Thermal Performance Enhancement of Earth Tube Heat Exchanger

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Abstract: The fabrication of an earth tube heat exchanger involves designing an efficient system for natural cooling or heating using underground pipes. The system circulates air through buried tubes, leveraging the earth's stable temperature to cool or warm the air, reducing reliance on traditional HVAC systems. Aluminium tube of length 21 m, 205 w/mk thermal conductivity, results in COP of 1.5 to 2.9.A copper tube of length 15m, 385 w/mk thermal conductivity results in COP 1.3 to 3.2. A 15m copper serpentine tube with thermal conductivity of 385 W/m·K exhibits a COP improvement from 1.3 to 3.2 at increased inlet velocity. This suggests that increased fluid velocity enhances the efficiency, heat transfer, and thermal performance of the system, hence the earth tube heat exchanger becomes more efficient. The result indicates that the analysed earth tube heat exchanger with copper serpentine tube and calculated COP will significantly improve the thermal performance of an earth tube heat exchanger.

1 INTRODUCTION

Leveraging the natural thermal characteristics of the Earth, Earth Tube Heat Exchanger (ETHE) is an alternative to efficient temperature control in this contemporary period. Air is supplied through copper tubing of 15 m length and 385 W/mK thermal conductivity at varying velocities of 1, 2, 3, and 4 m/s in a soil environment with a blower for 12 V, 0.45 amps DC. This system employs the earth's perpetual temperature of 26.2 °C to generate outlet temperatures at similar rates of 33.6 °C, 34.5 °C, 34.8 °C, and 35.2 °C.

Observation and system control based on desired and ambient temperature levels allow a relay and temperature sensors to reduce the use of conventional heating and cooling systems and significantly reduce energy consumption and costs. By making use of constant earth temperatures underground to provide winter heat and summer coolness, earth-air heat exchangers (ETHE) reduce building energy consumption. Design, performance, and ground temperature fluctuations of ETHE are the focus of this research, its ability to lessen greenhouse gas emissions and energy consumption, especially in India with a COP of 1.5(Shams Forruque Ahmed,et.al., 2021). Heat Exchanger in conjunction with natural ventilation to create the best of indoor conditions with reduced costs and energy use. It will give the heat transfer rate to 600 watts (Giouli Mihalakakou, et.al.,2022). An Earth-to-Air Heat Exchanger (ETHE) utilizes ground thermal energy to provide heat in winters with higher efficiency. Simulation using CFD for a 13-meter pipe indicated higher heat transfer and efficiency with lower velocities of air in winter in Bhopal with a cop of 1.8(Ahmed A Serageldin, et.al.,2016). (GAHE) employs geothermal energy in effective cooling and heating. Its performance was simulated in this work with ANSYS Fluent and SOLIDWORKS, and its COP values and best temperatures were between 0.5 to 1.3(Hadi,et.al., 2024). The Earth-Air Heat Exchanger (EHX) improves home comfort and conserves energy. A 2021 Baghdad experiment revealed 12.3°C increase in January and 17.2°C in June demonstrated that it was extremely effective (Lattieff,et.al., 2022).

2 RELATED WORKS

Number of papers published on this topic in the last five years is more than 95 papers in IEEE Xplore, 60 papers in Google Scholar, 110 papers in Academia. A soil-to-air heat exchanger (EAHE) using an evaporative cooler can minimize pipe length by as

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much as 93.5%. Surface-to-volume ratio, airflow rate, and pipe diameter are the most significant factors influencing outlet temperature with a COP of 2.5(Benzaama, M. H.,et.al., 2022). Earth tubes are an environmentally friendly method of saving energy expenses through cooling houses and warming houses during winter, with studies showing notable savings in energy and a smaller climate footprint with a COP of 1.9(Sofyan,et.al., 2024).Earth tube heat exchangers use geothermal energy for heating and cooling, providing a green HVAC system that is energy-saving and simple to install achieves 40% air ventilation. Optimization of earth-air heat exchanger (EAHE) systems involves pipe properties and airflow rate 4 m/s, and also exploration of the impact of soil density and moisture on performance temperature up to 35 degree Celsius(Omer AM , 2008).Earth tube heat exchangers energy- efficient heating and cooling, satisfying HVAC requirements effectively with COP of 1.9(Esen H,et.al.,2007).The research maximizes the Naples, Italy Earth to Air Heat Exchanger (EAHX) and discovers that an ETHE of diameter 0.1 m, 1.5 m/s velocity, and length 50 m has maximum output temperatures 40% more efficient(Givoni B, et.al.,1981). Earth-air tunnel ventilation relies on constant ground temperatures to control air, yet soil- atmosphere exchanges may be underestimated, and this leads to performance overestimation. Good simulations are highly critical max COP of 2.5(Deshmukh MK, et.al., 1991).

Inference: From the previous findings, it is concluded that the use of an Aluminium tube will result in less COP due to less thermal conductivity and poor pipe design. The aim of this is to enhance the thermal performance of an earth tube heat exchanger by using copper tube which having high thermal conductivity and serpentine (design)

3 MATERIALS AND METHODS

Indian earth tube heat exchangers are affordable, offering cooling and heating. BMR-HVAC in Faridabad saw temperature fluctuations of 3.93°C to 12.6°C in summer and 6°C to 10°C in winter (Esen H,et.al., 2017). Aluminium tube of length 21m, 205 w/mk thermal conductivity, results in COP of 1.5 to 2.9. A copper waveflow tube of length 15m, 385 w/mk thermal conductivity results in COP of 1.3 to 3.2. Earth-air heat exchangers utilize earth temperatures to provide cooling and heating by minimizing energy utilization. Ventilation Information Paper prescribes their operation and specifications (Lucia U,et.al., 2017).

3.1 Flowchart/Process Steps/Method/Block Diagram

An Earth Tube Heat Exchanger employs buried pipe to passively control air temperature. External fresh air is pulled through the pipe and cooled or heated by the soil seasonally. The conditioned air is fed to the ventilation system in the building, creating an energy-saving means of creating comfortable indoor temperatures.

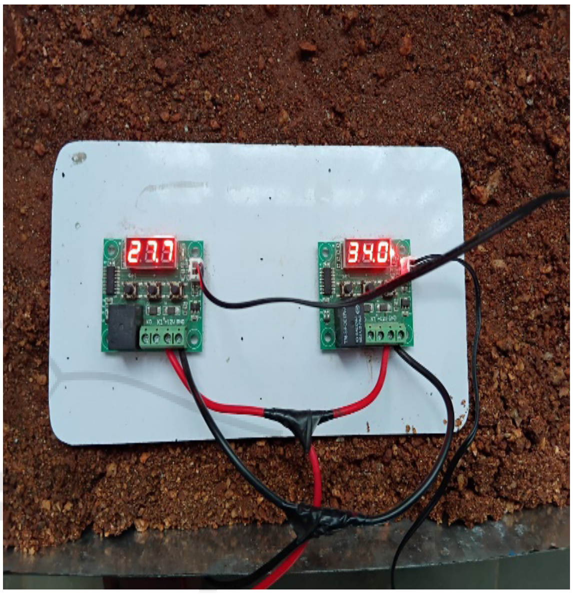

Figure 1: Temperature Monitoring Setup.

SSPL Tool: The ANSYS Fluent R19.0 CFD simulation of a serpentine heat exchanger used a k-ε turbulence model and tetrahedral meshing. Velocity inlet, pressure outlet, and no-slip walls were used by the solution that used second-order upwind discretization and 1e-6 convergence. Results indicated pressure drop (103618 Pa to 100745 Pa), temperature range (299.47 K to 350 K), and maximum velocity of 55.69 m/s, which indicated design optimization.

Design Calculation

Amount of heat transfer $Q = mCpdt$ (J) (1)

Coefficient of performance Q/W (2)

By using above these formulas, we found out the length of ETHE. Calculation results are given below.

4 RESULTS

A copper tube of length 15m, 385 w/mk thermal conductivity results in COP 1.3 to 3.2. Thus the data indicates that with the rise in inlet velocity, temperature, heat flow, and COP all rise. This indicates that the efficiency and ability of heat transfer of the system improve with higher fluid velocity Table 2 This table illustrates the inlet velocity (in m\s) and the associated temperature (in °C). When the inlet velocity increases from 1 m/s to 4 m/s, the numerical solution output temperature increases from 27.9°C to 32.7°C, proving the positive correlation of inlet velocity and temperature. Table3 Inlet velocity rises from 1 m/s to 4 m/s, and heat flow and COP are also increased. Heat flow is increased from 332.8 W to 819.2 W, and COP is increased from 1.3 to 3.2, which indicates higher efficiency and heat transmission at elevated velocities. Figure 2. The picture depicts a helical pipe mesh in ANSYS Fluent (R19.0), which is optimized for CFD simulation.

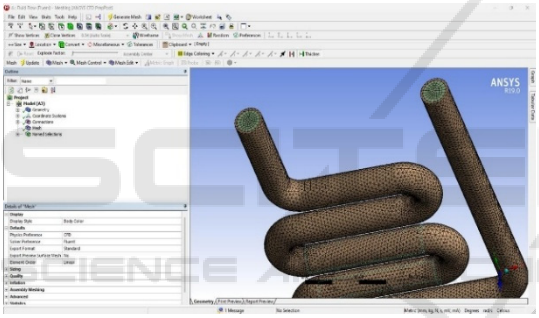

Figure 2: A helical pipe mesh in ANSYS Fluent (R19.0), which is optimized for CFD simulation.

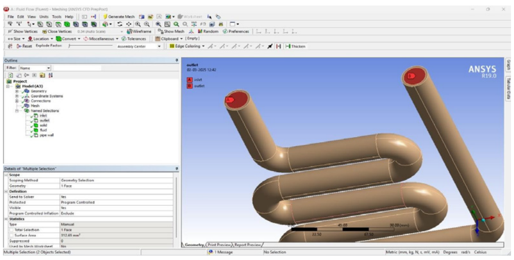

Figure 3: ANSYS Fluent Meshing (R19.0) with a piping system ready to be used for CFD simulation, specifying inlet, outlet, and boundary conditions for fluid flow or heat transfer.

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Figure 4. It shows pressure contours with numeric values in Pascals (Pa), from about 1.010e+005 Pa up to 4.036e+005 Pa, which suggests a fluid flow or heat transfer calculation.

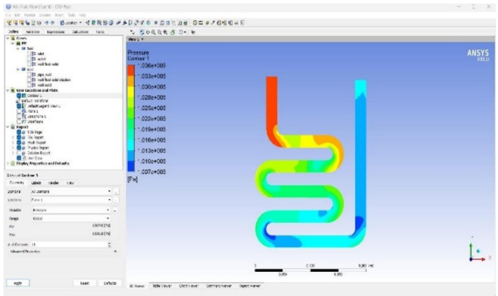

Figure 4: ANSYS Fluent Meshing (R19.0) with a piping system ready to be used for CFD simulation, specifying inlet, outlet, and boundary conditions for fluid flow or heat transfer.

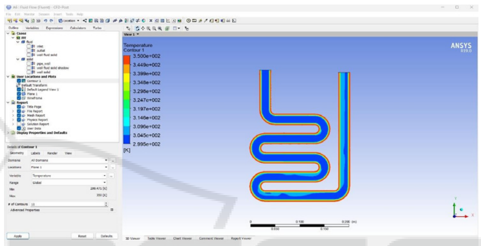

Figure 5: Temperature contour plot of fluid flow through a serpentine tube. High temperatures (red) are at the walls, and low temperatures (blue) are within the core flow, showing heat transfer. Analysis enhances the analysis of thermal performance and flow behaviour.

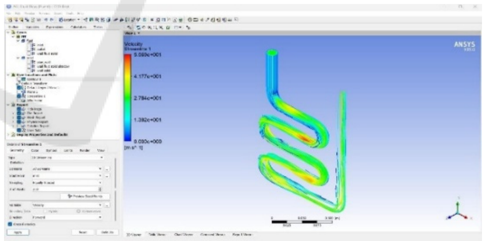

Figure 6: Velocity streamline plot of fluid flow through serpentine pipe. Red indicates higher velocities in bends and blue for low velocities in straight sections, which shows flow behaviour and turbulence.

Figure 5. ANSYS Fluent (R19.0) CFD-Post and a temperature contour plot of fluid flow through a serpentine tube. High temperatures (red) are at the walls, and low temperatures (blue) are within the core flow, showing heat transfer. Analysis enhances the analysis of thermal performance and flow behavior. Figure 6. Velocity streamline plot of fluid flow through serpentine pipe. Red indicates higher velocities in bends and blue for low velocities in

straight sections, which shows flow behavior and turbulence. Figure 7. This graph is depicted between inlet velocity vs temperature output and heat flow.

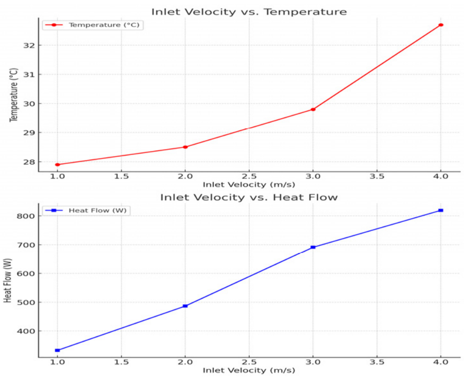

Figure 7: Inlet velocity vs temperature output inlet velocity vs heat transfer.

5 DISCUSSIONS

This project shows that the fluid flow velocity can be enhanced in an Earth Tube Heat Exchanger with a copper serpentine tube for greater heat transfer to improve the Coefficient of Performance (COP) from 1.3 to 3.2. Copper's high thermal conductivity improves efficiency, and the system is more energy efficient and effective. The research maximizes the Naples, Italy Earth to Air Heat Exchanger (EAHX) and discovers that an ETHE of diameter 0.1 m, 1.5 m/s velocity, and length 50 m has maximum output temperature (Inalli M,et.al., 2004). This research analyzes the thermal efficiency of an Earth- to-Air Heat Exchanger (EAHX) during warm weather. A 60 m long, 100 mm diameter model with 239 fins is subjected to a temperature drop of 20.5°C (Wu W, et.al., 2014).

Table 1: Input parameters.

S.NO	INPUT PARAMETERS	SYMBOL S	VALUE
1	Inlet Temp	T_{in}	35
2	Length of Tube	L	15
3	Pipe wall Temp (below 5ft)	T_{wall}	25
4	Thermal conductivity of the air	K_{air}	0.0266
5	Thermal conductivity of the pipe	K_{Pipe}	385
6	Thermal capacity	C_p	1006
7	Viscosity	μ	0.000018 4
8	Density of air	P	1.1465
9	Velocity of air	v_{air}	1,2,3,4

The system's performance was analyzed under 72-hour conditions of temperature fluctuation, COP, and efficiency (Balbay A,et.al., 2010). This research mimics a 45m, 0.08m diameter EATHE pipe 5m deep, with air speed at 1 m/s. ANSYS and CFD Fluent are used to model heat transfer and temperature changes according to Bhopal's climate from June 2016 to May 2017(Balbay A,et.al., 2010).

Table 1 shows the input parameters. Table 2 shows the inlet velocity (in m\s) and the associated temperature (in °C). When the inlet velocity increases from 1 m/s to 4 m/s, numerical solution output temperature increases from 27.9°C to 32.7°C, proving the positive correlation of inlet velocity and temperature.

Table 2: Inlet velocity vs associated temperature.

S. No	Inlet Velocity (m/s)	Numerical Method Output Temperature
1	1	27.9
2	2	28.5
3	3	29.8
4	4	32.7

Table 3 shows the Inlet velocity rises from 1 m/s to 4 m/s, and heat flow and COP are also increased. Heat flow is increased from 332.8 W to 819.2 W, and COP is increased from 1.3 to 3.2, which indicates higher efficiency and heat transmission at elevated velocities.

Table 3: Inlet velocity, heat flow & COP.

S. No .	Inlet Velocity (m/s)	Heat flow (watt)	COP
1	1	332.8	1.3
2	2	486.4	1.9
3	3	691.2	2.7
4	4	819.2	3.2

6 SCOPE FOR FUTURE WORK

The future of Earth Tube Heat Exchangers lies in increased efficiency through integration with renewable power, better materials, and intelligent automation. They can also be made suitable for urban settings, tailored to particular climates, and integrated with energy storage, and thus more scalable, cheaper, and more sustainable.

7 CONCLUSIONS

It is observed that by increasing the velocity of the inlet of the 15m copper serpentine tube, heat transfer is increased dramatically, from 1.3 to 3.2. This indicates that fluid velocity improves system and thermal efficiency, thereby making the earth tube heat exchanger more efficient.

REFERENCES

Ahmed A Serageldin, Ali K Abdelrahman, Shinichi Ookawara Energy Conversion and management 122, 25-38, 2016.

Balbay A, Esen M. Experimental investigation of using ground source heat pump system for snow melting on pavements and bridge decks. Sci Res Essay 2010;5(24):3955–66.

Balbay A, Esen M. Temperature distributions in pavement and bridge slabs heated by using vertical ground-source heat pump systems. Acta Sci-Technol 2013;35(4):677–85.

Benzaama, M. H., S. Menhoudj, A. M. Mokhtari, and M. Lachi. "Comparative study of the thermal performance of an earth air heat exchanger and seasonal storage systems: Experimental validation of Artificial Neural Networks model." Journal of Energy Storage 53 (2022): 105177.

Deshmukh MK, Sodha MS, Sawhney RL. Effect of depth of sinking on thermal performance of partially underground buildings. Int J Energy Res 1991;15(5):391–403.

Esen H, Inalli M, Esen M. Numerical and experimental analysis of a horizontal ground-coupled heat pump system. Build Environ 2007;42(3):1126–34.

Esen H, Inalli M, Esen M. A techno- economic comparison of ground-coupled and air-coupled heat pump systems for space cooling. Build Environ 2007;42(5):1955–65.

Esen H, Esen M, Ozsolak O. Modelling and experimental performance analysis of solar-assisted ground source heat pump systems. J Exp Theor ArtifIntell 2017;29(1):1–17.

Giouli Mihalakakou, Manolis Souliotis, Maria Papadaki, George Halkos, John Paravantis, Sofoklis Makridis, Spiros Papaefthimiou Renewable and Sustainable Energy Reviews 155, 111921, 2022

Givoni B, Katz L. Earth temperatures and underground buildings. Energy Build 1985;8(1):15–25.

Givoni B. Earth-integrated buildings an overview. Archit Sci Rev1981;24(2):42– 53.

Hadi, Faeza Mahdi, Muntadher Hashim Abed, and Karrar Abed Hammoodi. "Thermal Performance of Earth Air Heat Exchanger for Geothermal Energy Application in Hot Climate using CFD Simulation." Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 115, no. 1 (2024): 99-117.

Inalli M, Esen H. Experimental thermal performance evaluation of a horizontal ground-source heat pump system. Appl Therm Eng 2004;24(1415):2219–2232.

Khatry AK, Sodha MS, Malik MAS. Periodic variation of ground temperature with depth. Sol Energy 1978;2

Lattieff, Farkad A., Mohammed A. Atiya, Rudainah Ali Lateef, Anmar Dulaimi, Muhsin J. Jweeg, Azher M. Abed, Jasim M. Mahdi, and Pouyan Talebizadehsardari. "Thermal analysis of horizontal earth-air heat exchangers in a subtropical climate: An experimental study." Frontiers in Built Environment 8 (2022): 981946.

Lucia U, Simonetti M, Chiesa G, Grisolia G. Ground-source pump system for heating and cooling: review and thermodynamic approach. Renew Sustain Energy Rev 2017.

Omer AM. Ground-source heat pumps systems and applications. Renew Sustain Energy Rev 2008;12(2):344–71.

Shams Forruque Ahmed, Suvash C Saha, JC Debnath, G Liu, M Mofijur, Ali Baniyounes, SMEK Chowdhury, Dai-Viet N Vo Environmental Chemistry Letters 19 (6), 4191-4210, 2021.

Sofyan, Sarwo Edhy, Teuku Meurah Indra Riayatsyah, Eric Hu, Akram Tamlicha, Teuku Muhammad Reza Pahlefi, and H. B. Aditya. "Computational fluid dynamic simulation of earth air heat exchanger: A thermal performance comparison between series and parallel arrangements." Results in Engineering 24 (2024): 102932.

Wu W, You T, Wang B, Shi W, Li X. Simulation of a combined heating, cooling and domestic hot water system based on ground source absorption heat pump. Appl Energy 2014; 126:113–22.