A REVIEW ON CFD based Thermal Performance Analysis of Earth Air Tube Heat Exchanger System with Water Impregnation

Prakash[1], Dr. Himanshu Agarwal[2], D.S. Mandloe[3]

[1]Research Scholar, M. Tech. (Thermal Engg.)
[2]Professor and Head, Department of Mechanical Engineering
[3]Assistant Professor, Department of Mechanical Engineering
Jhada Sirha Government Engineering College Jagdalpur, Bastar Chhattisgarh India

---

Abstract - *This is the characteristic of the earth where the temperature of the ground is relatively constant year-round at a depth of approximately 1.5 to 2 meters. The term "earth's undisturbed temperature" refers to this steady state of temperature, which is greater in the winter and lower in the summer. The design of the earth-air heat exchanger (EATHE) is necessary for the efficient use of the earth's heat capacity. Buildings can benefit from the use of EATHE as an efficient passive heating and cooling system. This is essentially a network of pipes made of metal, plastic, or concrete that are buried at a specific depth and through which heat-producing fresh air from the atmosphere flows.*

winter and supplying to the building if the temperature is high enough, and vice versa in the summer. Numerous researchers have conducted numerous studies on the planning, modeling, and testing of EATHEs systems to date. Much work has been done over the past two years to create mathematical and analytical models for the analysis of EATHE systems. The CFD analysis of EATHE systems is presented in this review paper study.

Key Words: Earth-air heat exchanger, soil characteristics, thermal performance.

1.Introduction

Globally, it is estimated that residential buildings, offices, and commercial spaces account for approximately 40% of total energy consumption and 70% of electricity usage. A significant portion of this energy demand comes from heating and cooling systems in residential, commercial, and industrial sectors. To alleviate the load on active systems that convert renewable energy into thermal or electrical power, the first essential step is to implement an optimal mix of passive design strategies, with passive solar design being one of the most important. Geothermal energy, recognized as a renewable resource, offers a sustainable and endless energy supply.

Traditional heating and cooling systems rely on components like compressors, condensers, and evaporators. In contrast, an earth tube heat exchanger is a buried heat exchanger that leverages geothermal energy by absorbing heat from the ground for heating or releasing it into the ground for cooling. This innovative use of geothermal energy benefits both heating and cooling inside a building. An earth tube heat exchanger uses a blower to circulate air through the underground loop of pipes, facilitating heat transfer between the air and the ground. This straightforward system reduces both operational costs and electricity consumption by eliminating the need for compressors, condensers, and evaporators, while efficiently harnessing geothermal energy for climate control.

1.1 Working Principle of Earth Tube Heat Exchanger (ETHE)

The concept of thermal inertia has been utilized for heating and cooling purposes since ancient times. Before the Christian era, it was utilized by the ancient Greeks and Persians. In more recent times, the Italians created caves for the purpose of precooling and preheating. These days, air travels through underground pipes that are used for either heating, cooling, or both purposes. The temperature of the earth changes from its surface to a fixed depth, where thermal equilibrium takes place. At that point, the temperature of the earth's interior is known as the undisturbed subsoil temperature.

ETHE is positioned at the temperature-fixation point. The ground temperature surrounding ETHE is higher than ambient air in the winter, so the supply air is warmer during that season. Conversely, in the summer, the ground temperature surrounding ETHE is lower than ambient air, so the supply air is colder. Heat transfer from/to air through ETHE to the ground happens when air enters ETHE. The effectiveness of ETHE determines the efficiency of the heat transfer process from/to air [1]. In 1826, Thomson proposed the first harmonic model to determine the temperature of undisturbed soil; Kelvin then developed this model in the following ways [1].

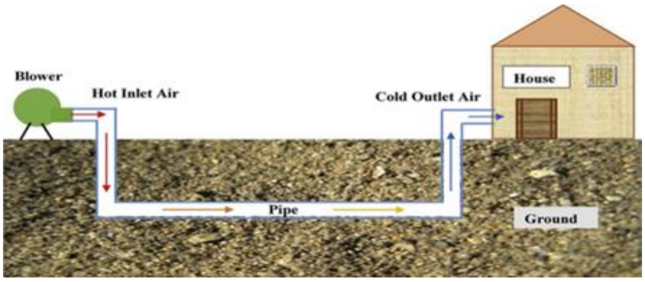

Figure 1. Working principle of EATHE system for summer cooling

1.2 Classifications of ETHE

(a) Classification of ETHE According to The Passage of Air Flow:

I. Open system: In an open system, the outside air is first heated or cooled by subterranean tubes, then it enters the building and is heated or cooled by a conventional air conditioner. Open loop, as Fig. 2-b illustrates.

II. Closed system: In this case, heat exchangers are buried horizontally, vertically, or obliquely. Heat is transported from the soil to a heat pump, or the other way around, by the movement of a heat carrier medium inside the heat exchanger. sealed loop, as depicted in Figure 2-a.

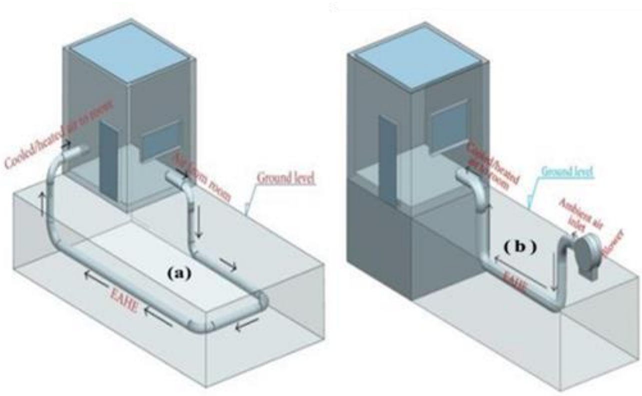

Figure 2. EATHE: (a) closed loop and (b) open loop [2]

(b) ETHE Classified according to buried tubes configuration.

1. The multi-tubes as shown in Fig. 3-a.

2. Single tube as shown in Fig. 3-b.

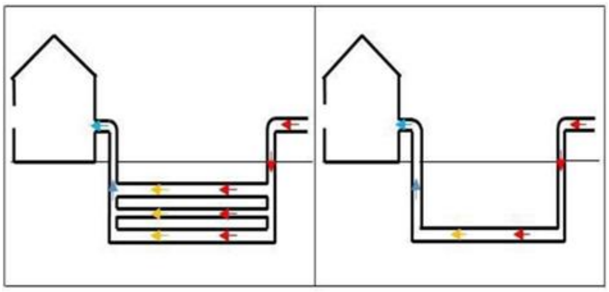

Figure 3. (a) multiple tubes and (b) Single tubes ETHE

(c) ETHE classified according to the buried tubes assortment:

1. Vertical ETHE as shown in Fig. 4-a.

2. Horizontal ETHE as shown in Fig. 4-b.

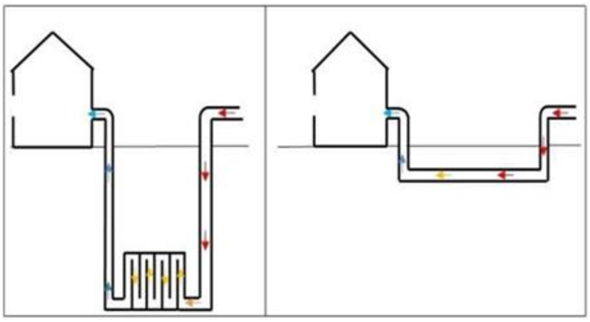

Figure 4. (a) Vertical and (b) horizontal ETHE [2]

2. Literature Review

A scope study is a review of the literature. It serves as a guide while doing this analysis. It will provide some information regarding the use of CFD for Earth Air Heat Exchanger analysis. Numerous literature reviews have been conducted since the project's inception. The primary sources for the project guides were books, research journals, and printed or online conference articles.

Vikas Bansal, Rohit Misra, Ghanshyam Das Agrawal, Jyotirmay Mathur et al (2009) [3] This paper develops an implicit and transient model based on computational fluid dynamics to forecast the heating capacity and thermal performance of earth-air-pipe heat exchanger systems. The model is created within the simulation application FLUENT. The developed model is verified through experimental studies conducted on an experimental setup located in Ajmer, Western India. These are their conclusions from the study. For the modeling of the EPAHE system, there is a reasonable degree of agreement between the simulation and experimental results, with a maximum deviation of 2.07 percent. It is discovered that as flow velocity increases, air temperature rises decreases. This analysis leads to the conclusion that the buried pipe's material has no bearing on the EPAHE system's performance. As a result, a less expensive pipe can be used in its construction.

Trilok Singh Bisoniya et al (2015)

This paper describes a promising technique called the earth-air heat exchanger (EATHE), which works by preheating the air in the winter and cooling it in the summer, thereby reducing the building's heating and cooling load. The author has used a set of streamlined design equations to create a one-dimensional model of the EATHE systems in this work. Improved heat transfer calculation accuracy is achieved through the use of the earth's undisturbed temperature (EUT) method and, more recently, correlations for the friction factor and Nusselt number. Equations have been developed that allow designers to determine the EATHE system's length of pipe, pressure drop, convective heat transfer coefficient, and heat transfer. The EATHE system functions better when a longer, smaller-diameter pipe is buried deeper and has a slower air flow velocity.

Shashank Srivastava, Ashish Sherma, Ketan Ajay et al (2016) [6] The effectiveness of an earth tube heat exchanger model based on CFD modeling and simulation is assessed for various pipe/duct geometries. The earth tube heat exchanger's cooling potential was found to have increased as a result of the corrugation geometry's eddy formations and increased internal surface area. The current Earth Air Exchanger can undoubtedly perform much better if we continue in this direction.

Aashish sharma, Shashank Srivastava, Sanjeev Kumar, et al (2017) [7] The EATHE model's performance is estimated for various source/sink mediums using CFD modeling and simulation. It was found that the earth tube heat exchanger's cooling potential greatly increases. This is because the medium-chosen materials have higher thermal properties. Throughout the section, different mediums display varying temperature drops. It is certain that if we proceed in this manner, the current Earth Air Heat Exchanger will perform far better.

Description of CFD model:

A computer-based simulation technique called computational fluid dynamics (CFD) is used to study fluid flow, heat transfer, and related phenomena like chemical reactions. In this project, flow and heat transfer are analyzed using CFD. The following are some instances of application areas: aerodynamic lift and drag (i.e. aircraft or windmill blades), combustion in power plants, chemical reactions, heating and cooling systems, and even biomedical engineering (which replicates blood flow through veins and arteries). Research and development, as well as the manufacturing of aircraft, combustion engines, and numerous other products, rely on CFD analyses conducted across multiple industries. For many years, researchers have used computational fluid dynamics (CFD) to study heat and mass transfer. Fluid flow problems can be solved numerically, which is how CFD codes are organized. It offers discretized numerical solutions to partial differential equations controlling heat transfer and airflow. This study used CFD software, FLUENT 6.3, to investigate the intricate airflow and heat transfer processes in an earth-pipe-air heat exchanger system. FLUENT packages have complex user interfaces to input problem parameters and view the results, creation it simple to access the solving power of CFD codes. CFD codes in FLUENT contain three main elements: (i) a pre-processor, (ii) a solver and (iii) a post-processor.

A flow problem is input into a CFD program through pre-processing, which includes defining the geometry of the computational domain—the region of interest—and grid generation, which divides the domain into several smaller, nonoverlapping sub-domains—a grid (or mesh) of cells, control volumes, or elements. Additionally, pre-processing includes choosing the physical and chemical phenomena that require modeling, defining fluid properties, and specifying suitable boundary conditions at cells that touch or coincide with the domain boundary. When solving the governing equations of fluid flow and heat transfer, the solver employs the finite control volume method. Utilizing graphs, animations, vector plots, contour plots, and other visual aids, the post-processor displays the simulation results.

Utilizing FLUENT, 3-D transient turbulent flow (standard k–e model) was considered in the CFD simulations, which were heated to a maximum. With 20 iterations per step, the time step in this transient analysis is 100 s. The CFD analysis utilized a total of approximately 3.8 million control volumes. CFD analysis is performed for two distinct pipe materials, namely. both PVC and mild steel. This CFD study's primary goals were to find out how buried pipe material (PVC and mild steel were the two materials taken into consideration) affected the EPAHE system's performance as well as how air velocity affected it. Air was considered to be incompressible for the purposes of the research. [4]

3. DESIGNE PARAMETERS

The following factors are crucial when designing an Earth Tube Heat Exchanger (ETHE):

1.Tube Material: A number of important characteristics, such as strength, corrosion resistance, durability, and cost-effectiveness, must be taken into account when selecting the material for ETHE pipes.

Table 1. List of tube materials have been used in the past studies

Authors	Type of Tube Material used	References
Bansal et al.,	PVC	[8]
Ascionne et al.,	PVC, Metallic, Concrete	[9]
Sanusi et al.,	Polyethylene (PE), PVC, Brick, Clay	[10]
Aziah et al.,	Polyethylene (PE), Copper, PVC	[11]
Jahkar et al.,	High Density Polyethylene (HDPE), Galvanized Iron, Steel	[12]
Ahmed et al.,	PVC, PE, Concrete, Clay	[13]
Serageldin et al.,	PVC, Steel, Copper	[14]

2. Tube Length: The surface area of the pipe, which is established by its diameter and length, affects heat transfer. Greater surface area from a longer tube results in a faster rate of heat transfer and increased system efficiency. Optimizing the tube length is crucial because, beyond a certain length, no more substantial heat transfer takes place. Longer tubes may also result in higher pressure drops, which call for a greater amount of fan energy to counteract.

3. Tube Diameter: Lower diameter tubes generally perform better thermally but have higher pressure drops. On the other hand, a greater diameter results in decreased air velocity and lower heat transfer efficiency.

4. Tube Depth: Various factors, such as the composition of the soil, moisture content, and thermal characteristics of the soil, affect the ground's temperature.

5. Nature of Soil:

The seasonally fluctuating inlet temperature and the tunnel-wall temperature, which also depends on the ground temperature, are the foundations of the EATHE performance. Therefore, the temperature and moisture distribution in the earth, in addition to surface conditions, indirectly affect the thermal performance of the EATHE system. From a thermal perspective, saturated soils are ideal; deeper levels are therefore preferred as they offer colder winter temperatures and warmer summer temperatures; smaller pipes are more thermally efficient, i.e. they require larger installations and result in greater pressure losses, but they also yield a higher heat exchange per unit volume of air.

Table 2. Summary of Site Characteristics for various EATHE System Installations

Authors	Weather types	Location	Type of ground heat exchanger	Application	References
Bansal et al.	Winter	Ajmer, India	Earth air pipe heat exchanger (EAPHE)	Passive heating	[8]
Jahkar et al.	Winter	Ajmer, India	Earth water heat exchanger (EHWE)	Passive heating	[16]
Jahkar et al.	Winter and summer	Pilana Rajastan India	Earth water heat exchanger (EHWE)	Passive cooling and heating	[17]
Ghosal and Tiwari.		Premises ITT, Delhi, India	EATHE	Passive cooling and heating	[15]

Bansal et al. [3] used experimental and computational fluid dynamics modeling with FLUENT software to investigate the impact of soil thermal conductivity on the thermal performance of an earth air tunnel heat exchanger under transient operating conditions in the primarily hot and dry climate of Ajmer, India. According to the findings, the maximum air temperature drops that could be achieved under EATHE's steady state operation for a 100-meter pipe length were 18.4°C, 18.7°C, and 18.4°C, respectively, for soil thermal conductivities of 0°52, 2°0, and 4°0 Wm-1K-1. However, for soil thermal conductivity of 0.52, 2.0, and 4.0Wm-1 K-1, respectively, the maximum air temperature drops under transient conditions varied between 18.3°C and 14.0°C, 18.3°C and 17.2°C, and 18.6°C and 18.0 °C for a 24-hour period of operation. This was caused by increased soil thermal conductivity, which improved the EATHE system's thermal performance even after a longer operating period.

Air flow: Several studies were conducted to examine the effects of variable air velocities; the findings are outlined below. It has been discovered that an increase in the mass flow rate of air causes the winter and summertime air temperatures in greenhouses to drop and rise, respectively. This may be caused by the air that has a shorter time in contact with the soil, causing lower thermal exchange rate between soil and air.

Misra et al. [4] To investigate the impact of soil pipe diameter thermal conductivities, flow velocity, and time duration of continuous operation on the thermal performance of the earth air tunnel heat exchanger (EATHE system), a transient and implicit numerical model based on coupled simultaneous heat transfer and turbulent flow was developed. To study the impact on the transient performance of the EATHE system to work in long continuous operation, three different velocities—2.0 m/s, 5.0 m/s, and 8.0 m/s—were selected, and the pipe diameter was maintained at 0.1 m for all different flow velocities. The outcome showed that the EATHE system's thermal performance declined as a result of the increased flow velocity. This is because more heat is transferred from the air to the soil per unit of time when the flow velocity increases.

4. Advantages and disadvantages of ETHE

The following are some advantages of the earth tube heat exchanger:

- It can operate in a variety of soil types.
- The outlet air temperature for fully buried ETHE is solely dependent on the inlet air temperature.
- The installation's ease of use.
- The working fluid is air.
- Requires less maintenance with lower costs.
- Does not require it to operate in high wind conditions.
- No pollution or greenhouse gases because there isn't a source of combustion [5].

Although of these benefits, it has the following disadvantages:

- The cost of installation is high.
- Reduced indoor air quality as a result of the heat exchanger's condensation phenomenon and potential for the growth of microorganisms.
- Non-uniform outlet air temperature; and
- Local climate conditions in the presence of the earth's surface heat exchanger directly affect the thermal performance of ETHE [5].

5. Conclusions

Around 1.5 to 2 meters below the surface, the temperature of the earth stays nearly constant. The term "earth's undisturbed temperature" refers to this steady temperature. In the winter, the unaltered temperature of the earth is always higher than the ambient air temperature, and in the summer, the opposite is true. The EATHE system needs to be designed in order to effectively use the earth's heat capacity. If the amount of heating or cooling that is achieved is insufficient, the EATHEs' outlet can be connected to a traditional air conditioner. Everywhere there is a strong emphasis on using clean and green energy to reduce conventional energy use and CFC emissions. By preheating air for heating various types of buildings in the winter and vice versa in the summer, EATHE systems can significantly reduce energy consumption. As a result, it is crucial to optimize the design, model, and test EATHE systems. Numerous calculation models that mimic the thermo-physical behavior of earth-air heat exchangers can be found in the literature. A well-designed EATHE can cut a typical house's electricity use by 30%.

EATHE systems, which have been widely used for years, provide reductions in the heating and cooling load of buildings, power consumption, CFC and HCFC consumption, and greenhouse gas emissions. Generally speaking, the EATHE system's thermal performance rises as pipe length and burial depth increase, but performance tends to decrease as pipe diameter and air velocity increase. When it comes to the use of EATHE systems, the United States and Europe lead the globe. The performance of the EATHE system can be further enhanced by combining its hybrid systems with renewable energy sources like solar and wind power. It is possible to draw the conclusion that effective EATHE system use, along with practical energy sources and cutting-edge technology, will be crucial to reducing energy consumption and protecting the environment both in India and globally. According to the authors, scientists and researchers working in the field of passive heating and cooling of buildings, particularly with the use of EATHE systems, will find great value in this review paper.

References

[1] Belloufi, Y., Brima, A., Zerouali, S., Atmani, R., Aissaoui, F., Rouag, A., Moummi, N. (2017). "Numerical and experimental investigation on the transient behavior of an earth air heat exchanger in continuous operation mode". International Journal of Heat and Technology, 35(2): 279-288.

[2] Ali, S., Muhammad, N., Amin, A., Sohaib, M., Basit, A., Ahmad, T. (2019). "Parametric optimization of earth to air heat exchanger using response surface method". Sustainability, 11(11): 3186.

[3] Bansal V, Misra R, Agarwal G D and Mathur J, 2013 Transient effect of soil thermal conductivity and duration of operation on performance of Earth Air Tunnel Heat Exchanger. Applied Energy. pp 1-11

[4] Rohit Misra, Vikas Bansal, Ghanshyam Das Agrawal, Jyotirmay Mathur, Tarun K. Aseri; CFD analysis based parametric study of derating factor for Earth Air Tunnel Heat Exchanger; Applied Energy 103 (2013) 266–277.

[5] Nasreddine Sakhria et. al (2020). "Earth to Air Heat Exchanger and Its Applications in Arid Regions - An Updated Review". TECNICA ITALIANAItalian Journal of Engineering Science, Vol. 64, No 1

[6] Shashank Shirvastava, Ashish Sharma, Ketan Ajay; CFD based study on an Earth pipe heat exchanger with different geometries (2016)

[7] shish sharma, Shashank Srivastava, Sanjeev Kumar; Heat Transfer analysis of source/sink of an Earth tube heat exchanger by CFD modeling and simulation (2017) 1260-1271.

[8] Bansal V, Misra R, Agrawal G D and Mathur J, 2009 Performance analysis of earth-airpipe-air heat exchanger for winter heating. Energy and Buildings. pp 1151-1154

[9] Ascione F, Bellia L and Minichiello F, 2011 Earth-to-air heat exchangers for Italian climates. Renewable Energy. pp 2177-2188

[10] Sanuzi, Aliyah N Z, and Ibrahim M N, 2013 Passive ground cooling system for low energy buildings in Malaysia (hot and humid climates). Renewable Energy. pp. 193-196

[11] Mohd, Noor A, Aliyah N Z, Sanusi and Aminuddin M, 2014 Materials for earth air pipe heat exchanger (EAPHE) system as a passive ground cooling technology for hothumid climate. International Conference on Emerging Trends in Scientific Research, Pearl International Hotel (Kuala Lumpur)

[12] Jakhar S, Soni M S and Gakkhar N, 2016 Performance analysis of earth water heat exchanger for concentrating photovoltaic cooling. Energy Procedia. pp 145-153

[13] Ahmed S, Amanullah M, Khan M, Rasul M and Hassan N, 2016 Parametric study on thermal performance of horizontal earth pipe cooling system in summer. Energy Conversion and Management. pp 324-337

[14] Serageldin A, Abdelrahman A K and Okawara S, 2016 Earth-Air Heat Exchanger thermal performance in Egyptian conditions: Experimental results, mathematical model, and Computational Fluid Dynamics simulation. Energy Conversion and Management. pp 25-38

[15] Ghosal M K, Tiwari G, Das D and Pandey K P, 2005 Modeling and comparative thermal performance of ground air collector and earth air heat exchanger for heating of greenhouse. Energy and Buildings. pp 613-621

[16] Jakhar S, Misra R, Soni M and Gakkhar N, 2016 Parametric simulation and experimental analysis of earth air heat exchanger with solar air heating duct. Engineering Science and Technology. pp 1059-1066

[17] Jahkar S, Soni M and Gakkhar N, 2016 Performance analysis of earth water heat exchanger for concentrating photovoltaic cooling. Energy Procedia. pp 145-153