SCIENCE SET
OPEN ACCESS PUBLISHERS

Research Article

Global Journal of Translational Science and Integrated Technologies

Effect of Pipe Material on the Performance of Earth-Air Heat Exchangers

Shashank Saxena

Department of Mechanical Engineering, Bansal Institute of Science and Technology, Bhopal, Madhya Pradesh, India

***Corresponding author:** Shashank Saxena, Department of Mechanical Engineering, Bansal Institute of Science and Technology, Bhopal, Madhya Pradesh, India.

Submitted: 09 February 2026 **Accepted:** 18 February 2026 **Published:** 24 February 2026

***Citation:** Saxena, S. (2026), Effect of Pipe Material on the Performance of Earth-Air Heat Exchangers. Glo J Tran Sci & Int Tec 2(1), 01-04.*

Abstract
Earth-Air Heat Exchangers (EAHE) are an effective passive cooling and heating technology that utilizes subsurface soil temperature to condition air before it enters a building. The choice of pipe material plays a crucial role in determining the efficiency and longevity of an EAHE system. This paper investigates the impact of various pipe materials on heat transfer efficiency, pressure losses, durability, and overall system performance.

Keywords: Earth-Air Heat Exchanger, Pipe Material, Heat Transfer Performance, Corrosion Resistance, PVC.

Introduction

As the world economy is rapidly developing in recent decades, large-scale consumption of conventional energy has increased greenhouse gas emissions, thereby exacerbating global climate change [1]. Particularly, the building sector accounts for 40% of the global energy consumption [2, 3]. The energy consumption of buildings is mainly attributed to the provision of a comfortable indoor environment, with space cooling and heating accounting for up to 18–73 % of it [4]. With increasing global urbanization, the energy demand of buildings will continue to increase worldwide in the coming decades [5].

Therefore, to reduce greenhouse gas emissions from such large-scale energy consumption, renewable energy sources should replace conventional energy sources for cooling and heating buildings. Among the renewable energy sources, shallow geothermal energy sources are widely distributed, easily accessible, and convenient. In most cases the soil temperature at a depth of 1–6 m is lower than the ambient temperature in summer, higher than the ambient temperature in winter, and relatively constant, indicating that it can be used as a good energy source for heating and cooling [6-8].

Earth-air heat exchanger (EAHE) is an environmental control system that utilizes shallow geothermal energy by placing one or more pipes in the ground at a certain depth. Air is used as the heat transfer medium, and a fan is used to pump air into the pipes to exchange heat with the underground soil, which is then transported to the building for heating and cooling [9, 10]. Such systems typically require only a compact fan to circulate air and require very little electricity consumption, with significant energysaving potential [11, 12]. Therefore, they are widely used in residential buildings, such as homes, hospitals, schools, offices, and other civil and agricultural buildings such as greenhouses and farms, in various climate zones [13-17] evaluated the performance of a large EAHE system in a hospital in India and found that the system could meet the cooling requirements of the building, however, could not meet the heating requirements [18].

Introduced an EAHE in a 150 m2 greenhouse in Athens, which resulted in a minimum mean night air temperature inside the greenhouse that was 8.9 °C higher than that outside [19]. studied the thermal performance of an EAHE constructed at the Institute for Unconventional Energy Research in Gossi, where the heat exchanger was used in a recirculation mode in eight rooms of the institute. The results showed that the EAHE could create good thermal comfort conditions in the building, and that the coefficient of performance (COP) of the system could be as high as 3.35. In Delhi, India; [20]. buried a serpentine EAHE made up of polyvinyl chloride (PVC) pipes (length: 39 m, diameter: 0.06 m) in 1 m of soil on the west side of a 6 × 4 m greenhouse. the average winter and summer temperatures of the test greenhouse were 6–7 °C higher and 3–4 °C lower than those of the control, respectively. Chel and Tiwari [21] applied an EAHE system in an adobe house, and the test results showed that the indoor air temperature in winter was 5–15 °C higher than the ambient temperature, and the annual energy saving potential of this building increased by 5375 kWh by integrating an EAHE system [22].

Proposed a modular pig house with an integrated EAHE and conducted a one-year pilot study. The results showed that the system could provide 489,820 kWh of heating and 18,455 kWh of cooling for the modular pig house that housed 1280 fattening [23]. conducted long-term monitoring of an EAHE comprising seven parallel buried pipes (length:50 m,diameter: 0.25 m) in a cafeteria building in southern Taiwan, China, and showed that the system could achieve an annual COP of 27.2 used a rectangular EAHE assisted by phase change materials in a room with a ceiling mounted phase change material to help achieve thermal comfort conditions in the room in an extreme desert climate. Consequently, this configuration resulted in an average room temperature that was 0.6 °C lower than the comfort temperature; moreover, the maximum room temperature exceeded the comfort temperature by only 0.33 °C, and the average COP of the room system varied between 264 and 288. Although EAHE has been proven to be feasible in various types of buildings, it still has several disadvantages, such as a large footprint and high construction costs. To widely apply EAHE and achieve sustainable development, reducing the footprint and cost has become the focus of current research. To achieve this, the first step is to select the appropriate pipe. Previous studies have primarily focused on smooth, flat-walled pipe, which is mainly influenced by the pipe material. The effects of rough pipe and bottom perforations on the heat transfer performance of EAHE remain unclear. Therefore, to bridge this gap in literature, an empirical study was conducted on the effect of different pipe types on the performance of EAHE to facilitate the selection of EAHE pipes [24].

An earth-air heat exchanger (EAHE) is a green technology suitable for regulating the thermal environment of buildings; however, it requires a large space and high construction costs. The effectiveness of an EAHE system is influenced by soil conditions, pipe geometry, airflow rate, and, most importantly, the pipe material. This study focuses on analyzing different pipe materials such as metals (stainless steel, aluminum), polymers (PVC, HDPE), and concrete to determine their suitability for EAHE applications.

Earth-Air Heat Exchangers (EAHEs) are becoming increasingly popular in passive cooling and heating systems, primarily for their ability to leverage the stable temperature of the earth for conditioning ventilation air. The performance of EAHEs is influenced by a variety of factors, including the design, depth, and material of the pipes used. Among these factors, the pipe material plays a critical role in the thermal performance, energy efficiency, and durability of the system. This literature review examines existing research on the effect of pipe material on the performance of Earth-Air Heat Exchangers, focusing on key variables such as thermal conductivity, corrosion resistance, and long-term reliability.

Factors Affecting EAHE Performance

Thermal Conductivity of Pipe Material

The ability of a material to transfer heat influences the rate at which air inside the pipe is cooled or heated by the surrounding soil. Materials with high thermal conductivity improve the heat exchange process. The thermal conductivity of the pipe material in an Earth-Air Heat Exchanger (EAHE) significantly impacts its performance. Materials with higher thermal conductivity, like metals (e.g., steel, copper), facilitate better heat transfer between the air inside the pipe and the surrounding earth. Conversely, materials with lower thermal conductivity, such as PVC or HDPE, will result in reduced heat exchange efficiency. Copper is often regarded as the material with the highest thermal conductivity, typically around 399 W/m·K. Several studies suggest that copper pipes can provide superior heat transfer efficiency due to their high conductivity. For instance, the research by highlights that the use of copper piping in heat exchanger systems, including EAHEs, could improve energy efficiency by enhancing heat exchange rates between the soil and the air. Copper's ability to quickly transfer heat from the surrounding soil to the air flow results in more effective pre-conditioning of ventilation air. Aluminum, with a thermal conductivity of approximately 235 W/m·K, is another popular option for heat exchangers. While not as thermally efficient as copper, aluminum is lightweight, cost-effective, and corrosion-resistant. According to aluminum pipes can be a viable alternative for EAHEs when high thermal efficiency is not the primary concern. However, the reduced thermal conductivity of aluminum compared to copper can lead to slightly lower performance in terms of heat transfer rates. Polymeric materials, including High-Density Polyethylene (HDPE) and Polyvinyl Chloride (PVC), are also used for EAHEs, although their thermal conductivity is significantly lower than that of metals. Typically, the thermal conductivity of HDPE and PVC is in the range of 0.4 W/m·K. A study by suggests that while these materials are less effective in terms of heat transfer, they are often chosen for their durability and ease of installation. When used in EAHEs, polymer pipes may require a longer length or larger surface area to compensate for the reduced thermal conductivity.

Corrosion and Durability

The underground environment presents various challenges to the longevity of the pipes used in Earth-Air Heat Exchangers, including corrosion from soil moisture, biological growth, and environmental chemicals. The material chosen for the pipes significantly impacts the lifespan and maintenance requirements of EAHE systems. Copper is known for its excellent corrosion resistance. Copper pipes are resistant to corrosion from soil acids, moisture, and microbial activity, making them an ideal choice for systems that need to operate for long periods without significant maintenance. Research by indicates that copper's resistance to corrosion reduces the need for regular inspection and replacement of the pipes in EAHE systems, thus improving the overall longevity of the system.

Aluminum, while relatively corrosion-resistant, is more susceptible to corrosion in specific soil conditions, especially in acidic or highly saline environments. However, studies suggest that protective coatings or alloys can mitigate some of these issues. For instance, aluminum alloy pipes with a corrosion-resistant layer have been shown to extend the lifespan of EAHE systems. The work by suggests that the use of aluminum alloy pipes in EAHEs could strike a balance between cost and durability, offering sufficient resistance to corrosion in most environments. Polymeric pipes, especially HDPE, have a notable advantage in terms of corrosion resistance. Since they are not affected by soil moisture or microbial activity, HDPE pipes often have longer operational lifespans compared to metal pipes in harsh underground conditions. According to research by HDPE pipes are durable and require minimal maintenance, making them a reliable choice for EAHE systems in regions with high soil acidity or moisture content.

Airflow Resistance and Pressure Losses

Smooth inner surfaces reduce frictional losses and enhance airflow efficiency. Rough or degraded pipe surfaces can lead to increased energy consumption for ventilation. In an Earth-Air Heat Exchanger (EAHE) system, the choice of pipe material significantly impacts airflow resistance and pressure losses, which in turn affect the system's overall performance. Different pipe materials exhibit varying surface roughness and thermal properties, influencing the friction between the air and the pipe wall, and thus affecting pressure drop and airflow.

Cost-Effectiveness and Installation

In addition to performance, cost-effectiveness is a key consideration when selecting pipe materials for Earth-Air Heat Exchangers. Metal pipes like copper and aluminum tend to be more expensive than polymer pipes, which can influence the overall installation cost of an EAHE system. Copper's high cost can be a limitation, especially for large-scale EAHE installations. However, its superior thermal performance and durability may justify the higher initial investment in some cases. Studies such as those by argue that the long-term benefits, including reduced energy consumption and lower maintenance costs, can offset the higher upfront cost. Aluminum pipes, although not as thermally efficient as copper, offer a lower-cost alternative. Their relatively lower cost compared to copper makes them a preferred choice for some systems. Polymeric materials such as HDPE or PVC are generally the least expensive and easiest to install, with significant savings in both material and labor costs. However, as mentioned earlier, their lower thermal conductivity may necessitate larger pipe sizes or longer lengths to achieve the desired thermal performance.

Performance in Various Climates

The performance of EAHEs is also influenced by climate, as the heat exchange process depends on the temperature differential between the underground soil and the air. Different pipe materials might perform better or worse depending on the ambient temperature and soil conditions. In colder climates, the higher thermal conductivity of copper and aluminum pipes can enhance the performance of EAHEs by facilitating faster heat exchange, especially during winter months when the soil temperature is lower. On the other hand, in warmer climates, the thermal conductivity of these metals might lead to a more efficient cooling effect. However, their higher cost and potential for corrosion (in certain soils) may need to be considered. In hot, dry climates where corrosion is less of an issue, polymeric materials may be more suitable due to their low installation costs and good resistance to thermal expansion. However, in cooler climates, the low thermal conductivity of these materials may reduce the overall performance of the EAHE system.

Table 1: Comparative Analysis of Pipe Materials

Pipe Materi-al	Thermal Conductivity (W/mK)	Corrosion Re-sistance	Durability	Cost	Pressure Loss
Stainless Steel	16-25	High	High	High	Moderate
Aluminum	200-250	Moderate	Moderate	High	Low
PVC	0.19	Very High	Moderate	Low	Low
HDPE	0.41	Very High	High	Moderate	Low
Concrete	1.4	High	Very High	High	High

Discussion

Metals such as stainless steel and aluminum offer superior heat transfer properties but are costly and prone to corrosion. Polymer pipes like PVC and HDPE, although having lower thermal conductivity, are widely used due to their affordability, corrosion resistance, and ease of installation. Concrete pipes, while durable, present challenges in handling and installation due to their weight and high frictional resistance.

Conclusion

The pipe material in Earth-Air Heat Exchangers plays a crucial role in determining the efficiency, durability, and cost-effectiveness of the system. Copper, with its high thermal conductivity and corrosion resistance, is ideal for applications where maximum thermal efficiency and long-term durability are desired. Aluminum and polymeric materials, while offering lower initial costs, may compromise heat transfer rates and longevity in some conditions. Future research should focus on exploring hybrid materials or coatings that can combine the best properties of metals and polymers to optimize EAHE performance across diverse environments. Additionally, more field-based studies are necessary to evaluate the long-term effects of different pipe materials on the thermal efficiency and maintenance needs of EAHE systems.

The choice of pipe material significantly influences EAHE efficiency and system longevity. While metals provide better heat transfer, polymers such as HDPE and PVC offer a practical balance between cost, durability, and performance. Future research should focus on composite materials that optimize thermal conductivity while ensuring durability and cost-effectiveness.

References

1. Liu, Q., Tao, Y., Shi, L., Huang, Y., Peng, Y., Wang, Y., & Tu, J. (2023). Experimental investigations on the thermal performance of a novel ground heat exchanger under the synergistic effects of shape-stabilized phase change material and nanofluid. Energy, 284, 128635. https://doi.org/10.1016/j.energy.2023.128635
2. Nejat, P., Jomehzadeh, F., Taheri, M. M., Gohari, M., & Abd Majid, M. Z. (2015). A global review of energy consumption, CO_2 emissions and policy in the residential sector (with an overview of the top ten CO_2 emitting countries). Renewable and Sustainable Energy Reviews, 43, 843–862. https://doi.org/10.1016/j.rser.2014.11.066
3. Li, J., Jimenez-Bescos, C., Calautit, J. K., & Yao, J. (2023). Evaluating the energy-saving potential of earth-air heat exchanger (EAHX) for Passivhaus standard buildings in different climates in China. Energy and Buildings, 288,

113005. https://doi.org/10.1016/j.enbuild.2023.113005
4. Ürge-Vorsatz, D., Cabeza, L. F., Serrano, S., Barreneche, C., & Petrichenko, K. (2015). Heating and cooling energy trends and drivers in buildings. Renewable and Sustainable Energy Reviews, 41, 85–98. https://doi.org/10.1016/j.rser.2014.08.039
5. Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L., & Acquaye, A. (2013). Operational vs. embodied emissions in buildings—A review of current trends. Energy and Buildings, 66, 232–245. https://doi.org/10.1016/j.enbuild.2013.07.026
6. Mongkon, S., Thepa, S., Namprakai, P., & Pratinthong, N. (2013). Cooling performance and condensation evaluation of horizontal earth tube system for the tropical greenhouse. Energy and Buildings, 66, 104–111. https://doi.org/10.1016/j.enbuild.2013.06.040
7. Singh, R., Sawhney, R. L., Lazarus, I. J., & Kishore, V. V. N. (2018). Recent advancements in earth air tunnel heat exchanger (EATHE) system for indoor thermal comfort application: A review. Renewable and Sustainable Energy Reviews, 82, 2162–2185. https://doi.org/10.1016/j.rser.2017.08.097
8. Bordoloi, N., Sharma, A., Nautiyal, H., & Goel, V. (2018). An intense review on the latest advancements of Earth air heat exchangers. Renewable and Sustainable Energy Reviews, 89, 261–280. https://doi.org/10.1016/j.rser.2018.03.037
9. Santamouris, M., Mihalakakou, G., Argiriou, A., & Asimakopoulos, D. N. (1995). On the performance of buildings coupled with earth to air heat-exchangers. Solar Energy, 54(6), 375–380. https://doi.org/10.1016/0038-092X(95)00028-K
10. Zajch, A., & Gough, W. A. (2021). Seasonal sensitivity to atmospheric and ground surface temperature changes of an open earth-air heat exchanger in Canadian climates. Geothermics, 89, 101944. https://doi.org/10.1016/j.geothermics.2020.101944
11. Domingues, A. M. B., Nobrega, E. S. B., Ramalho, J. V. A., Brum, R. S., & Quadros, R. S. (2021). Parameter analysis of Earth-air heat exchangers over multi-layered soils in South Brazil. Geothermics, 93, 102074. https://doi.org/10.1016/j.geothermics.2021.102074
12. Li, H., Ni, L., Li, G., & Yao, Y. (2019). Performance evaluation of earth to air heat exchange (EAHE) used for indoor ventilation during winter in severe cold regions. Applied Thermal Engineering, 160, 114111. https://doi.org/10.1016/j.applthermaleng.2019.114111
13. Boutera, Y., Boultif, N., Rouag, A., Beldjani, C., & Moummi, N. (2022). Performance of earth-air heat exchanger in cooling, heating, and reducing carbon emissions of an industrial poultry farm: A case study. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 44, 9564–9583. https://doi.org/10.1080/15567036.2021.1901409
14. Cao, S., Li, F., Li, X., & Yang, B. (2021). Feasibility analysis of earth-air heat exchanger (EAHE) in a sports and culture center in Tianjin, China. Case Studies in Thermal Engineering, 26, 101054. https://doi.org/10.1016/j.csite.2021.101054
15. Rosa, N., Soares, N., Costa, J. J., Santos, P., & Gervásio, H. (2020). Assessment of an earth-air heat exchanger (EAHE) system for residential buildings in warm-summer Mediterranean climate. Sustainable Energy Technologies and Assessments, 38, 100649. https://doi.org/10.1016/j.seta.2020.100649
16. Zhong, K., Meng, Q., Liu, X., & (Author missing in provided citation). (2021). A ventilation experimental study of thermal performance of an urban underground pipe rack. Energy and Buildings, 241, 110852. https://doi.org/10.1016/j.enbuild.2021.110852
17. Sodha, M. S., Sharma, A. K., Singh, S. P., Bansal, N. K., & Kumar, A. (1985). Evaluation of an earth–air tunnel system for cooling/heating of a hospital complex. Building and Environment, 20(2), 115–122. https://doi.org/10.1016/0360-1323(85)90020-3
18. Mavroyanopoulos, G. N., & Kyritsis, S. (1986). The performance of a greenhouse heated by an earth-air heat exchanger. Agricultural and Forest Meteorology, 36, 263–268. https://doi.org/10.1016/0168-1923(86)90052-6
19. Sawhney, R. L., Buddhi, D., & Thanu, N. M. (1999). An experimental study of summer performance of a recirculation type underground airpipe air conditioning system. Building and Environment, 34(2), 189–196. https://doi.org/10.1016/S0360-1323(98)00016-9
20. Ghosal, M. K., Tiwari, G. N., & Srivastava, N. S. L. (2004). Thermal modeling of a greenhouse with an integrated earth to air heat exchanger: An experimental validation. Energy and Buildings, 36(3), 219–227. https://doi.org/10.1016/j.enbuild.2003.08.006
21. Chel, A., & Tiwari, G. N. (2009). Performance evaluation and life cycle cost analysis of earth to air heat exchanger integrated with adobe building for New Delhi composite climate. Energy and Buildings, 41(1), 56–66. https://doi.org/10.1016/j.enbuild.2008.07.006
22. Krommweh, M. S., Roesmann, P., & Buescher, W. (2014). Investigation of heating and cooling potential of a modular housing system for fattening pigs with integrated geothermal heat exchanger. Biosystems Engineering, 121, 118–129. https://doi.org/10.1016/j.biosystemseng.2014.02.010
23. Hsu, C.-Y., Huang, P.-C., Liang, J.-D., Chiang, Y.-C., & Chen, S.-L. (2020). The in-situ experiment of earth-air heat exchanger for a cafeteria building in subtropical monsoon climate. Renewable Energy, 157, 741–753. https://doi.org/10.1016/j.renene.2020.05.022
24. Maytorena, V. M., Hinojosa, J. F., Moreno, S., & Buentello-Montoya, D. A. (2023). Thermal performance analysis of a passive hybrid earth-to-air heat exchanger for cooling rooms at Mexican desert climate. Case Studies in Thermal Engineering, 41, 102590. https://doi.org/10.1016/j.csite.2022.102590