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A CFD ANALYSIS FOR EVALUATING THERMAL PERFORMANCE OF EARTH AIR TUNNEL HEAT EXCHANGER

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ABSTRACT

This study investigates the use of an Earth-to-Air Tunnel Heat Exchanger (EATHE) for lowering indoor building temperatures. EATHE is a subterranean heat exchanger that uses free cooling and heating to transfer heat from the ground. A computational fluid dynamics model was created using ANSYS to examine the system's thermal efficiency and cooling capability. The model, which includes a 20-meter PVC pipe, provides cooling within the range of 10.5K to 13K for flow velocities of 3–5 ms^{-1}. The EATHE system's performance is largely unaffected by the underground pipe configuration, but the use of fin and fin block significantly impacts its performance. The EATHE approach exhibits significant potential for reducing the temperature within the building, with an energy payback period ranging from 5 to 9 years, subject to regional variations. Regarding the overall outcomes, it can be stated that utilizing EATHE can be a significant stride towards conserving the natural energy supply.

KEYWORDS: EATHE; heat transfer; fluid dynamics; energy.

1. INTRODUCTION

In the present period, the process of producing power has become increasingly challenging due to the gradual depletion of energy resources. Consequently, there is a widespread shift towards utilizing renewable energy sources. In this discussion, we will explore a heat exchanger that operates without the need for any external power source. Research into thermal comfort dates back to the beginning of human existence on Earth.[1] Throughout history, humans have consistently strived to modify their living environments in order to establish and maintain stability. The concept of utilizing the ground as a heat sink was recognized in ancient civilizations. During approximately 3000 B.C., Iranian architects employed wind towers and subterranean air tunnels to provide passive cooling. Underground air tunnels (UAT) systems, often referred to as earth-to-air heat exchangers, have been utilized for many years in industrialized nations because of their superior energy usage efficiencies in comparison to traditional heating and cooling systems.[2] An earth-air heat exchanger is a system that utilizes the earth's thermal inertia to provide heating and cooling for various types of buildings, including offices, residential, and industrial structures. The latest architectural designs have emphasized the benefits and possibilities of natural ventilation systems in ensuring the thermal comfort of building inhabitants.[3] Natural ventilation has emerged as a viable approach for not only minimizing energy consumption and expenses, but also for ensuring optimal thermal comfort and maintaining high indoor air quality. Ventilation refers to the process of replacing or exchanging air within a confined area. To ensure good interior air quality, it is necessary to consistently remove air and replace it with fresh air from a clean external source. Good indoor air quality can be described as a condition in which no dangerous concentrations of known contaminants are present.[4] The aim of this study is to introduce a refined and verified transient, implicit numerical model that incorporates the concurrent and interconnected heat transport between the soil and the pipe. An earth-air heat exchanger system refers to the process of transferring heat between the soil, tubes, and air that flows through the tubes. This occurs when the tubes are positioned underground at a specific depth, where the soil temperature remains relatively stable throughout the year. As air flows through the tube, it undergoes heating in winter and cooling in summer, which conditions the space as it enters the enclosed area.[5]

The primary objective of this research is to suggest a practical investigation and computational modeling of an earth-to-air thermal exchanger (EATHE) employed during the summer season for the purpose of building air conditioning. EATHE has the capability to provide heating, cooling, and fresh air for buildings, and the thermal performances of these functions have been thoroughly examined separately. The study found that the soil thermal conductivity is the primary determinant, followed by the depth of the solar air heater channel and the intensity of solar radiation. It has been observed that when the diameter of the pipe increases, the total temperature changes in summer or winter decreases and the overall heating and cooling capacity improves. Crucially, this system also has the capability of supplying buildings with fresh air. The subterranean pipes facilitate the exchange of heat between the outdoor air and the earth, which then supplies the structure with the conditioned air. This partially mitigates the advantages of EATHE in relation to energy conservation and enhancement of interior thermal comfort. A computational fluid dynamics (CFD) model was created using ANSYS (version 19.2) to analyze the thermal efficiency and cooling capability of the Earth-air heat exchanger (EATHE) system. The characteristics under investigation are burial depth, length, and pipe diameter. The aforementioned investigations demonstrate that the thermal efficiency of EATHE has been thoroughly elucidated, and the findings are adequate to provide guidance for an actual project.

2. METHODOLOGIES

2.1 Model Used

An examination of the EATHE system has been conducted using a three-dimensional simulation model developed in the ANSYS FLUENT software (version 19.2). This software application use the finite volume method to transform intricate governing equations into algebraic equations that can be solved numerically. The control volume of the EATHE system was established by constructing a cylindrical volume of dirt surrounding the pipe. The physical model of the EATHE system was discretized using 3D hybrid meshing in ANSYS Workbench Meshing, with medium-sized elements and a growth rate. The current numerical model is founded on the continuity equation, the momentum equation, the energy equation, and the realizable k-ε equation. The k-ε model is a widely used turbulence model integrated into FLUENT. It is particularly effective in accurately predicting turbulent behavior in confined wall and internal flows characterized by modest mean pressure gradients.

2.2 Boundary Conditions

Inlet boundary: The velocity at the entrance of the EATHE system has been defined as the inlet. The EATHE utilizes a uniform velocity at its inlet, with the direction perpendicular to the opening. The velocity in the x-axis was measured to be 3 meters per second. The turbulence characteristics at the inlet are determined by specifying a turbulence intensity of 5% and an inlet hydraulic diameter of 0.1 m.

The boundary of the soil: The boundary of the soil is defined as the outside surface of the soil cylinder that surrounds the EATHE pipe. This cylinder has a diameter that is 10 times the diameter of the pipe. It is assumed that the temperature at this boundary is constant and equal to 300.1 K.

The soil pipe interface: The soil pipe interface is considered a coupled heat transfer condition. Velocity and temperature at the duct surfaces are enforced to remain constant, ensuring no slippage. The outlet utilizes a zero diffusion flux for all flow variables in the direction perpendicular to it.

The outlet boundary: The outlet boundary was defined as a "pressure outlet" for all models, with the turbulent intensity and hydraulic diameter matching those of the input section.

Physical and thermal parameters

Table 1: Physical and thermal parameters used in simulation.

Material	Density (kgm^{-3})	Specific heat capacity ($J\ kg^{-1}\ K^{-1}$)	Thermal conductivity ($W\ m^{-1}\ K^{-1}$)
Air	1.225	1006	0.024
Soil	2050	1840	0.75
Soil	2050	1840	1.5
Soil	2050	1840	3.75
PVC	1380	900	1.16

2.3 Description and Setup of the System and Simulation

An evaluation of the thermal performance of an EATHE system (under stable conditions) has been conducted using the research Computational Fluid Dynamics software package, ANSYS FLUENT v 19.2. The software possesses the capacity to forecast fluid flow that is incompressible, compressible, laminar, and turbulent, as well as phenomena related to buoyancy and compressibility. Fluent turbulence models utilize extended wall functions to accurately forecast the turbulence patterns in close proximity to walls.

2.3.1 The Physical Model

The physical configuration of EATHE systems, which includes pipes and the soil around them, was simulated using ANSYS's workbench platform, specifically ANSYS's DESIGN MODELER (Figure 1). The physical model of the EATHE system was meshed using the patch conforming approach, specifically employing tetrahedrons.

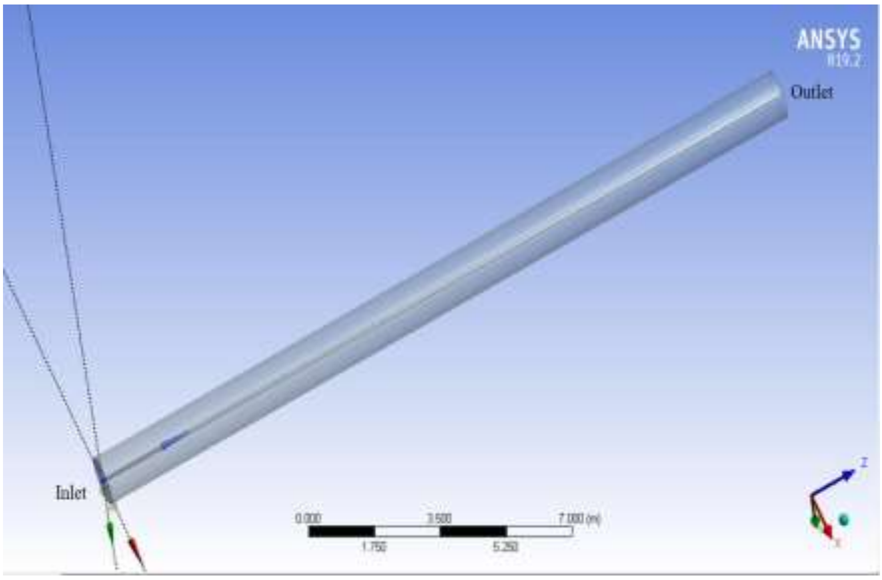

Figure 1 (a): Physical geometry of EATHE systems.

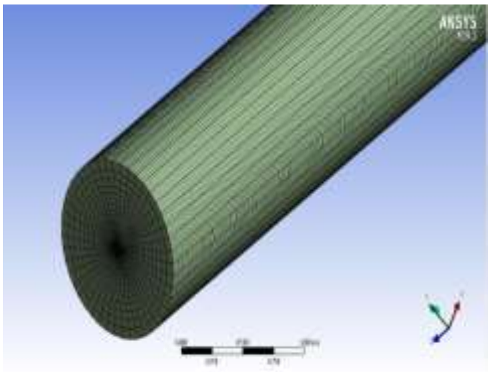

Figure 1(b): Geometry(side view).

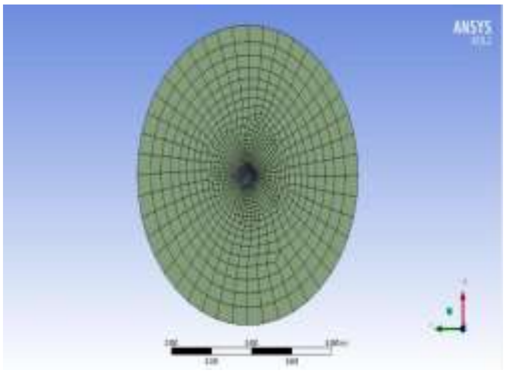

Figure 1(c): Geometry (front view).

2.3.2 Model for Simulating

The study employed ANSYS FLUENT v 19.2, utilizing the finite volume approach to transform the governing equations into algebraic equations that can be solved numerically. The numerical investigations were conducted under the following assumptions.

- The thermo-physical parameters of soil, pipe, and air do not change during thermal contact between the soil and buried pipe.
- At the beginning, the temperatures of the earth and pipes are assumed to be the same.
- The air inside an EATHE (Earth Air Tube Heat Exchanger) undergoes thorough and uniform mixing within each segment along the tube, without any deviations.

2.3.3 Algorithmic Method

The assumptions employed for the CFD simulation are as follows.

i. The thermo-physical parameters of earth, PVC pipe, and air stay unchanged during the process.

ii. The vertical pipes are adequately insulated, and no heat transfer is accounted for at the exit.
iii. The thermal contact between the soil and the buried pipe is optimal.
iv. The air flow through the test part is completely
v. The pipe surface is subject to a no-slip condition for velocity.
vi. The air inside EATHE is uniformly distributed within each section along the tube.
vii. The soil surrounding the pipe exhibits isotropy, characterized by a uniform thermal conductivity throughout the ground.
viii. The heat resistance of the pipe material is insignificant due to the pipe's minimal thickness.
ix. The pipe has a consistent circular cross-sectional shape.
x. The thermal impact of the earth around the pipe becomes insignificant at a distance of '10 r' from the outer surface of the pipe, where 'r' represents the radius of the pipe.

2.3.4 Utilized numerical solver

FLUENT has two primary numerical solvers: a segregated solver and a coupled solver, which can be either implicit or explicit. FLUENT use either of these methods to numerically solve the integral equations regulating the conservation of mass, momentum, and energy (where applicable). In addition to these equations, other equations that include scalar values, such as turbulence and chemical species, can also be solved in a fluid. In these situations, a technique based on control volume is employed. The current investigation employed a segregated solver for the CFD analysis. In the segregated algorithm, the governing equations for each solution variable (such as velocity, temperature, pressure, turbulent kinetic energy, etc.) are solved sequentially, one after another. During the solving process, each governing equation is separated or isolated from the other equations, a process known as "decoupling" or "segregation". The segregated algorithm is memory-efficient as it just requires storing the discretized equations in memory one at a time. Given the solver's efficient use of memory, it has been taken into account in the current scenario.

In this methodology, the governing equations are solved in a sequential manner, as they are both non-linear and linked. Consequently, multiple iterations of the solution loop must be executed until a converged solution is obtained. The CFD analysis involves the passage of air through a rectangular duct. Heat is transferred from the heating plate to the air that is passing through the duct. By establishing suitable operational parameters, limits can be set by considering the conditions, solution parameters, and convergence criteria, a numerical solution that has reached convergence is obtained for each step. Various solution variables, including velocity, temperature, pressure, and turbulent kinetic energy, were examined at each stage utilizing the sequential outcomes of the CFD simulation. Thermal performance analysis of the Earth Air Tunnel using Computational Fluid Dynamics (CFD).

2.3.5 Methodology for solving a problem or achieving a desired outcome

A discretization scheme is necessary to solve the equations that govern scalars, such as temperature, pressure, and species concentrations. The two schemes pertinent to this study are.

a) The First Order Upwind scheme sets the values at the cell faces equal to the value at the center of the upstream cell.

b) On the other hand, the Second-Order Upwind scheme calculates the values at the cell faces using a Taylor Series expansion, allowing for a wider effect from the surrounding cells.

According to the Fluent User Guide (Fluent Incorporated), the first-order scheme provides a stable solution with a satisfactory rate of residual convergence, but the accuracy of the solution may be limited. On the other hand, the second-order upwind scheme will yield a more accurate solution. Consequently, a second-order upwind strategy has been implemented to achieve more precise outcomes.

2.3.6 Experiment to determine the level of grid resolution required for accurate results

A grid independence test (Figure 2a) was performed to evaluate the accuracy of the constructed CFD model. If the mesh is refined, meaning that the cells are reduced in size and consequently increased in number, the behavior observed during post processing should stay unaltered if the solution is grid-independent. In order to achieve a solution that is not dependent on the grid, simulations are conducted using three different types of mesh: coarse, medium, and fine. The same operational parameters are applied in all three scenarios. Figure 2 (b-d) illustrates the perspectives of several mesh types.

Figure 2 (a): Grid Independence Test.

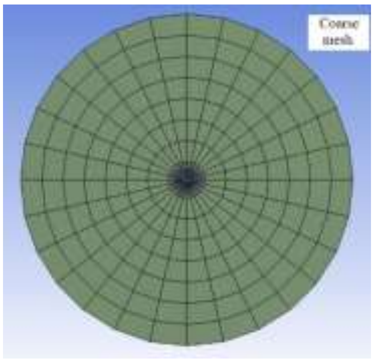

Figure 2 (b): Coarse Mesh.

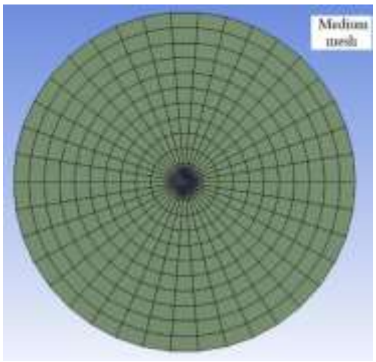

Figure 2 (c): Medium Mesh.

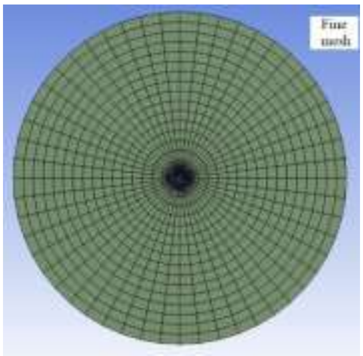

Figure 2 (d): Fine Mesh.

Table 2 and Figure 2 (a) reveal a temperature drop difference of 7.6% between coarse mesh and medium mesh, which occurs when there is a change in grid meshing. The temperature drop is considered the primary operating parameter.

Table 2: Results of Grid Independence Test.

Mesh Type	No. of Nodes	No. of Elements	Temperature Drop in (K)
Coarse Mesh	1431120	1411119	10.5
Medium Mesh	2161836	2135703	11.3
Fine Mesh	3315780	3281916	11.5

An observed temperature decrease of 1.7% is noted when transitioning from a medium mesh to a fine mesh. Considering the significant decrease in temperature (7.6% for medium mesh) seen between coarse and medium mesh, it may be concluded that medium mesh is the more appropriate choice. Conversely, the temperature decrease between medium and fine mesh is approximately 1.7%, which might be considered insignificant. Hence, the medium mesh is selected as the model grid meshing type due to its favorable combination of accuracy and reduced calculation time.

2.4 Validation of the model

The generated model underwent validation using both theoretical models and experimental data obtained from other researchers. The theoretical model used for comparison was formulated by Al-Ajmi et al., 2006[6] and was verified against pertinent experimental and theoretical investigations. Goswami, D. Y. and Dhaliwal, 1985[7] conducted an experimental investigation in North Carolina using a pipe with a diameter of 30 cm, a length of 24.7 m, and a depth of 1.7 m. The input parameters for the comparison with experimental and theoretical investigations are outlined in Table 3, providing thorough information.

Table 3: Input parameters for comparative validation.[8]

Input parameters	Value of Parameters
Pipe diameter (cm)	30
Pipe length (m)	24.7
Air velocity (ms^{-1})	1.5
Soil temperature (K)	291.89
Pipe depth (m)	2.13
Soil thermal conductivity ($Wm^{-1}K^{-1}$)	1.16

The findings from both the empirical and theoretical investigations are displayed in Table 4 and Figure 3 below.

Table 4: Simulation model validation (ambient air temperature: 298.56 K).

Axial distance from the EATHE pipe inlet (m)	Experimental data of Goswami, D. Y. and Dhaliwal, 1985. (K)	Theoretical data of Al-Ajmi et al. 2006 (K)	Results of simulationmodel (K)
3.35	298.00	297.94	297.97
6.4	297.40	297.43	297.82
9.45	298.00	296.97	297.44
12.5	297.40	296.54	297.11
15.55	296.80	296.15	296.84
24.7	296.80	295.16	296.11

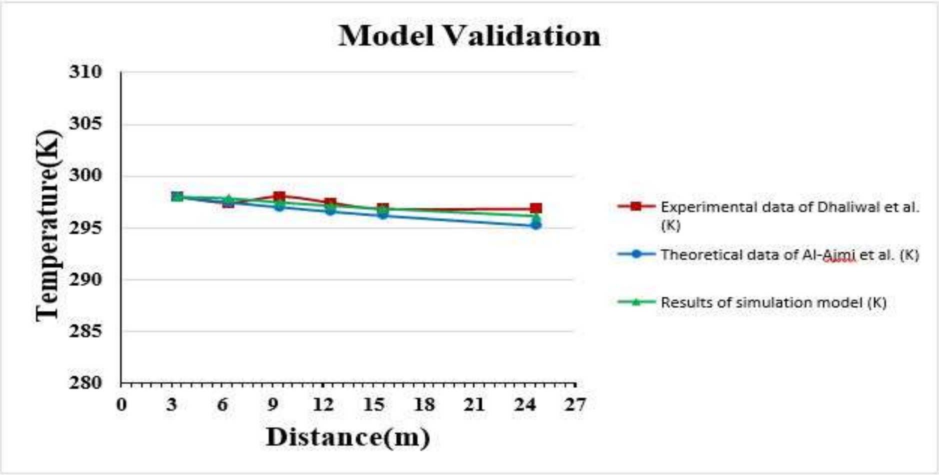

Figure 3: Simulation model results vs. experimental/theoretical data.

The aforementioned results demonstrate a high level of concordance and exhibit values that fall within the range of the two studies being examined. The discrepancy in the earth tube inlet temperature between the experimental data and the modeling results can be attributed to a clear data mistake in the experimental results (Figure 3). Nevertheless, the disparities between the simulation model and the Al-Ajmi model are negligible, suggesting that the model is capable of accurately forecasting the efficiency of an EATHE system.

3. RESULTS AND DISCUSSION

3.1 Analysis of the EATHE System's Performance at Various Air Velocities

Previous studies have shown that when a hot fluid, such as air, flows through a pipe buried in soil, it transfers heat to the surrounding soil. The amount of heat that the system will dissipate to the surrounding earth is heavily influenced by the velocity of the air moving through the pipe. The velocities utilized to determine the optimal velocity are 3 ms^{-1}, 3.5 ms^{-1}, 4 ms^{-1}, and 5 ms^{-1}, respectively. The simulation involves analyzing a 20-meter long pipe with a thermal conductivity of 1.6 $Wm^{-1}K^{-1}$, together with the surrounding soil which also has the same thermal conductivity. The data obtained at four distinct air velocities is presented in Table 5 below.

Table 5: Temperature drop data for different air velocity.

Air Velocity(ms^{-1})	Temperature at Different Distance (m) Along the Pipe (from inlet)										
	0	2	4	6	8	10	12	14	16	18	20
3	319	318.5	315.9	314.1	312.5	311	309.8	308.7	307.7	306.8	306
3.5	319	318.5	316.2	314.5	313	311.7	310.5	309.4	308.4	307.5	306.8
4	319	318.6	316.5	314.9	313.5	312.2	311.1	310	309.1	308.2	307.4
5	319	318.7	316.9	315.5	314.2	313.1	312	311	310.1	309.3	308.5

The thermal performance of the EATHE system has been analyzed by considering four distinct flow velocities. The pipe diameter remained constant at 0.1 m across four different flow conditions. The temperature decreases of the air passing through the pipe at velocities of 3 ms^{-}1, 3.5 ms^{-1}, 4 ms^{-1}, and 5 ms^{-1}, as shown in Table 5 and Figure 4, are 13K, 12.2K, 11.6K, and 10.5K, respectively. As the air velocity increases, the temperature drop decreases. The maximum temperature loss is observed at an air velocity of 3 ms^{-1}. Therefore, for future simulation, an air velocity of 3 ms^{-1} is employed.

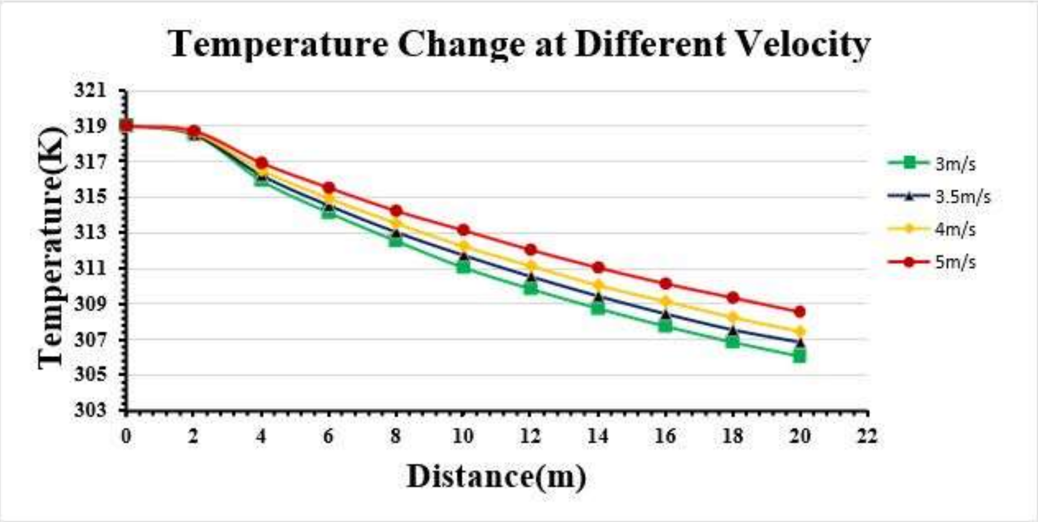

Figure 4: Graphical view of temperature drop for different air velocity.

3.2 Analyze the performance of the EATHE system under varying soil thermal conductivity

Soil thermal conductivity refers to the capacity of soil to transfer heat. In order to assess the influence of soil thermal conductivity on the efficiency of the EATHE system, three distinct conductivity values are employed: 0.75 Wm^{-1}K^{-1}, 1.5 Wm^{-1}K^{-1}, and 3.75 Wm^{-1}K^{-1}, respectively. The length of the pipe is maintained at a constant value of 20 meters. The pipe diameter remained consistent across all three situations, measuring 0.1m. Based on the prior examination of the effect of air velocity, it has been determined that the optimal velocity for air is 3 meters per second (ms^{-1}), regardless of the thermal conductivity being constant. Therefore, we employed an air flow velocity of 3 ms^{-1}. Next, we gather the temperature data (as indicated in table 6) at various distances from the intake while maintaining a constant velocity. This is done for three distinct soil thermal conductivities.

Table 6: Temperature drop for different soil thermal conductivity.

Thermal Conductivity (Wm^{-1}K^{-1})	Temperature at Different Distance (m) Along the Pipe (from Inlet)										
	0	2	4	6	8	10	12	14	16	18	20
0.75	319	318.6	316.6	315.1	313.7	312.5	311.4	310.3	309.4	308.6	307.8
1.5	319	318.4	315.5	313.5	311.8	310.2	308.9	307.8	306.7	305.9	305.1
3.75	319	318.1	314.4	311.9	309.8	308	306.6	305.4	304.5	303.7	303.1

According to Table 6 and Figure 5, the temperature difference between the starting point and ending point is 11.2K, 13.9K, and 15.9K for soil thermal conductivity values of 0.75 Wm^{-1}K^{-1}, 1.5 Wm^{-1}K^{-1}, and 3.75 Wm^{-1}K^{-1}, respectively. The temperature drop is directly proportional to the increase in soil thermal conductivity. The highest decrease in temperature is 15.9 Kelvin, found with a thermal conductivity of 3.75 Watts per meter per Kelvin. The maximum thermal conductivity observed is 11.2 Watts per meter per Kelvin. For a more in-depth examination, we can deem a soil thermal conductivity of 3.75 Wm^{-1}K^{-1} as optimal for the given setting.

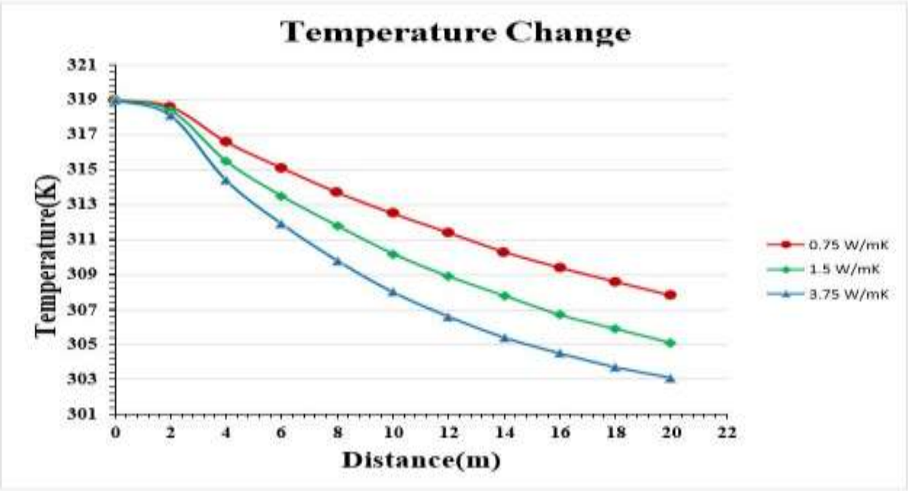

Figure 5: Graphical view of temperature drop for different soil thermal conductivity.

3.3 Analyze the performance of the EATHE system for various pipe arrangements

Four distinct pipe configurations are employed in this section to analyze the thermal efficiency of the EATHE system. The pipe length remains constant at 20 m while being bent into various forms. The shapes include I-shape, L-shape, S-shape, and U-shape. All four shapes have the same inner diameter of 0.1m. The air velocity entering the pipe is 3 m/s. Furthermore, the soil's thermal conductivity is maintained at a value of 3.75 Wm-1K-1. Once the variable value is configured as described, data on temperature change at various distances along the pipe is gathered. The data that has been gathered is displayed in Table 7 below.

Table 7: Temperature drop for different pipe arrangements.

Pipe Arrange-ment	Temperature at Different Distance (m) Along the Pipe (from Inlet)										
	0	2	4	6	8	10	12	14	16	18	20
I-shape	319	318.2	314.4	311.9	309.8	308	306	305.5	304.5	303.7	302.8
L-shape	319	318	314.4	311.9	309.7	307.8	306	305.3	304.4	303.6	302.8
U-shape	319	318.2	314.4	311.8	309.7	307	305.6	305	304.2	303.5	302.8
S-shape	319	318.2	314.4	310.4	307.8	307.5	306.3	304.1	303.7	303.4	302.8

Table 7 and Figure 6 demonstrate that the temperature decrease from the pipe's entrance to its exit remains constant across four distinct geometries. A temperature decrease of 16.2K has been seen for all four forms. Therefore, regardless of the pipe's shape, as long as the pipe length remains constant at 20 m and the air velocity and soil thermal conductivity remain unchanged, the temperature difference between the inlet and output remains constant. To conduct a more in-depth analysis, we will utilize a linear pipe configuration, as the geometry of the pipe has no impact on the thermal efficiency of the EATHE system.

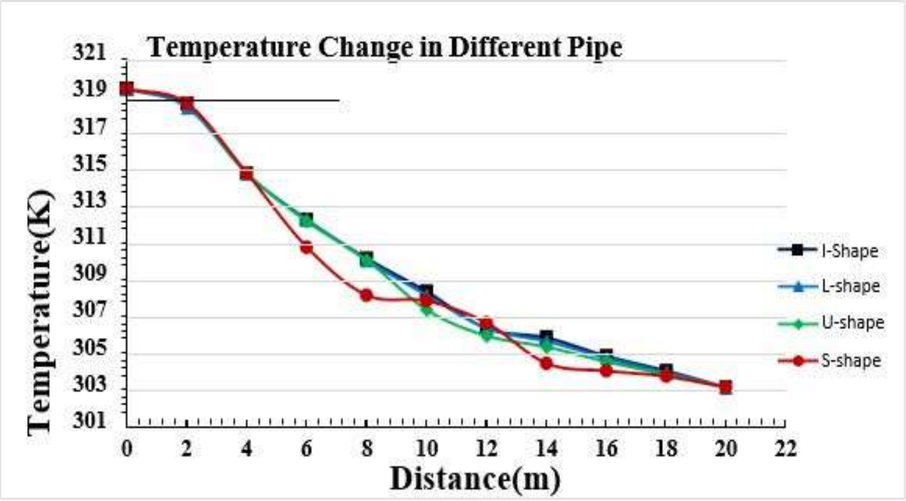

Figure 6: Graphical view of temperature drop for different pipe arrangement.

3.4 The Impact of Fin on the Performance of the EATHE System

3.4.1 Measurement of the fin at a distance of 1 meter

Fins, in the context of heat transfer, refer to surfaces that protrude from an item with the purpose of enhancing the efficiency of heat transfer to or from the surrounding environment. In order to assess the influence of fins on the efficiency of the EATHE system, we positioned the fins at a spacing of 1 meter apart. Data on temperature variation has been gathered (as presented in Table 8) and documented for single, double, triple, and quadruple fins employed in a 20-meter pipe, with each fin placed 1 meter apart from one another, commencing from the pipe's entrance. A velocity of 3 m/s for the air flow and a thermal conductivity of 3.75 W/mK for the soil are utilized. The pipe's inner diameter is maintained at 0.1m for the analysis. Once the setup is finished, the simulation data is gathered and recorded in Table 8.

Table 8: Temperature drop for fin at 1m distance.

Fin at 1m Distance	**Temperature at Different Distance (m) Along the Pipe (from Inlet)**										
	0	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
No. of fin 1	319	316	315.2	313.7	311.8	310.4	308.6	307.8	306.8	305.9.	305.1
No. of fin 2	319	316.8	314.3	313	311.4	309.6	308.6	307.5	306.5	305.7	305
No. of fin 3	319	316.8	313.4	312.3	310.9	309.5	308.3	307.2	306.2	305.5	304.7
No. of fin 4	319	316.8	313.5	311.6	310.5	309.1	308	306.9	306	305.2	304.5

The temperature difference between the intake and outlet for single, double, triple, and quadruple fins is 13.9K, 14K, 14.3K, and 14.5K, respectively, as shown in Table 8 and Figure 7. Based on the data presented in Figure 7, it can be concluded that there is a positive correlation between the number of fins employed and the magnitude of the temperature reduction. The quadruple fin exhibits a maximum temperature decrease of 14.5K, while the single fin demonstrates a minimum decrease of 13.9K. Consequently, augmenting the quantity of fins can enhance the thermal efficiency of the EATHE system.

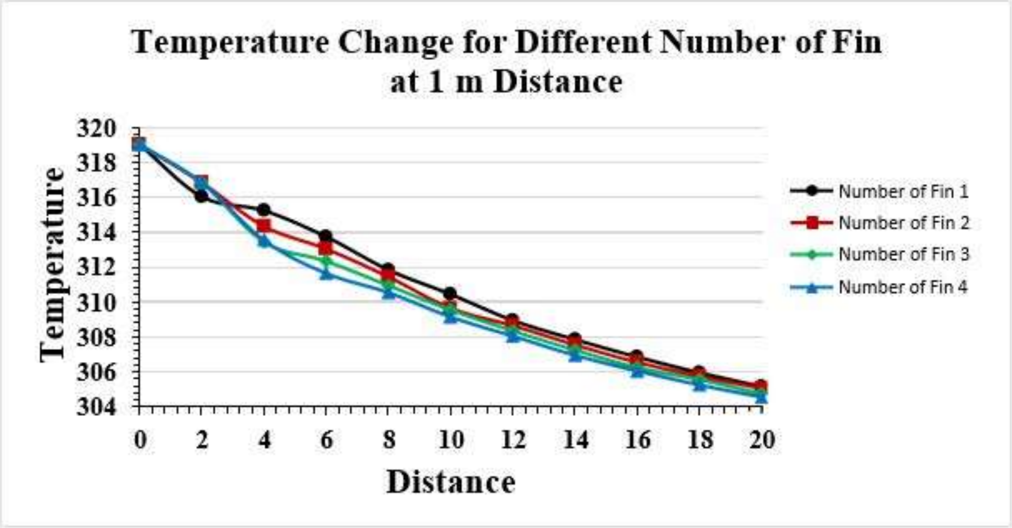

Figure 7: Graphical view of temperature drop for fin at 1m distance.

3.4.2 Fin located at a distance of 2 meters

The fins enhance the structural integrity of the heat exchanger, enabling it to withstand high pressure, while also offering an expanded surface area for efficient heat transmission. Similar to the preceding analysis in section 3.4.1, this study also employs single, double, triple, and quadruple fins. However, instead of using a 1-meter gap, we opted for a 2-meter distance between each fin. The velocity of the air flow at the entrance is 3 meters per second, and the thermal conductivity of the soil is 3.75 watts per meter per Kelvin. The length and inner diameter of the pipe are consistent throughout all four installations, measuring 20m and 0.1m, respectively. The temperature difference between the input and output is recorded in Table 9 below.

Table 9: Temperature drop for fin at 2m distance.

Fin at 2m Distance	**Temperature at Different Distance (m) Along the Pipe (from Inlet)**										
	0	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
No. of fin 1	319	318.3	314.8	313.4	311.7	310.3	308.8	307.3	306.7	305.8	305.1
No. of fin 2	319	318.3	315	312.3	311.1	309.7	308.5	307.3	306.4	305.6	304.8
No. of fin 3	319	318.3	314.9	312.4	310.2	309.2	308.1	307	306.1	305.3	304.6
No. of fin 4	319	318.3	315	312.4	310.2	308.4	307.6	306.7	305.8	305	304.3

Due to the increased surface area provided by fins, heat transfer is enhanced in comparison to a standard state. Based on the data shown in Table 9 and Figure 8, it is evident that the temperature drops for the single, double, triple, and quadruple fin setups at a distance of 20m from each other are 13.9K, 14.2K, 14.4K, and 14.7K, respectively. Therefore, when the number of fins utilized rises, the corresponding decrease in temperature similarly escalates. In a single-fin setup, the smallest temperature loss is recorded, whereas in a quadruple-fin setup, the maximum temperature loss occurs.

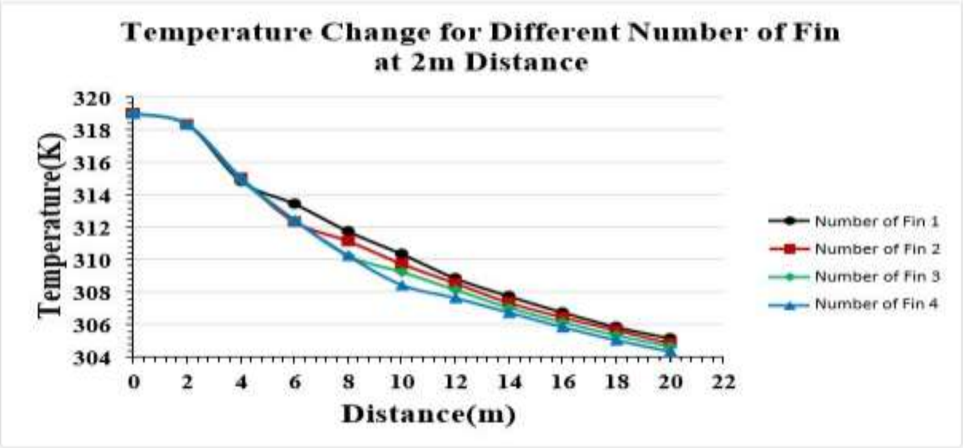

Figure 8: Graphical view of temperature drop for fin at 2m distance.

3.4.3 Fin observed at a distance of 3 meters

Fins, also known as expanded surfaces, are commonly employed in heat transfer applications to augment the heat exchange between the primary surface and the surrounding fluid. A round fin with a length of 0.02m was inserted into the inner section of the pipe for analysis.

We employ four distinct fin configurations, namely single, double, and quadruple, at intervals of 3 meters from the intake to measure the temperature decrease between the inlet and output. The pipe has a length of 20 meters and an inner diameter of 0.1 meters. The soil's thermal conductivity is maintained at 3.75 $Wm^{-1}K^{-1}$. Additionally, the velocity of air flow within the pipe is 3 meters per second. The temperature is documented in Table 10 at different intervals along the length of the pipe.

Table 10: Temperature drop for fin at 3m distance.

Fin at 3m Distance	**Temperature at Different Distance (m) Along the Pipe (from Inlet)**										
	0	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
No. of fin 1	319	318.2	314.5	313.3	311.9	310.2	308.9	307.8	306.8	305.9	305.1
No. of fin 2	319	318.2	314.5	313.2	310.7	309.6	308.5	307.3	306.4	305.6	304.8
No. of fin 3	319	318.2	314.5	313.4	310.7	308.6	307.9	307	306	305.3	304.5
No. of fin 4	319	318.2	314.6	313.4	310.7	308.6	307.9	306.3	305.7	305	304.3

Based on the statistics shown in Table 10 and the graphical representation in Figure 9, it is evident that there is a temperature decrease of 13.9K, 14.2K, 14.5K, and 14.7K for the single, double, triple, and quadruple fin configurations, respectively. Similar to prior investigations on the efficiency of fins at distances of 1m and 2m, an increase in the number of fins resulted in a decrease in temperature. The highest temperature decrease seen is 14.7 Kelvin, whereas the lowest temperature decrease recorded is 13.9 Kelvin in a single-fin configuration. The temperature decrease in a single fin configuration is 5.76% greater compared to a quadruple fin configuration.

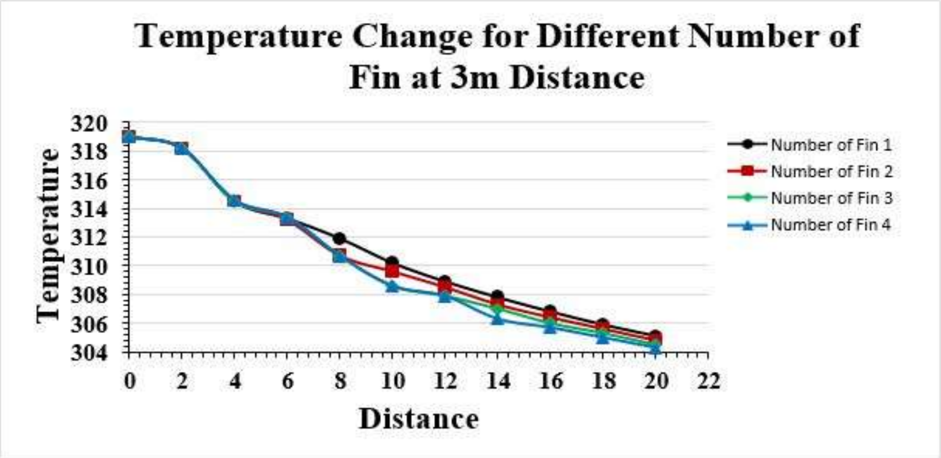

Figure 9: Graphical view of temperature drop for fin at 3m distance.

3.5 Utilizing the Fin Block for Convergence and Divergence

Convergence refers to the phenomenon where forces are coming together, whereas divergence indicates that objects are going apart. During this phase of the analysis, the convergence and divergence techniques are utilized. In order to generate this scenario, we employed a fin that was obstructed by five more fins. The five fins sequentially extended to lengths of 0.02m, 0.03m, 0.05m, 0.03m, and 0.02m. This configuration results in a restricted area within the internal diameter of the pipe. This simulation setup is considered complete by utilizing sets of fin blocks numbered 1, 2, 3, and 4. Air is flowing through a pipe with a length of 20 meters and an inner diameter of 0.1 meters at a velocity of 3 m/s. The thermal conductivity of the soil in the immediate area is 3.75 Wm-1K-1. The simulation is conducted for one, two, three, and four sets of this fin block. Data was gathered from four distinct situations as presented in Table 11.

Table 11: Temperature drop in convergence and divergence method.

Fin at 4m Distance	**Temperature at Different Distance (m) Along the Pipe (from Inlet)**										
	0	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**
No. of fin 1	319	315.3	310.8	309.3	308.4	307.1	306.2	305.3	304.4	303.8	303.2
No. of fin 2	319	315.2	310.9	308.5	305.9	304.5	304.1	303.6	303.1	302.7	302.3
No. of fin 3	319	315.3	310.9	308.5	305.9	304.6	303.3	303.4	302.1	301.9	301.6
No. of fin 4	319	315.2	310.9	308.5	305.9	304.5	303.3	302.4	301.9	301.3	301

According to the data presented in Table 11 and Figure 10, the temperature difference between the inlet and exit for the fin blocks is 15.8K, 16.7K, 17.4K, and 18K for sets 1, 2, 3, and 4, respectively. As the number of fin blocks used rises, the temperature drop also increases. The temperature decrease is 5.7% and 10.1% greater for 2 sets and 3 sets of fin blocks, respectively, compared to 1 set of fin blocks. The temperature decrease for 4 sets of fin blocks is 13.9% more than that of 1 set of fin blocks. The temperature decrease is far greater when fins are used in their typical manner. The greatest decrease in temperature occurs during convergence and divergence, namely when utilizing 4 sets of fin blocks. This results in a temperature drop of 18K, which is approximately 3.3K higher than when using the standard number of fins.

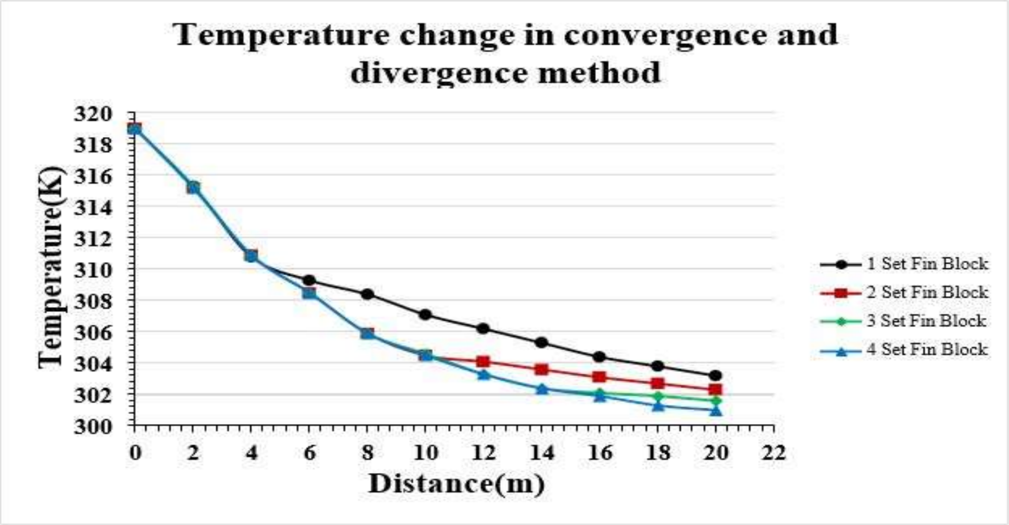

Figure 10: Graphical view of temperature drop in convergence and divergence.

4. Conclusions and Prospects of the Study

It is widely acknowledged that all items have both benefits and drawbacks. The real-world application of EATHE is limited by the low heat conductivity of the soil and the slow velocity of air moving through the pipe. In order to assess the influence of soil thermal conductivity and air velocity on the EATHE system, three distinct thermal conductivities for soil and four varying values of air velocity are employed. The simulation investigates the influence of thermal conductivity and air velocity on a pipe that is 20 meters in length and has an inner diameter of 0.1 meters. We also determine the efficacy of fins in enhancing the thermal efficiency of the EATHE system. In this particular task, fins are employed at three distinct intervals, specifically 1m, 2m, and 3m apart. The quantity of fins utilized varies between one and four. The analysis focuses on the impacts of convergence and divergence by examining a fin block composed of five fins in a specific configuration. This study presents a numerical simulation model of the EATHE system, which has been developed and verified using established experimental and theoretical data.

Based on our investigation, the following conclusion may be inferred.

- The study focused on analyzing various velocity fluctuations of air flowing through the pipe. A simulation was conducted with four distinct velocities: 3 ms^{-1}, 3.5 ms^{-1}, 4 ms^{-1}, and 5 ms^{-1}. The results indicate that when the velocity of entering air increases, the rate of heat transfer decreases. Consequently, the greater the velocity of the incoming air, the increased time it will require to cool the air.
- The study also examined three distinct soil thermal conductivities: 75 Wm^{-1}K^{-1}, 1.5 Wm^{-}

$^1K^{-1}$, and 3.75 $Wm^{-1}K^{-1}$. Unlike the air velocity, when we increase the thermal conductivity, the heat transfer rate likewise increases.

- Furthermore, the effects of the pipe configuration were examined. Four distinct pipe configurations, namely I-shape, L-shape, S-shape, and U-shape, were employed. However, as we maintained consistent input values for all four pipe forms, the temperature drop remained constant. Therefore, we may infer that the layout of the pipes does not affect the outcome of the experiment.
- Fin is employed to augment the surface area in order to enhance heat transfer. The spacing between the fins utilized in the study is 1 meter, 2 meters, and 3 meters, respectively. The quantity of fins varies from 1 to 4, and the thermal efficiency escalates with an increase in the number of fins. Utilizing fins in the pipe set of the EATHE system has the potential to enhance its thermal performance.
- The convergence and divergence methods using fin blocks exhibit the highest level of heat transmission. As the quantity of fin blocks rises, the temperature decreases correspondingly. The smallest decrease in temperature was recorded when we employed four fin blocks, resulting in a reduction of 18k.

Despite extensive research conducted by numerous scholars, the EATHE system remains incomplete. This study contributes to the expansion of research on the EATHE system. However, there is still ample opportunity for additional investigation. Here are a few examples.

- An additional investigation is to determine the optimal combination of soil thermal diffusivity, thermal conductivity, pipe length, pipe diameter, and velocity.
- The effects of various air flow patterns and their comparisons can be examined.
- Various comprehensive comparisons can be made between the steady and transient analysis approaches when utilizing identical input parameters.
- Given that circular fins are employed in this task; many varieties of fins can be utilized for the purpose of thermal performance analysis.

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