derating factor for earth air tunnel heat exchanger. Applied Energy, 103: 266-277. https://doi.org/10.1016/j.apenergy.2012.09.041
[16] Bisoniya, T.S., Kumar, A., Baredar, P. (2013). Experimental and analytical studies of earth–air heat exchanger (EAHE) systems in India: A review. Renewable and Sustainable Energy Reviews, 19: 238-246. https://doi.org/10.1016/j.rser.2012.11.023
[17] Hasan, M.I., Muter, D.M. (2021). Study the effects configuration and design parameters on the performance of earth to air heat exchanger used in poultry houses. Journal of Mechanical Engineering Research and Developments, 44(7): 159-179.
[18] Hasan, M.I., Noori, S.W. (2018). Evaluating the influence of some design and environmental parameters on the performance of earth to air heat exchanger. Journal of Engineering and Sustainable Development, 22(2): 10-29. http://doi.org/10.31272/jeasd.2018.2.2
[19] Nashee, S.R., Hmood, H.M. (2023). Numerical study of heat transfer and fluid flow over circular cylinders in 2D cross flow. Journal of Advanced Research in Applied Sciences and Engineering Technology, 30(2): 216-224. https://doi.org/10.37934/araset.30.2.216224
[20] Muhtaq, I.H., Rageb, A.A., Yaghoubi, M., Homayoni, H. (2009). Influence of channel geometry on the performance of a counter flow microchannel heat exchanger. International Journal of Thermal Sciences, 48(8): 1607-1618. https://doi.org/10.1016/j.ijthermalsci.2009.01.004
[21] Muhtaq, I.H. (2011). Influence of wall axial heat conduction on the forced convection heat transfer in rectangular channels. Basrah Journal for Engineering Science, 31-43.
[22] Muhtaq, I H., Hasan, H.M, Ghassan, A.A. (2014). Study of the axial heat conduction in parallel flow microchannel heat exchanger. Journal of King Saud University-Engineering Sciences, 26(2): 122-131. https://doi.org/10.1016/j.jksues.2012.12.004
[23] Alaa, H. (2015). Theoretical and experimental study of using earth tube heat exchanger and solar chimney for cooling in Basrah city. Mechanical Engineering.
[24] Bisoniya, T.S., Kumar, A., Baredar, P. (2014). Parametric analysis of Earth-air heat exchanger system based on CFD modelling. International Journal of Renew Energy Systems, 1: 36-46.
[25] Hasan, M.I., Noori, S.W., Shkarah, A.J. (2019). Parametric study on the performance of the earth-to-air heat exchanger for cooling and heating applications. Heat Transfer—Asian Research, 48(5): 1805-1829. http://doi.org/10.1002/htj.21458
[26] Nashee, S.R. (2023). Numerical study for fluid flow and heat transfer characteristics in a corrugating channel. International Journal of Heat & Technology, 41(2): 392-398. https://doi.org/10.18280/ijht.410213

Nomenclature

Cp	heat capacity per unit mass (J/kg·K)
k	thermal conductivity (W/m.K)
m	mass flow rate (kg/s)
T	temperature (K)
P	total pressure (Pa)
X	horizontal coordinate (m)
Y	vertical coordinate (m)
Z	axial coordinate (m)
ΔP	the overall pressure decline along the EAHE pipe (Pa)
t	pipe thickness
δ	thickness of disturbed soil

Greek symbols

ρ	density (kg/m^3)
μ	dynamic viscosity (m^2/s)

Subscripts

i	inlet
o	outlet
s	surface of soil undisturbed
f	fluid
t	tube (pipe)