International Journal of Engineering and Techniques - Volume 12 Issue 2, March-April - 2026

CFD-Based Thermal Performance Evaluation and Optimization of Earth–Air Heat Exchanger for Sustainable Cooling in Indian Climates

Kiranmai Iragavarapu and Dr.k.Bharradwaja

department of mechanical engineering,mallareddy (mr) deemed to be university

kiranmai.anu@gmail.com, bharradwaja@mrec.ac.in

Abstract

Another recent innovation that has become an efficient passive cooling technology is the Earth-Air Heat Exchanger (EAHEs), which takes advantage of the comparatively constant earth temperature in the ground to decrease the heat burden in buildings. In this work, an EAHE system has been analyzed in detail with the use of Computational Fluid Dynamics (CFD) in ANSYS Fluent in order to determine its thermal performance in Indian climatic conditions. A three dimensional model is created which is a 28 m long and 0.15 m diameter buried PVC pipe and three configurations straight pipe, serpentine pipe and grooved serpentine pipe are explored. The findings show that geometric modifications are very important in improving the thermal performance of the system. The grooved serpentine design attains highest temperature drop of 12.4degC as opposed to 7.1degC in the straight pipe. The enhancement of the heat transfer is however at the cost of higher pressure losses hence there is a trade off between thermal performance and pumping power. The results confirm that optimized EAHE systems could help minimize cooling loads up to 30-40 percent and can therefore be a solution to sustainable buildings application in India.

Keywords: EAHE, CFD, Sustainable Cooling, ANSYS Fluent, Heat Transfer, HVAC

1. Introduction

Sustained increase in the number of energy needs in the world and growing interest in global warming has heightened the demand to use sustainable and energy saving cooling technologies. The construction industry is consumed by roughly high percentage of total energy consumed by the world, mainly the building sector because of heating, ventilation and air conditioning (HVAC) systems [1]. In regions such as India with temperatures mostly at high level all year round, the economic demands of mechanical cooling systems are growing at a very high rate, resulting in high energy use and emission of green house gases [2]. Passive cooling cooling technologies like Earth-Air Heat Exchangers (EAHEs) have a potential to be applied in this context.

The principle of EAHE systems is that ground thermal inertia allows the soil temperature at a specific depth to be fairly constant over time over a year. The heat exchange is caused between the air and the surrounding soil by passing ambient air through buried pipes, thus, cooling it in summer and warming it in winter [3]. The workability of this system is determined by the different factors such as the geometry of the pipes, the soil, the speed of air, and the depth of burial. Thus, the parameters need to be optimized in order to get maximum out of the system.

2. Methodology

In the current research, the author uses the Computational Fluid Dynamics (CFD) to examine the thermal efficiency of an EAHE system. ANSYS Fluent is used to develop a three dimensional model of a buried pipe that is 28 meters long and has a diameter of 0.15 meters. The pipe assumed to be of the material PVC and the depth of the burial is 3 meters deep and the soil temperature of the area is taken to be 28degC. The working fluid is air, and the flow is considered to be turbulent.

The inlet air temperature is also fixed at 40degC to reflect the characterization of the actual summertime in India and the inlet velocity is kept at 3 m/s. The flow behavior and the heat transfer characteristics are simulated with the help of the standard k-e turbulence model. Three configurations are examined, including a straight pipe, a serpentine pipe and a serpentine pipe with internal grooves. Such geometry is selected to examine how geometry affects the enhancement of heat transfer.

3. Results and Discussion

The outcomes of the CFD simulations indicate that there is a high variation in thermal performance of the three configurations. The straight pipe arrangement exhibits minimum temperature drop as a result of the creation of a stable thermal boundary layer around the walls of the pipes thus restricting the transfer of heat. Conversely, the serpentine pipe layout improves the heat transfer since it generates second-order flows at the bends and this elevates the air mixing and heightens thermo-hydraulic contact between the pipe walls and the air [4]. The further enhancement of the performance is the grooved serpentine arrangement that constantly disconnects the airflow and decreases the thickness of the boundary layer that results in increased convective heat transfer [5].

Table 1 shows the thermal performance of the three configurations. The straight pipe attains an outlet temperature of 32.9degC, which is equivalent to a temperature drop of 7.1degC. The serpentine pipe cools the outlet of the pipe to 30.5degC and the grooved serpentine to the lowest outlet temperature of 27.6degC thus the temperature is dropped by 12.4degC. This is a clear indication that geometric modification is effective in the improvement of heat transfer.

Table 1: Thermal Performance Comparison

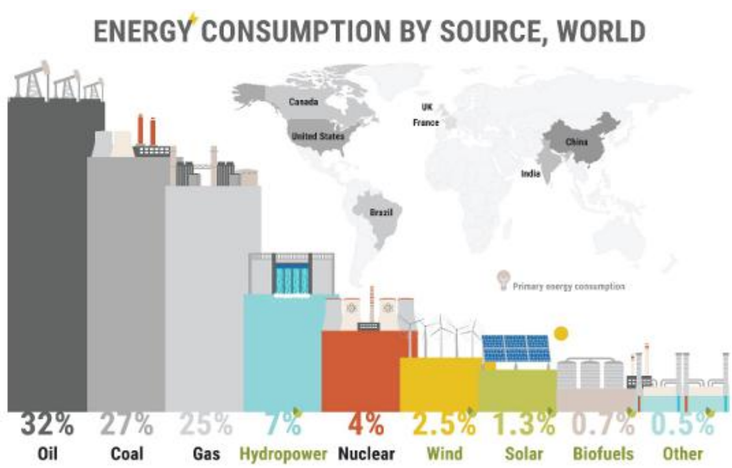
Configuration	Outlet Temperature (°C)	Temperature Drop (°C)	Effectiveness
Straight Pipe	32.9	7.1	0.56
Serpentine Pipe	30.5	9.5	0.68
Grooved Serpentine Pipe	27.6	12.4	0.81

However, the improved thermal performance comes at the cost of increased pressure drop, as shown in Table 2. The straight pipe exhibits the lowest pressure drop of 18 Pa, while the serpentine and grooved serpentine configurations show higher pressure drops of 32 Pa and 51 Pa, respectively.

Table 2: Pressure Drop Analysis

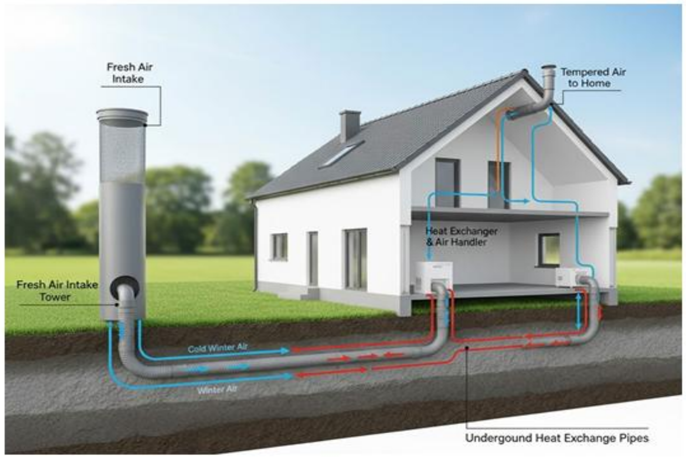
Configuration	Pressure Drop (Pa)	Velocity (m/s)
Straight Pipe	18	3
Serpentine Pipe	32	3
Grooved Serpentine Pipe	51	3

Figure 1: Energy consumption by source



This colossal demand is driven primarily by the need for thermal comfort, encompassing heating, ventilation, and air conditioning (HVAC) systems. As urbanization accelerates, particularly in developing economies, the installation of mechanical cooling systems has surged, leading to a phenomenon known as the "cooling crisis" or the "rebound effect." Conventional HVAC systems, such as vapor-compression chillers and furnaces, are energy-intensive and place a significant strain on the electrical grid, especially during peak demand periods in summer and winter. Therefore, any technology capable of preconditioning or mitigating the thermal load of a buildingbefore it reaches the active HVAC system holds immense potential for global energy savings and grid stabilization**.**

Figure 2: Earth-air heat exchanger



The schematic representation of the Earth-Air Heat exchanger (EAHE) system as the topic of the current research is depicted in the figure 2. The system involves a buried pipe with the ambient air being forced to flow through the pipe and the air and soil exchange heat. Since the temperature of the ground at a certain depth is relatively constant, the incoming hot air moves the heat to the cooler soil, and this leads to a lowering of the air temperature at the outlet. The figure shows the main parts, the air inlet, buried pipeline and outlet section aware of the main principle of the passive cooling principle working. It is also an energy-efficient and a long-lasting solution to the conventional cooling systems, and this is due to its ability to harness the thermal inertia of the earth thus applicable in hot climatic conditions such as those experienced in India.

Figure 3: Double pipe heat exchanger discretized model

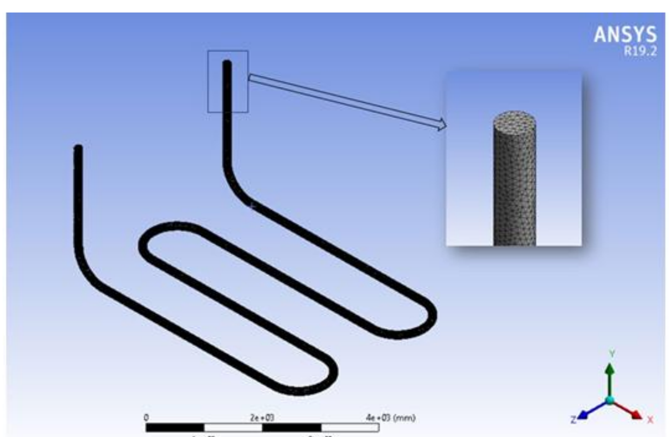


Figure 4: Configuration of Working Fluid Entry and Exit Points in Earth Heat Exchanger

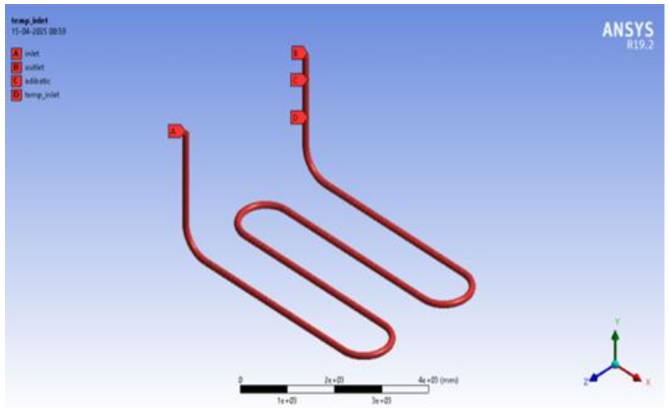


Figure 5: Air Outlet Temperature vs Time

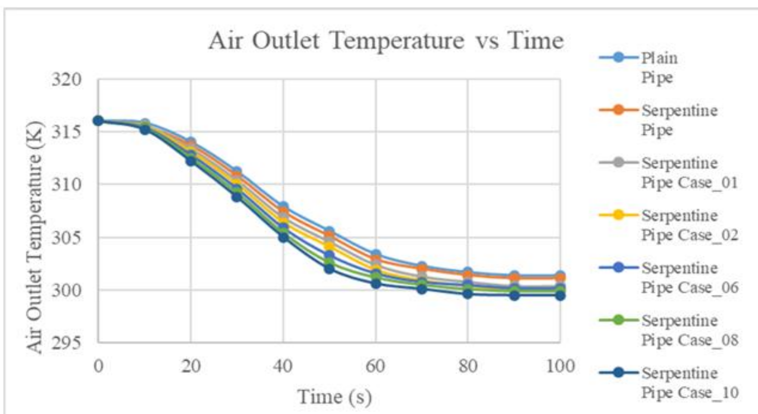


Figure 5 demonstrates how the outlet air temperature changes over the period of time in regards to the various combinations of EAHE setups used in the current study. One may notice that the temperature of the outlet is reduced markedly during the work of the system, which proves that the heat is effectively transferred to the air and the soil that is located nearby. The grooved serpentine pipe has the lowest outlet temperature with time with the serpentine then the straight pipe. This is boosted performance due to high turbulence, enhanced mixing of air, and constant disturbance of the thermal boundary layer which adds up to the growth of the convective heat transfer. The trend is also indicative of the fact that as the soil temperature is stabilized then this means that the system is slowly moving towards the steady-state condition. In general, the figure shows conclusively the effect of geometrical adjustments in enhancing the cooling action of the EAHE system.

4. Conclusion

As evidenced by the current study, the behavior of an Earth-Air Heat Exchanger is very much sensitive to the geometry of the pipes and the nature of the flow. The serpentine grooved arrangement offers the best temperature drop as it will increase the turbulence and heat transfer. Nonetheless, such an enhancement is accompanied by a drastic upsurge in the pressure drop, which is why there is the necessity of a specific compromise between thermal activity and energy use. In general, EAHE systems have high potential of minimizing cooling loads in buildings, and it can be an effective long-term cooling solution to Indian climatic conditions. Although work may go into the future to make experimental validation and add the effect of soil moisture to achieve a more precise prediction.

References

1. Bisoniya, T.S. (2014). A review of Earth-Air Heat Exchanger systems. Renewable Energy.
2. IPCC (2021). Climate Change Report.
3. Mihalakakou, G. (1997). Passive cooling systems using ground heat.
4. Vaz, J. et al. (2011). Experimental and numerical analysis of EAHE.
5. Serageldin, A. et al. (2016). CFD modeling of EAHE systems.
6. Gan, G. (2015). Dynamic simulation of ground heat exchangers.
7. Krarti, M. (1994). Analytical modeling of EAHE.
8. Givoni, B. (1994). Passive cooling techniques.
9. Rosa, A. et al. (2020). EAHE in residential buildings.
10. Jakhar, S. (2019). Thermal saturation in soil.
11. Al-Ajmi, F. (2020). Optimization of EAHE systems.
12. Zhao, J. (2024). CFD advancements in heat exchangers.
13. Koshlak, G. (2025). Review of EAHE systems.
14. Ben Cheikh, R. (2017). Pipe configuration analysis.
15. Sehli, A. (2018). HVAC integration with EAHE.
16. Taşdelen, A. (2020). CFD-based EAHE modeling.
17. ASHRAE Handbook (2021). HVAC Systems.
18. Incropera, F.P. (Heat Transfer Fundamentals).
19. Çengel, Y.A. (Thermodynamics).
20. IEA (2022). Indian Energy Outlook.