International Journal of Mechanical and Thermal Engineering

E-ISSN: 2707-8051
P-ISSN: 2707-8043
IJMTE 2024; 5(1): 56-65
Received: 18-12-2024
Accepted: 21-01-2024

Azhar Abeda
Mechanical Power Department. Technical Institute, Northern Technical University, Kirkuk, Iraq

Abdulrazzaq Mohammed
Department of Mechanical Engineering, College of Engineering - Alshirqat, Tikrit University, Tikrit, Iraq

Harith A Ali
Department of Mechanical Engineering, College of Engineering - Alshirqat, Tikrit University, Tikrit, Iraq

Mohammed Abidb
Department of Mechanical Engineering, College of Engineering - Alshirqat, Tikrit University, Tikrit, Iraq

Abdullah Jasim
Department of Mechanical Engineering, College of Engineering - Alshirqat, Tikrit University, Tikrit, Iraq

Corresponding Author:
Azhar Abeda
Mechanical Power Department. Technical Institute, Northern Technical University, Kirkuk, Iraq

A numerical analysis of the operational factors influencing the effectiveness of a building air conditioning systems employing geothermal energy

Azhar Abeda, Abdulrazzaq Mohammed, Harith A Ali, Mohammed Abidb and Abdullah Jasim

Abstract
The operation of air conditioning systems necessitates a substantial amount of electrical energy. Passive air cooling is an energy-saving technique that is effective in hot and arid regions such as Iraq. The ground-cooling approach involves the utilization of a stationary surface temperature to passively cool a given space, hence reducing energy consumption in buildings. This research uses geothermal methods to model the building's air conditioning (cooling) system under various operating conditions. Also, utilizing ANSYS FLUENT to simulate the open-loop heat exchanger behavior and its impact on outside air temperature and cooling efficiency. Simulations were carried out on a ground heat exchanger with different designs, the following dimensions of length (15, 33, and 40) m and diameter (0.1, 0.1524, and 0.2) m at different airflow speeds (1, 1.5, and 2) m / s with depth (3 m) underground. The findings indicated that the air temperature differential between entrance and exit is directly related to pipe length and inversely proportional to air velocity and tube diameter. The largest difference between air entrance and exit temperatures was 22 K at 1 m/s, 33 m length, and 0.1 m diameter. Furthermore, the cooling efficiency improves with decreasing pipe flow speed and diameter, but it is linearly related to tube length. The geothermal heat exchanger achieved a peak cooling efficiency of 86.6% when operated at an air velocity of 1 m/s. The study recommended designing a network of geothermal exchangers to adapt homes. Additionally, the implementation of a soil humidification system around the pipe serves to decrease the temperature of the air exiting from the heat exchanger. Moreover, use ground shading techniques, such as vegetation.

Keywords: Building conditioning, diameter, heat exchanger, length, simulate

Introduction

The Fossil fuels are an unstable energy source and will decrease over the next few years. According to the World Energy Organization, the energy demand will increase from (665EJ) in (2020) to (865EJ) in (2040) compared to (552EJ) in (2010) [1]. Fossil fuels are the main contributor to climate change. At the same time, heating and cooling use over half of global energy output. As a result, customers are searching for environmentally conscious and energy-efficient building designs, so it is essential to get them ready using passive and active tactics [2]. One of the earliest and most well-liked methods of using geothermal energy is direct usage. It employs about (14.9%) of geothermal energy for heating buildings, (25.8%) for bathing and swimming, (2.7%) for heating water, and (0.2%) for other uses. Where the abundant energy from the use of geothermal energy reached about (250) million barrels of oil annually and (107) million tons of carbon dioxide in the atmosphere [3, 4]. The ground capacity is a negative way to cool and heat buildings, and to utilizing the thermal energy of the earth effectively must design a heat exchanger that includes long metal or plastic pipes placed underground at a certain depth and its end is above the ground where the air is drawn inside the pipe by a pull fan installed at one end of the pipe and during the passage of air inside the pipe, it absorbs or loses part of its heat to the soil surrounding the pipe and the air comes out from the other end to the space to be cooled as shown in the Figure (1) [5]. There are three different forms of geothermal heat exchangers: an open-ring type, a closed-loop type, and a hybrid system type [6]. The impact of soil moisture on the thermal efficiency of geothermal heat exchangers employed for heating purposes in India was examined through the implementation of two distinct systems: one equipped with a humidification system and the other lacking such a system. The present study demonstrates that heat exchangers equipped with humidification systems exhibited a notable improvement in efficiency, ranging from 15.8 to 26.1 percent, compared to their counterparts lacking such systems [7].

Zaidan, *et al*., [8] presented a study on the depth of burial through the study of air conditioning for buildings using geothermal energy techniques for cooling in the Iraqi city of Tikrit. The findings indicated that the earth's temperature at 3 m is 20–21 °C. Research by Badgujar *et al*. [9] examined the use of geothermal exchangers in air conditioning in India. The results indicate that the subsurface temperature of the Earth is relatively constant throughout the year, ranging from 15 to 20 °C at a certain depth. Thus, geothermal exchangers can cool and heat in winter and summer by utilising the differential between outside air and ground temperature. Noori and Hasan, [10] carried out numerical study of the impact of the type of pipe material and its thickness on the general behavior of geothermal exchangers under the climatic conditions of the city of Nasiriyah / Iraq. Two different types of pipes were used, the first type (PVC) and the second type is steel. The results display little improvement in the temperature air in case using steel materials. Moreover, the thermal performance of two different kinds of geothermal exchangers used to cool buildings in Algeria was also studied experimentally and numerically by Menhoudj *et al*. [11]. EAHE-Zinc, which stands for a zinc pipe attached to a chamber, is the first kind. EAHE-PVC, which stands for the plastic pipe attached to a second chamber, is the second kind. The findings indicated that the rate of temperature drop is equivalent for zinc and PVC pipes (6 °C and 6.5 °C, respectively) and that the energy provided by PVC pipes covers 58.42% of the room's cooling needs, while that provided by zinc pipe pumped in the first chamber only covers 35.44% of those needs. At the University of Biskra in Algeria, Belloufi *et al*. [12] presented a computational and experimental investigation on geothermal exchanger transitional behaviour in continuous operation mode, soil thermal conductivity, and environmental variables. The numerical and experimental findings correlate well with an error rate of 7.46%. The greatest temperature decrease (18.06 °C) and thermal efficiency (78.96%) for air inside at 48.87 °C were also found. Yousef *et al*. [13] conducted a theoretical investigation on geothermal exchanger thermal performance in tropical Malaysia. PVC pipe option with 25m length, 2m depth, and 100mm diameter. With a 25-m length, 100 mm diameter, and a 0.02 kg/s flow rate, a ground heat exchanger made of PVC has an interior temperature of 35 ºC and an outside temperature of 25.59 ºC. A numerical analysis of a ground heat exchanger in Turkey was conducted using ANSYS FLUENT 12.1 by Tasdelen and Degteken, [14]. The findings showed that raising the Reynolds number raises outside air temperature and decreases burial depth.

Anand and Mishar, [15] conducted an analysis of geothermal exchangers for Bhopal's climate. The researchers used ANSYS FLUENT to develop a two-dimensional ground heat exchanger model in the shape of a W. The largest temperature differential between air entering and leaving a horizontally buried pipe was 22 °C and 8.01 °C in summer and winter, respectively. The largest summer-to-winter temperature differential was 22 °C when the pipe was buried vertically. The largest summer-to-winter temperature differential was 22 °C when the pipe was buried diagonally.

The examination of previous research has revealed a notable absence of studies investigating the implementation of earth pipe building-integrated cooling systems in desert regions such as Iraq, specifically focusing on the utilization of geothermal energy without the reliance on mechanical equipment. This research will simulate an open-type heat exchanger in 3D. Along with research on how operating parameters (air velocity, pipe diameter, and length) affect ground heat exchanger performance

Theoretical Part

This chapter reviews the mathematical equations and the thermal balance equations for the ground heat exchanger. The mathematical equations aim to perform designed calculations to verify the temperature values leaving the exchanger. In addition, a three-dimensional simulation of the heat exchanger was conducted using the ANSYS FLUENT R 16.1 software to validate the temperature distribution throughout the whole length of the heat exchanger.

Geothermal heat exchanger design

In the current research, the heat exchanger used type (open ring) where the air is withdrawn from the external surroundings and passed inside the buried pipes to cool the air or heat it through heat exchange between the air and the soil surrounding the pipe and the air comes out into the space as air conditioner as shown in Figure. 1. The geothermal cooling system was developed with consideration for the specific environmental circumstances of Salah Aldin, a city located in Iraq. The heat exchanger used in simulation made of galvanized aluminum with different diameter and length are (0.1, 0.1542, 0.2 m) and (19, 33, 40 m) respectively, and distance between legs of 0.6 m. The approved design method for the geothermal cooling system is as follows [17]:

1. Determine the cooling load of the structure requiring cooling.
2. Choose the type of material the heat exchanger pipe.
3. The calculation of the length of the ground pipe is determined by a set of equations and in accordance with [18]:

$$L = \frac{Q_{room}}{h*\pi*D*\Delta T} \tag{1}$$

Whereas,

L = required pipe length (m), Q= Room cooling load (W), D = pipe diameter (m) and ΔT= difference between atmospheric and outgoing air temperatures (°C). The following equation calculates the convection heat transfer coefficient (h) [19]:

$$h = \frac{Nu*k_a}{2r_1} \tag{2}$$

Where

Nu = Nusselt number.

ka = air thermal conductivity (W/m. °C)

The equation below calculates Reynolds number [20]:

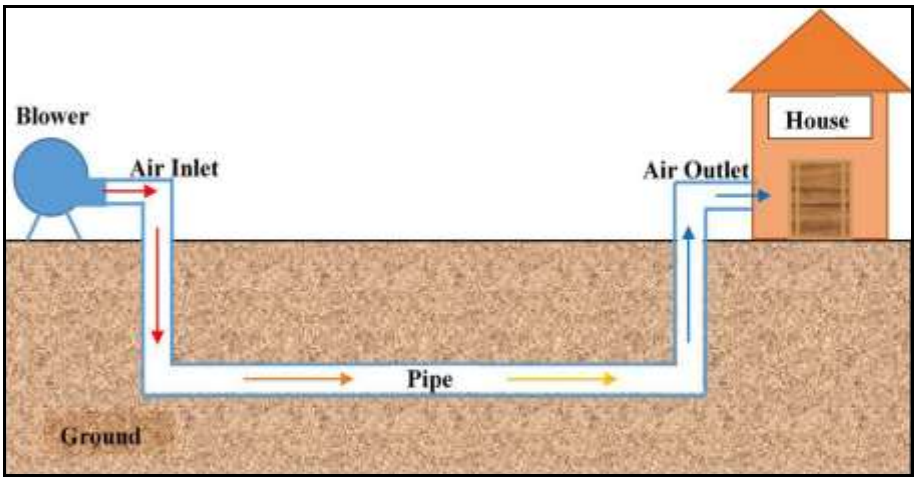

Fig 1: Ground heat exchanger system [16].

$$Re = \frac{\rho_a * v * D}{\mu_a} \quad (3)$$

Whereas

V = air velocity (m/s), ρa=Air density (Kg/m^3), μa = dynamic viscosity of air (kg/m.s) and D = pipe diameter (m)

The coefficient of friction can be calculated from the following equation [20]:

$$f = \frac{64}{Re} if\ (Re) < 2300 \quad (4)$$

$$f = (0.79 \log(Re) - 1.54)^{-2}\ f\ (Re)\ > 2300 \quad (5)$$

The Nusselt number is calculated from the following equation [21]:

$$Nu = \frac{(f/8)*(Re-1000)*Pr}{1+12.7*\sqrt{\frac{f}{8}}*\left(Pr^{\frac{2}{3}}-1\right)} \quad (6)$$

$$For\ (3000 < Re > 5 * 10^6)$$

This equation calculates Prandtl number:

$$Pr = \frac{c_a * \mu_a}{k_a} \quad (7)$$

Whereas:

ca = heat capacity of air (KJ/Kg. °C)

ka = thermal conductivity of air (W/m. °C)

Heat transfer between soil and air

The dissimilarity in air and soil temperatures leads to thermal interaction between the soil and air, which occurs via a submerged pipe positioned at a specific depth. This interaction results in alterations to the temperatures of both the air and soil in the vicinity of the pipe. As described in [22], divide the entire temperature difference by the total thermal resistance to determine the heat transfer rate.

$$q = \frac{(T_f - T_s)}{R_t} \quad (8)$$

Whereas: q = average heat transferred between air and soil (W/m), Rt =Total thermal resistance, (m. °C/w), Tf = fluid temperature (°C), and Ts = soil temperature (°C).

To get the overall thermal resistance (Rt) for the convection of heat between the air and soil around the pipe, it is necessary to calculate the sum of three individual thermal resistance values [23]:

$$R_t = R_c + R_p + R_s \quad (9)$$

Whereas:

The symbol Rc represents the thermal resistance associated with convection heat transfer between the inner surface of a pipe and the surrounding air (m. °C/W). The thermal resistance to conduction heat transmission between the outer and inner surfaces of a pipe is denoted as Rp (m. °C/W).

The thermal resistance, denoted as Rs, is the resistance to heat transfer caused by the connection between the outer surface of the pipe and the surrounding soil (m. °C/W).

The air flow rate can be calculated from the following equation [23]:

$$\dot{m} = \rho_a * v * A_p \quad (10)$$

Whereas:

$\dot{m}$ = air mass flow rate (Kg/s)

ρ_a = air density (Kg/ m^3)

A_p = pipe cross-sectional area (m^2)

There is no other fluid that may transport heat between the earth and air but air. Flowing through the pipe and into the nearby soil is the heat that the air gains or loses. Under the assumption of optimal contact between the outer pipe's surface and the surrounding soil and a significantly higher thermal conductivity of the soil compared to the surface resistance, it may be inferred that the inner pipe's surface temperature remains constant and is equivalent to the temperature of the Earth. The equation provided may be used to calculate the aggregate quantity of heat transferred through the airflow within the pipe [24].

$$Q = \dot{m} c_a (T_i - T_{out}) = \frac{L * \Delta T_m}{R_t} \quad (11)$$

$$\Delta T_m = \frac{(T_i - T_{out})}{\log\left[\frac{(T_i - T_{out})}{T_{out} - T_s}\right]} \quad (12)$$

Whereas:
T_i= Inlet air temperature (°C)
T_out= Outlet air temperature (°C)
T_s= soil temperature (°C)
From the two equations (11) (12) it is possible to calculate the temperature of the outgoing air:

$$T_{out} = T_s + (T_i - T_{out}) * e^{-\frac{L}{R_t * \dot{m} * c_a}} \quad (13)$$

The ratio of the actual temperature decrease refers to the greatest potential temperature reduction, which can be determined using the following equation:

$$\varepsilon = \frac{(T_i - T_{out})}{(T_i - T_s)} \quad (14)$$

Simulation

A numerical simulation (3-D) shows how altering air velocity, pipe length, and diameter affect heat exchanger heat transfer. Numerical simulations using ANSYS-Fluent 2020 R16.1. Analysis assumptions are [17]:

1. 1.The soil around the pipes has homogenous heat conductivity across all levels.
2. The Earth's surface temperature is approximately equivalent to the surrounding air temperature, commonly referred to as the ambient air temperature.
3. 3.The pipe is circular.

Geometry of Case Study

To solve the researched state numerically using CFD Fluent, the problem geometry must be explicitly constructed. In accordance with the stated design specifications (19, 33, and 40 m) of Length, Diameter (0.1, 0.1524, and 0.2 m), and Thickness (1.5 mm) as shown in Figure (2), a design model for the geothermal heat exchanger was produced using ANSYS Workbench.

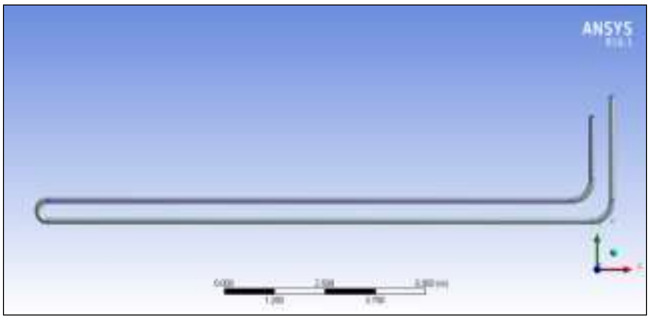

Fig 2: The model of the geothermal heat exchanger that is designed

Mesh Independence Test

To reduce the error rate and enhance the numerical simulation outcomes. Figure 3 shows the results of the mesh independent test using different numbers of sample mesh elements to determine the right amount that avoids divergence in the computations. According to the findings (see Table 1), the mesh element size and node count for heat exchanger forms were 91732 and 132450, respectively.

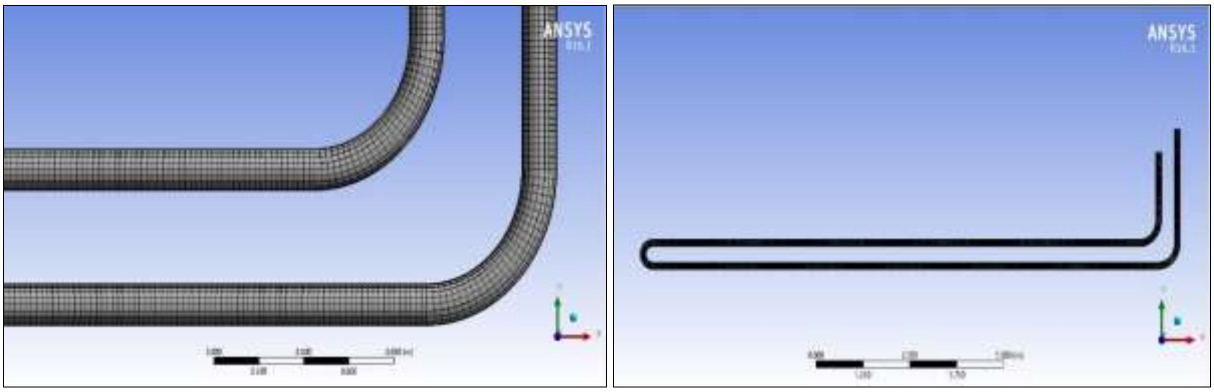

Fig 3: Mesh of the geothermal heat exchanger.

Setup Solver

In order to determine the solutions to the equations, it is necessary to establish a period, which is contingent upon the magnitude of the time step. Hence, the selection of an appropriate number of time steps is contingent upon the practical outcomes. A more favourable outcome was achieved while using a time step size of 0.05 seconds. To assure the convergence of the solution at each time step, a maximum iteration value of 10 was selected. The initial input air temperature was established at 317 K, and various time step sizes were examined. The time steps used in the study were 800,000, with the selection of the SIMPLE algorithm for the pressure-velocity coupling. The energy and momentum equations were estimated using a second-order upwind method, whereas the pressure energy equation was approximated using a second-order scheme.

Boundary Conditions

For any geometric form, to solve equations and simulate the heat transfer process and temperature distribution. The following criteria apply to the simulations that were chosen:

Table 1: Setup and Boundary Condition

Mesh		Input data For summer		Boundary Condition	
Nodes	132450	T_{in}	217 k	Inlet	Velocity inlet with time varying profile file
Elements	91732	T_{soil}	295 K		
		L	19, 33,40 m	Pipe	Stationary walls
Smoothing	Medium	V	1,2,3 m/s	Outlet	Pressure outlet with zero static pressure
Transition	Slow	d	0.1, 0.154, 0.2 m		
Inflation	3				
Face sizing	0.00045				

Results and Discussion

Results from the analytical investigation were reported here. The study investigated the impact of ambient air temperature, relative humidity, and air velocity on the performance of ground heat exchangers. The performance of the geothermal exchanger is influenced by factors such as air velocity, pipe length, and pipe diameter. The constant state values for each variable are as follows: the pipe material is aluminium, the air velocity is 1 m/s, the pipe length is 33 m, the pipe diameter is 0.1524 m, and the depth is 3 m. One variable is changed at each study and the values of the other variables are kept and the inlet air temperature is (317 K), soil temperature (295 K) and constant depth (3 m) underground.

Figures. 4 illustrates the ground heat exchanger's air temperature at 1 m/s, 22 mm diameter, 33 m length, and 317 K entering air. Results demonstrated a 17-K difference in entering and exiting air temperatures. if the air speed is raised to 1.5 m/s under the same circumstances. Figures. 5 shows a 13-K variation in entering and exiting air temperatures. As speed increases, heat exchange between air and earth around the pipe diminishes. With the entry-exit air temperature difference reduced to 11 K, raising the air velocity to 2 m/s had the same effect (Figures. 6). Due to reduced heat transfer, air speed inversely affects cooling efficiency. The greatest efficiency was 86% at 1 m/s, and the lowest was 54% at 2 m/s.

Figures. 7 illustrates the ground heat exchanger's air temperature at 1 m/s, 0.1 m diameter, 33 m length, and 317 K input air. The data reveal a 22 K drop in outside air temperature from input. Increasing the pipe diameter to 0.15 m reduces the entry-exit air temperature differential to 17 K (Figures. 8) In a tiny pipe diameter, air stays in the center and near the soil, and thermal energy transfers quickly, enabling increased heat transfer to the soil and raising the air temperature to the soil temperature. Increasing the pipe diameter to 0.2 m decreased the difference between entrance and exit air temperatures to 11 K (Figures. 9). The cooling effectiveness is inversely related to pipe diameter because the heat transfer coefficient decreases with pipe diameter. The maximum cooling efficiency value was (95%) at the lowest geothermal heat exchanger diameter (0.1 m), at the exchanger diameter (0.15 m), the cooling efficiency value was (81%) and the cooling efficiency value was (40%) at the largest geothermal exchanger diameter (0.2 m).

Figures. 10 to 12 demonstrate how ground heat exchanger pipe length affects outside air temperature. The difference between entrance and exit air temperatures is (10, 18, and 18) K for length (15, 33, and 40) m, velocity 1 m/s, and diameter 0.1 m. This feature allows heat transmission between air and earth to take longer in long pipes because air flows longer within them. Also, geothermal heat exchanger length directly affects cooling efficiency. The greatest cooling efficiency was 95% at the exchanger length (40m) and 54% at the pipe length (15 m).

Figure 13 illustrates the variation in theoretical temperatures while utilising an aluminium ground heat exchanger measuring 3 inches in diameter and 9 metres in length, at varied air flow rates of 31.8, 63.6, and 95.4 m3/hr, compared to the empirical findings of researcher Abdullah Jasim [27]. The results showed varying rates of difference, with the maximum value of 4.6% observed at the 13th hour at a flow rate of 95.4 m3/hr. The results indicated a discrepancy of 2.9% between the practical and theoretical outcomes.

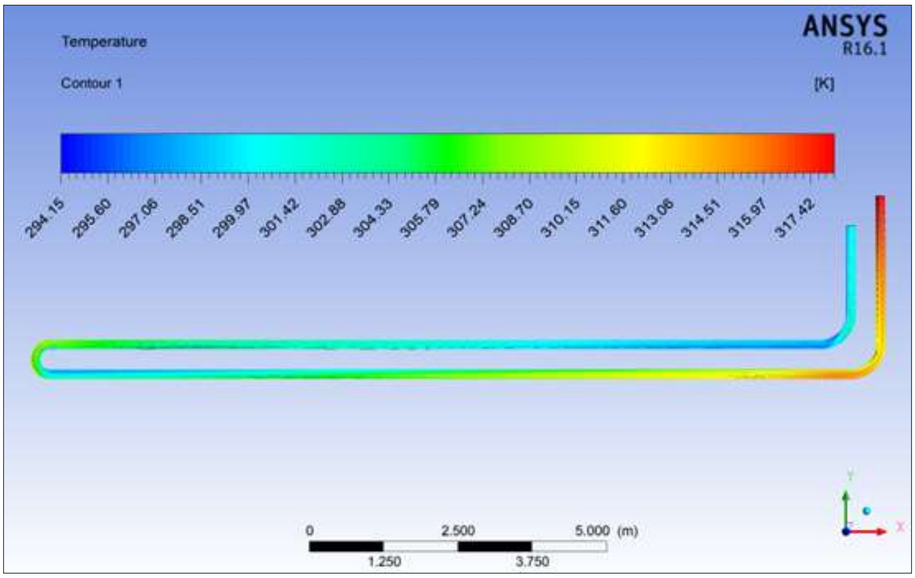

Fig 4: Show Air temperature distribution in a geothermal heat exchanger with a 1 m/s speed, a 33 m length, and a 0.15 m diameter.

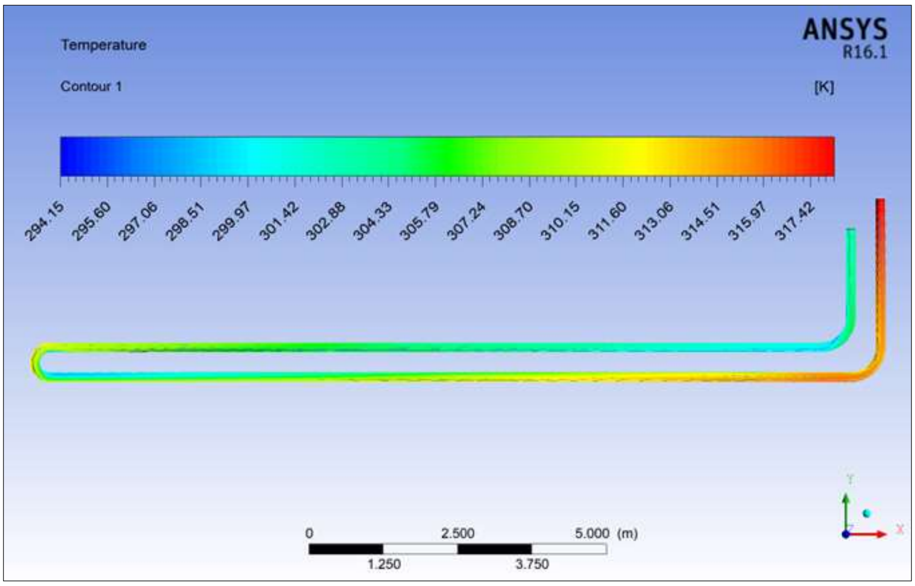

Fig 5: Show Air temperature distribution in a geothermal heat exchanger with a 1.5 m/s speed, a 33 m length, and a 0.15 m diameter.

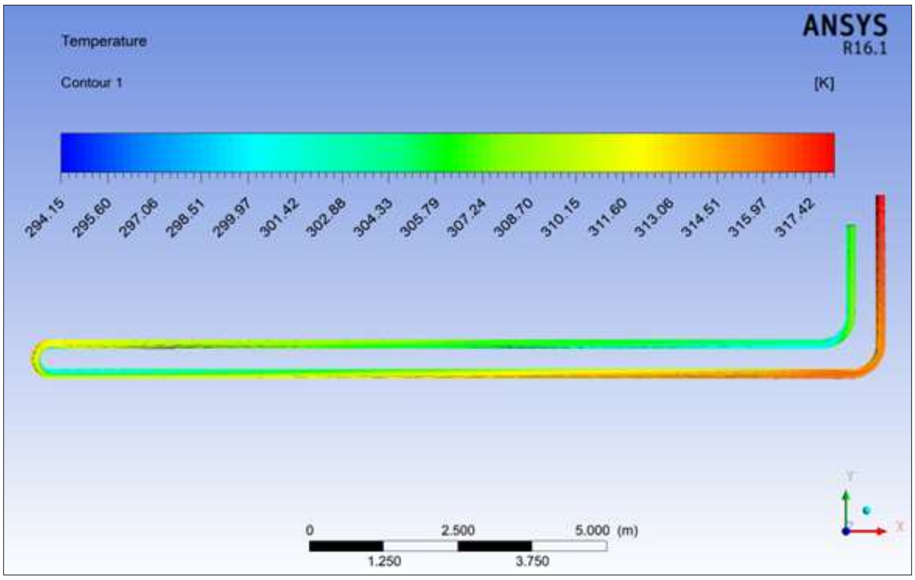

Fig 6: Show Air temperature distribution in a geothermal heat exchanger with a 2 m/s speed, a 33 m length, and a 0.15 m diameter.

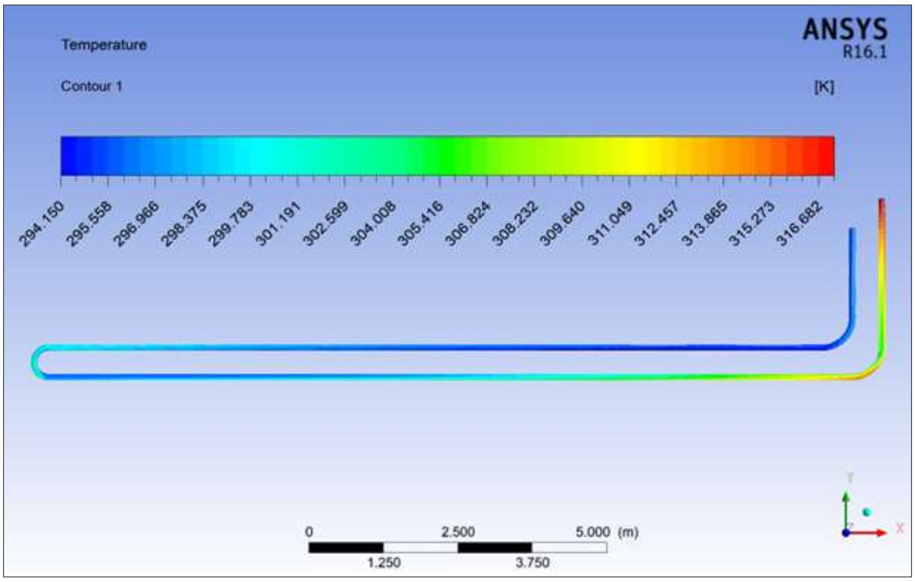

Fig 7: Show Air temperature distribution in a geothermal heat exchanger with a 1m/s speed, a 33 m length, and a 0.1 m diameter.

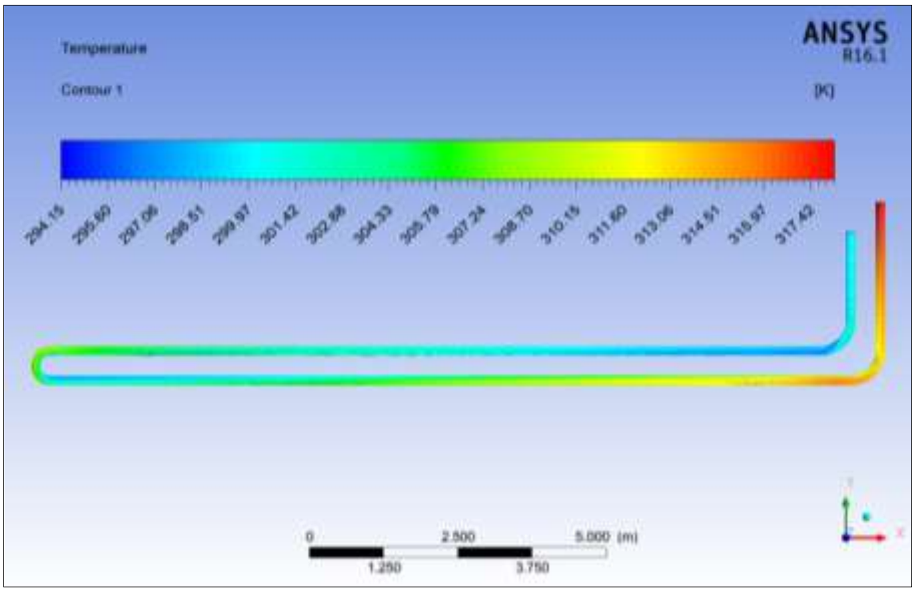

Fig 8: Show Air temperature distribution in a geothermal heat exchanger with a 1 m/s speed, a 33 m length, and a 0.15 m diameter.

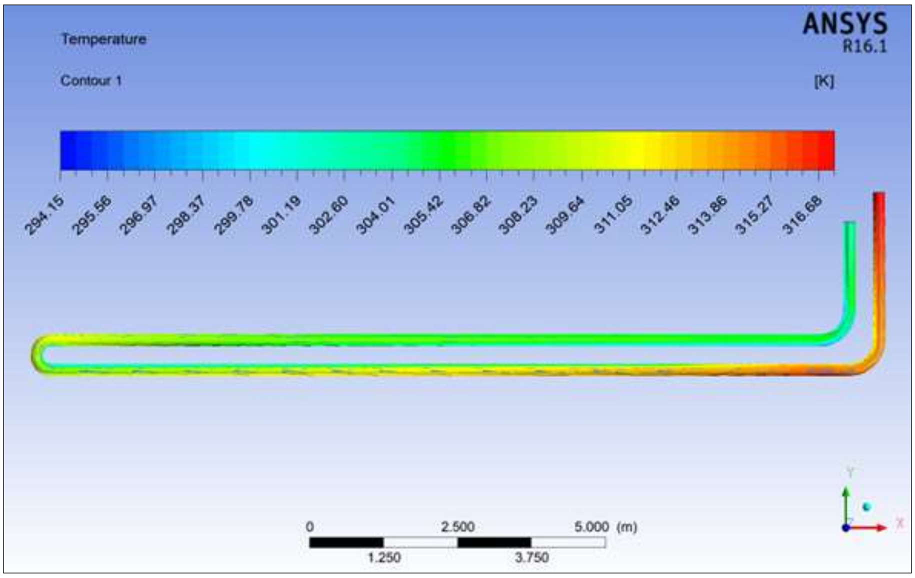

Fig 9: Show Air temperature distribution in a geothermal heat exchanger with a 1m/s speed, a 33 m length, and a 0.2 m diameter.

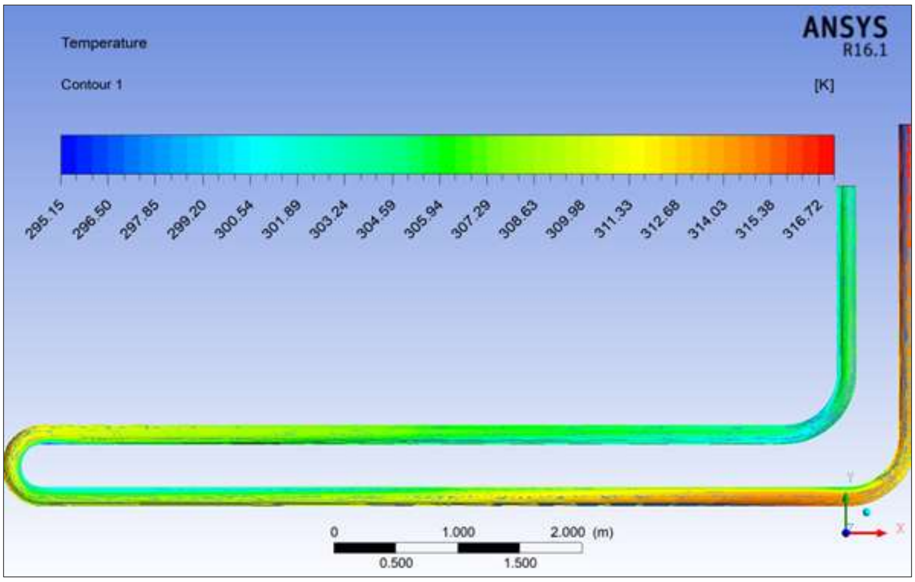

Fig 10: Show Air temperature distribution in a geothermal heat exchanger with a 1m/s speed, a 15 m length, and a 0.15 m diameter.

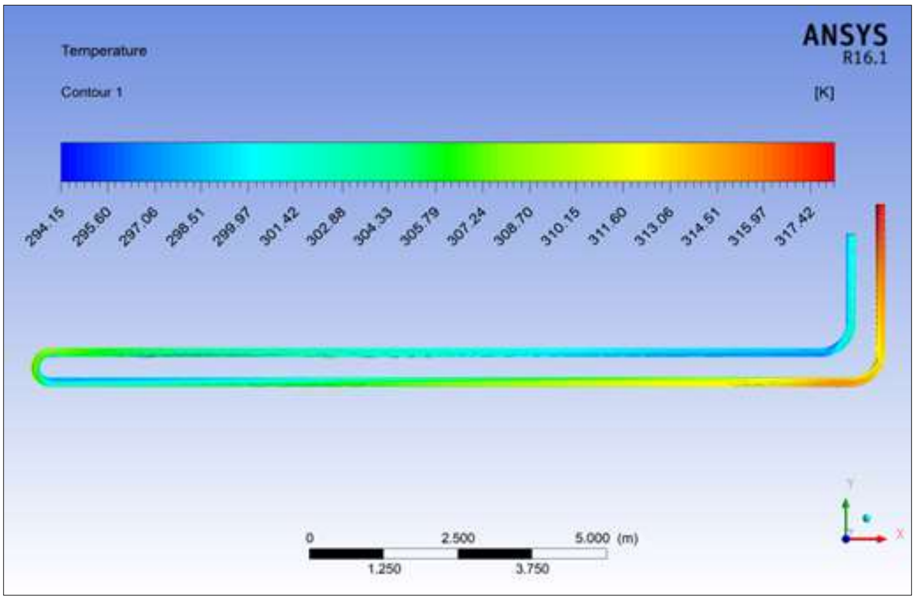

Fig 11: Show Air temperature distribution in a geothermal heat exchanger with a 1m/s speed, a 33 m length, and a 0.15 m diameter.

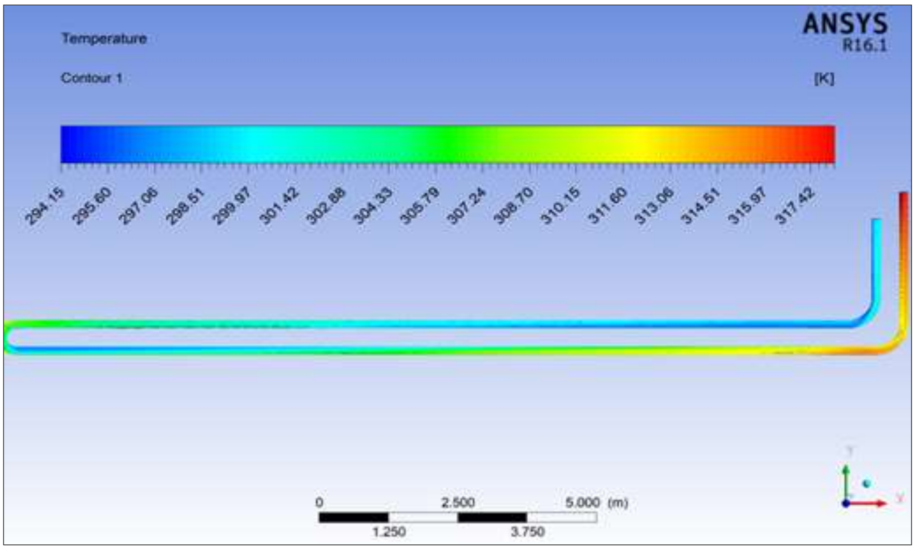

Fig 12: Show Air temperature distribution in a geothermal heat exchanger with a 1m/s speed, a 40 m length, and a 0.15 m diameter.

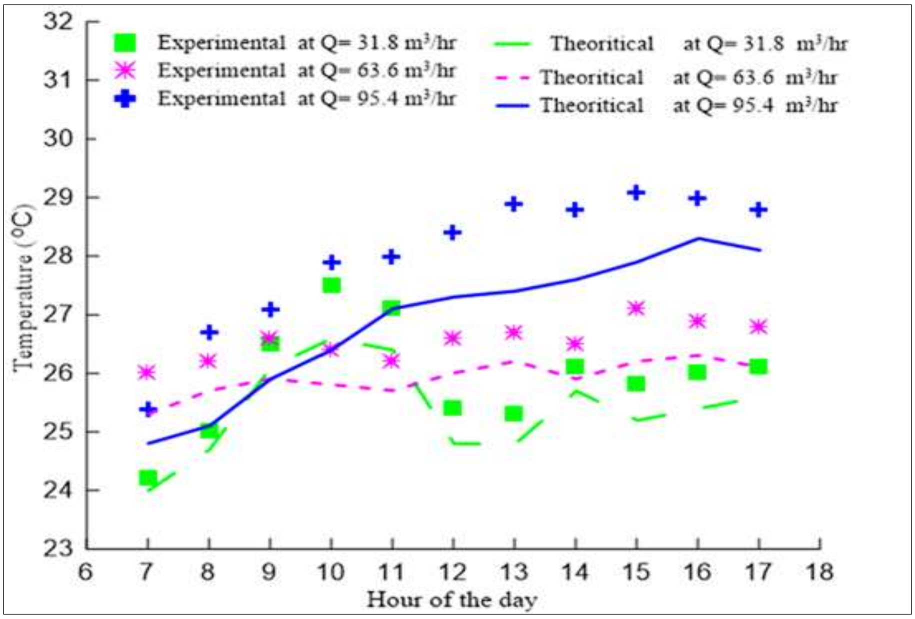

Fig 13: Illustrates the compered between the experimental and theoretical outcomes of an aluminum ground heat exchanger measuring 3 inches in diameter and 9 min length under varying air flow rates.

Nomenclature

$\dot{m}$	Mass flow rate Kg/s
η_{fan}	Overall fan efficiency
A	Area m2
C	Specific heat kJ/kg.K
D	Diameter m
H	Convective heat transfer coefficient $\frac{w}{m^2 k}$
K	Thermal conductivity $\frac{w}{m.k}$
Kel	Loss modulus of bending
L	Length of pipe used m
pf	Air pumping power W
pf	Pressure drop in bending Pa
pL	Pressure drop through the pipe Pa
pT	Total pressure drop Pa
Q	The amount of heat transferred W
Q	Rate of heat transfer $\frac{w}{m}$
Qroom	Cooling load for the room W
R1	Inner pipe radius mm
R2	Pipe thickness mm
R3	Outer pipe diameter mm
Rc	Thermal resistance between the air and the surface of the inner pipe $\frac{m.°C}{w}$
Rp	Thermal resistance between the inner and outer surface of the pipe $\frac{m.°C}{w}$
Rs	Thermal resistance between the soil and the surface of the outer pipe $\frac{m.°C}{w}$
Rt	Total thermal resistance $\frac{m.°C}{w}$
T	Present time Day
T	Temperature °C
to	Temporal shift Day
V	Air speed $\frac{m}{s}$
Z	Depth of the earth mm
$\dot{Q}$	Air flow rate $\frac{m^3}{hr}$

Greek symbols

α Thermal diffusivity, m^2/s

ν Kinematic viscosity, m^2/s

ρ Density, kg/m^3

Dimension less

F	*Friction coefficient*
Nu	*Nusselt number*
Pr	*Prantel number*
Re	*Reynolds number*

Subscripts

A	Air
I	Entrance
M	The average
Ma	Average air temperature
Ms	Earths average surface temperature
Out	Outer
P	Pipe
S	Soil
T	Total

Conclusions

Discussion of theoretical outcomes yields the following conclusions:

1. The earth's temperature fluctuates daily up to a depth of 0.25 m, declines with depth, is constant (24 °C) at 3 m underground, and stays stable throughout the year.

2. The geothermal heat exchanger's cooling efficiency is inversely related to air velocity, peaking at 86% at 1m/s.
3. Air temperature from pipes is proportional to air velocity and diameter, while length inversely proportional to air temperature decrease rate (12-17 °C).
4. Use a soil humidification system around the pipe to cool the outgoing air, which lowers the temperature of the outgoing air. Use vegetation to shade the ground. Design a geothermal exchanger network for house adaptation.

Acknowledgments
The authors are grateful for the financial support towards this research by the Mechanical Engineering Department, College of Engineering- Alshirqat, Tikrit University. Postgraduate Research

References
1. Briefing US. International Energy Outlook 2013. US Energy Information Administration 2013;506:507.
2. Kharseh M. Reduction of Prime Energy Consumption in the Middle East by Gshp Systems. Luleå tekniska universitet; c2009.
3. Thorhallsson S, Ragnarsson A. Multipurpose Use of Geothermal Energy. Tianjin, China, UNU-GTP, TBLRREM and TBGMED 2008.
4. Lund JW, Boyd TL. Direct Utilization of Geothermal Energy 2015 Worldwide Review. Geothermics 2016;60:66-93.
5. Ghosal M, Tiwari G. Modeling and Parametric Studies for Thermal Performance of an Earth to Air Heat Exchanger Integrated with a Greenhouse. Energy conversion and management 2006;47(13-14):1779-1798.
6. Kaushik S, Lal S, Bhargava P. Earth–Air Tunnel Heat Exchanger for Building Space Conditioning: A Critical Review. Nanomaterials and energy 2013;2(4):216-227.
7. Agrawal KK, Bhardwaj M, Misra R, Das Agrawal G, Bansal V. Optimization of Operating Parameters of Earth Air Tunnel Heat Exchanger for Space Cooling: Taguchi Method Approach. Geothermal Energy 2018;6(1):1-17.
8. Bansal V, Misra R, Agrawal GD, Mathur J. Performance Analysis of Earth–Pipe–Air Heat Exchanger for Summer Cooling. Energy and buildings 2010;42(5):645-648.
9. Lee KH, Strand RK. Implementation of an Earth Tube System into Energyplus Program. Proceedings of the SimBuild 2006 Conference, Boston MA, USA; c2006.
10. Lee KH, Strand RK. The Cooling and Heating Potential of an Earth Tube System in Buildings. Energy and Buildings 2008;40(4):486-494.
11. Krarti M, Lopez-Alonzo C, Claridge DE, Kreider JF. Analytical model to predict annual soil surface temperature variation. Journal of Solar Energy Engineering. 1995;117:91-99.
12. Maerefat M, Haghighi A. Passive Cooling of Buildings by Using Integrated Earth to Air Heat Exchanger and Solar Chimney. Renewable energy 2010;35(10):2316-2324.
13. Ismael L, Al Ezzi A, Ma H. Experimental Study of Combined Compact Evaporative Cooler with Desiccant Dehumidification. ASTFE Digital Library: Begel House Inc; c2021.
14. Taşdelen F, Dağtekin İ. A Numerical Investigation of Thermal Performance of Earth–Air Heat Exchanger. Arabian Journal for Science and Engineering 2019;44:1151-1163.
15. Patel AK, Mishra P. Cfd Analysis of Geothermal Heat Exchanger at Different Orientation. International Journal Online of Scince 2019;5:15-16.
16. Agrawal KK, Bhardwaj M, Misra R, Das Agrawal G, Bansal V. Optimization of Operating Parameters of Earth Air Tunnel Heat Exchanger for Space Cooling: Taguchi Method Approach. Geothermal Energy 2018;6(1):1-17.
17. Jacovides CP, Mihalakakou G. An Underground Pipe Systems as an Energy Source for Cooling/heating Purposes. Renewable Energy. 1995;6:893-900.
18. Ralegaonkar R, Kamath M, Dakwale V. Design and Development of Geothermal Cooling System for Composite Climatic Zone in India. Journal of The Institution of Engineers (India): Series A 2014;95:179-183.
19. Maerefat M, Haghighi A. Passive Cooling of Buildings by Using Integrated Earth to Air Heat Exchanger and Solar Chimney. Renewable energy. 2010;35(10):2316-2324.
20. Al-Ajmi F, Loveday D, Hanby VI. The Cooling Potential of Earth–Air Heat Exchangers for Domestic Buildings in a Desert Climate. Building and Environment 2006;41(3):235-244.
21. Incropera FP, DeWitt DP, Bergman TL, Lavine AS. Fundamentals of Heat and Mass Transfer. Vol. 6: Wiley New York; c1996.
22. Ismael L, Al Ezzi A, Ma H. Experimental Study of Combined Compact Evaporative Cooler with Desiccant Dehumidification. ASTFE Digital Library: Begel House Inc; c2021.
23. Necati, O. M. Heat Transfer: A Basic Approach, McGraw-Hill Book Company; c1985.
24. Labs K. In: Cook J. editor. Passive cooling. Cambridge Massachusetts, London, England: MIT Press; c1989.
25. Ashrae AHF, Atlanta G. American Society of Heating. Refrigerating and Air-Conditioning Engineers, 2009, 1.
26. Naili N, Attar I, Hazami M, Farhat A. Experimental Analysis of Horizontal Ground Heat Exchanger for Northern Tunisia; c2012.
27. Abdullah Jasim, Maki Zaidan. Cooling and condition of building by using a passive solar system. Thesis. College of Engineering Tikrit University; c2019.