Recent Advances in Heating and Cooling using Earth Air Heat Exchanger (EAHE): A Review

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Abstract - **A ground-coupled heat exchanger or earth air heat exchanger (EAHE or EAHX) is a heat exchanger in which heat interactions takes place between working fluid and earth. They are the most economical and promising alternative to conventional air-conditioning systems. This paper presents a comprehensive literature review that deal with heating, ventilation and air conditioning technologies using earth air heat exchanger (EAHE). Under the depth of 4 to 5 meters the ground temperature which is known as undisturbed temperature, is remains constant throughout the year because of high heat capacity and high insulation potential. The underground temperature at this depth is higher in winter and lower in summer than ambient temperature. In this paper various design factors and performance parameters were discussed. Simulation and Modeling is one of the very useful tools to predict the effect of the operating parameters of earth-air heat exchanger systems. Many study and research are carried out in last 25 years on different models and performance parameters. This paper also discussed various two and three dimensional models developed.**

Keywords: **Earth air heat exchanger, constant ground temperature, geothermal energy**

INTRODUCTION

Energy conservation is one of the important global challenges. A huge amount of the energy used for electricity generation and space heating and cooling which is derived from fossil fuels. Fossil fuels are not only non renewable resources of energy but their combustion also harms the environment, through the production of greenhouse gases and other pollutants. By using air conditioners and air heaters for the human comfort, building such as Residential, Institutional or offices have major contribution in energy consumption which impact the environment because of use of chlorofluorocarbons and results in global warming. Research and measurements reflect that the ground temperature remains constant under earth at some depth throughout the year because of high thermal inertia of earth which results in no temperature fluctuations at some depth. Heating and cooling of a space or system can be done by active or passive systems. Passive heating and cooling not only provide thermal conform but also consume less energy as compared with active systems.

At a sufficient depth, the ground temperature is always higher than that of the outside air in winter and is lower than that of the outside air in summer. The temperature difference can be utilised as a means for pre-heating in winter and as a means for pre-cooling in summer by operating an earth heat exchanger. Also, a heat pump may be used in winter to extract heat from the relatively warm ground and pump it into the conditioned space. In summer, the process may be reversed and the heat pump may extract heat from the conditioned space and send it out to an earth heat exchanger. An earth tunnel heat exchanger is an heat exchanger installed under the earth at some depth that can exchange heat with the earth or ground. Earth tubes or earth tunnel heat exchangers are often a viable and economical alternative to conventional heating or cooling systems since there is no use of compressors or chemicals. Earth tunnel heat exchanger uses only blowers to move the air.

Georgios Florides and Soteris Kalogirou [1] had done literature review on ground heat exchangers and explained that the temperature distribution of earth is divided in three zones the ground, the first zone is surface zone up to a depth of approximately 1m, the second zone is shallow zone, ranging from 1m to 20 m and the third zone is the deep zone having constant temperature around the year. They suggested that for effective utilization of heat capacity of the earth we need to design a heat-exchanger system in which an array of pipes vertically buried in earth and running along the length of the building. Air or water can be used as circulating fluid to extract or dump heat from earth during winter and summer respectively. Integration of heat pump to the system may also increase the efficiency of the system. In their literature, several calculation models are discussed for ground heat exchangers. One-dimensional models were devised in the first stages which during the nineties were replaced by two dimensional models and in the recent researches three-dimensional systems are considered. Their models are further refined and accept any type of grid geometry that may give detail of the temperature distribution around the pipes and in the ground. Earth heat exchangers are classified as [2]:

1. Open system [2]

In this case ambient air passes through tubes buried in the ground for preheating or pre-cooling and then the air is heated or cooled by a conventional air conditioning unit. In a similar way the ground water of a water bearing layer is used as a heat carrier medium and is brought in direct contact with the heat pump coils. In most cases two wells are required, one for extracting the ground water and one for injecting it back into the water bearing layer as indicated in Figure 1.

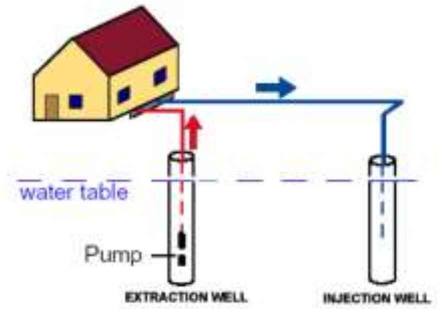

Figure 1. Ground Water Heat Pump

2. Closed System [2]

Heat exchangers are located underground, either in horizontal, vertical or oblique position and a heat carrier medium is circulated within the heat exchanger, transferring heat from the ground to a heat pump or vice versa. Fig. 2 indicates the horizontal type which has a number of pipes connected together either in series or in parallel. This configuration is usually the most cost effective when adequate yard space is available and trenches are easy to dig. The trenches have a depth of one to two meters in the ground and usually a series of parallel plastic pipes is used. Fluid runs through the pipe in a closed system. A typical horizontal loop is 35 to 60 meters long per kW of heating or cooling capacity. Horizontal ground loops are easiest to install while a building is under construction.

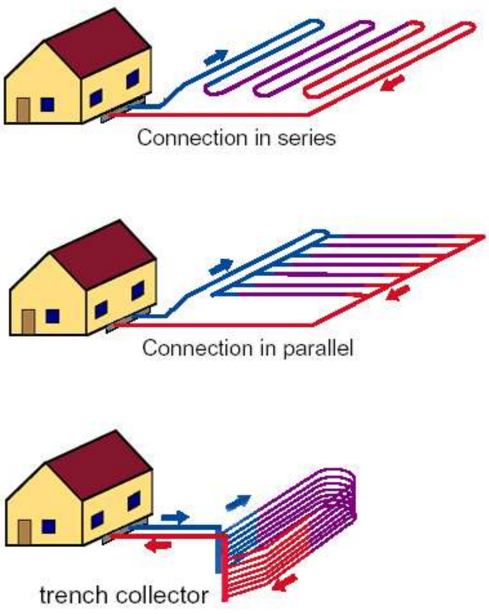

Figure 2. Horizontal type ground heat exchangers

Mihalakakou et al. [3] present a complete model for the prediction of the daily and annual variation of ground surface temperature. The model uses a transient heat conduction differential equation and an energy balance equation at the ground surface to predict the ground surface temperature. The energy balance equation involves the convective energy exchange between air and soil, the solar radiation absorbed by the ground surface, the latent heat flux due to evaporation at the ground surface as well as the long-wave radiation.

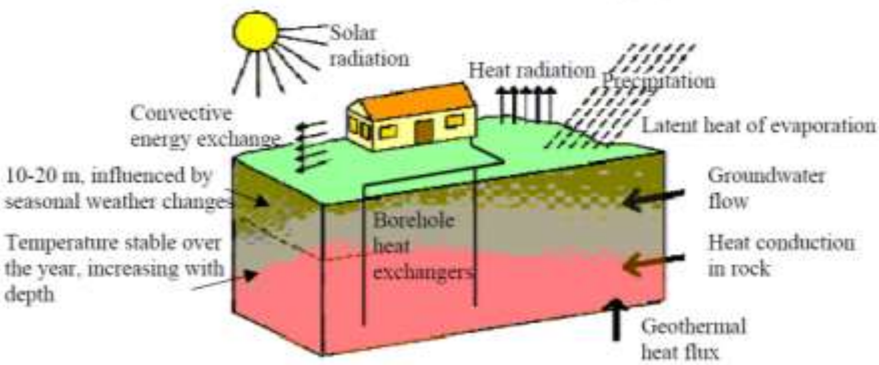

Figure 3. Energy flows in ground

The model is validated against 10 years of hourly measured temperatures for bare and short-grass covered soil in Athens and Dublin. The results are compared with the corresponding results of models using Fourier analysis. Furthermore, a sensitivity investigation is performed to investigate the influence of various factors involved in the energy balance equation at the ground surface on the soil temperature profile. **Kujawa et al. [4]** studied the case of deep geothermal heat plants. These plants operate with one or two-hole systems. A computational model is presented which estimates the temperature of the geothermal water extracted to the earth's surface as well as the temperature of the water injected into a deposit level. The predicted characteristics do not take into account specific working conditions of the systems.

Mihalakakou et al. [5] investigated the heating potential of a single earth- to- air heat exchanger as well as the potential of a multiple parallel earth tube system. An accurate numerical model was used to investigate the dynamic thermal performance of the system during the winter period in Dublin. The model had been successfully validated against an extensive set of experimental data. The results showed that the heating potential of the system during winter is significantly important. The obtained results showed that the effectiveness of the earth-to-air heat exchanger increases with an increase in the pipe length (checked range 30 m to 70 m). Also there is an increase in effectiveness when the pipe is buried in greater depths (3 m instead of 1.2m). By increasing the pipe diameter from 100 to 150 mm it was shown that the heating capacity of the system was reduced. This is due to a reduction in the convective heat transfer coefficient and an increase in the pipe surface therefore providing a lower air temperature at the pipe outlet. Finally a higher air velocity in the pipe (checked range 5 m/s to 15 m/s) leads to a reduction of the systems heating capacity, mainly because of the increased mass flow rate inside the pipe.

Bojic et al. [6] developed a model in which the soil is divided into horizontal layers with uniform temperature. All the pipes are placed in one layer at the same depth and parallel to each other. The heat transported to the soil by convection from the air and the solar irradiation is calculated. Also an equation describing the heat flow between the air flow in the pipe and the neighboring soil layer is used. All equations used for the soil layers in each time step, are steady state energy equations. This model is a 2-dimensional model therefore the influence that pipes have on each other may not be evaluated.

Sunil Kumar Khandelwal et. al.[7] in the design of earth air tunnel heat exchanger system for an institute library had developed a simple Excel based mathematical model to design the Earth air tunnel heat exchanger system for library of the MNIT Jaipur. Their model helps in determining characteristic dimensions, air flow rate, number of pipes, selection of blower and economic investments in an EATHE system. They also conducted a thermal comfort survey to find the thermal comfort temperature inside the library of MNIT, which is approx 28.6 ^{0}C, quiet near to the temperature obtained through this EATHE system. They also developed a simple mathematical model to design the Earth air tunnel heat exchanger for library of the MNIT Jaipur and to support the feasibility of the EATHE system economic analysis was also performed. They concluded that EATHE system has huge potential of saving electricity (32-50%) and it can also maintain indoor temperature around 29.5-32^{0}C. The smaller diameter pipes enhance performance of EATHE as compared to large diameter pipes. Mass flow rate of air in the pipe should be around 2-5 m/s. Also in case of multiple pipe arrangement distance between pipes must be around 5 times the diameter of pipe. They also concluded that sandy wet clay loam has higher cooling potential than dry sandy soil. Pipe material has very little effect on thermal performance.

Table 1 Description of building materials used in library [8]

Components	**Material**	**U Factor**
Roof/ Ceiling	6 ’’ concrete 15mm thick plaster	4.0
Exterior Walls	15’’ stone wall 15 mm thick cement plaster	2.61
Window	Clear single pane glass (metal frame)	0.56
Door	Glass door with aluminum frame	5.67
Partition Wall	4 ½ ’’ brick , 15 mm thick cement plaster	2.67

Table 2 Thermo physical properties of building material [8]

Material	**Density (Kg/m3)**	**Thermal conductivity (W/m K)**
Cement	1900	1.73
Brick	2000	1.32
Cement plaster	1885	8.65

Table 3 Thermo physical properties of various materials [8]

Material	Density (Kg/m3)	Specific Heat Capacity (J/Kg K)	Thermal Conductivity (W/m K)
Air	1.15	1005	0.02
Soil	2050	1840	0.52
PVC	1380	900	1.16

Manoj kumar Dubey et. al [8] perform experiments on earth air heat exchanger system and investigates the results for parallel connection in the summer climate. Their experimental result indicates that temperature difference between inlet and outlet of the pipe at a depth of 1.5 m varies from 8.6 to 4.18 °C at a velocity of 4.1 to 11.6 m/s. They also found that the COP in the parallel connection varies from 5.7 to 2.6 for velocity of 4.16 to 11.2 m/s respectively. **G.N. Tiwari et. al. [9]** designed an Earth Air Heat Exchanger (EAHE) for Climatic Condition of Chennai, India. In their design the temperature of ground has been validated for climatic condition of Sriperumbudur near Chennai, India to evaluate thermal conductivity and thermal diffusivity of the soil. After the evaluation of thermal conductivity of the soil, they had designed an EAHE for a given dimension of room with optimized values of mass flow rate of air, pipe length, radius of pipe and depth at which heat exchanger to be installed below the surface of the earth. They observed decrease of 5 – 6 ^{0}C in the outlet air temperature in summer for different mass flow rate of air, 0.10 m optimized diameter and 21 m optimized length of pipe.

Fabrizio Ascione et al [10] conducted experiments at three different cities of Italy and evaluate the performance for ground heat exchanger in both summer and winter seasons. They concluded that the ground heat exchanger placed in the wet soil gave the better results than the other two. They use different materials like PVC, metal and concrete for tube construction and concluded that material type has no effect on the performance of the ground heat exchanger. Different mass flow rate of air is used in ground heat exchangers and found that low speed of 8 m/s gives better results as it decreases the pressure drop inside the tubes and energy requirements.

Vikas Bansal et al [11] investigated the performance of earth heat exchanger with horizontal pipe for space heating during winter and effect of mass flow rate of air and pipe material are evaluated. A mathematical model was developed to predict the performance of the earth heat exchanger. The 23.42 m long earth tube was used. The heating is in the range of 4.1-4.8 0C for mass flow rate of air of 2-5 m/s. They concluded that the pipe material does not affect the performance of the earth pipe air heat exchanger system so therefore a cheaper material can be used for making the pipe.

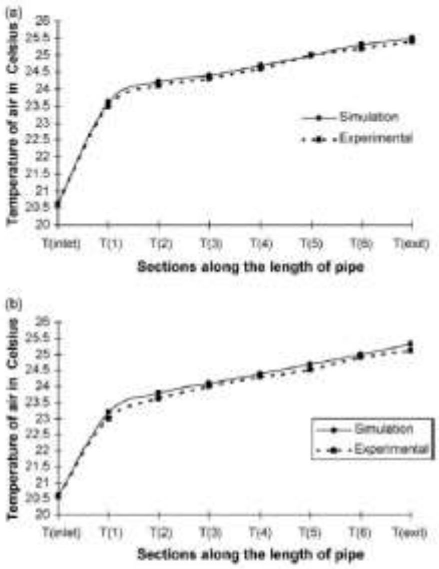

Figure 4: Temperature distribution along the length of the pipe for exit velocity 2.0 m/s for (a) steel pipe (b) PVC pipe.

Trilok Singh Bisoniya et. al. [12] developed a quasi-steady state, 3-dimensional model, based on computational fluid dynamics to evaluate the cooling potential of earth tunnel heat exchanger system. They developed the simulation model in CFD platform CFX 12.0 and they validate the results against experimental observations of set-up installed in Bhopal (Central India). They use air flow velocities of 2m/s, 3.5m/s and 5m/s for the simulation and experimental. They found that the maximum drop in air temperature of 12.9 ^{0}C occurred at air flow velocities of 2m/s and minimum drop in air temperature of 11.3 ^{o}C occurred at air flow velocities of 5m/s. They built the experimental set-up of EAHE with PVC pipe of length 19.228m and 0.1016m in diameter buried at 2m depth. They finally concluded that EAHE system can be used effectively to reduce cooling load of buildings in hot and dry summer weather conditions.

Arpit Thakur et. al.[13] conducted analysis with the help of computational fluid dynamics modeling and simulation considering weather conditions to be hot and dry with ambient temperature of 319K. They analysed the Effect of finned model and finless model on thermal performance. They developed a model having length60m and diameter 100 mm buried in soil of thermal conductivity of 4 W m-1K-1, consisting 239 fins i.e. pitch of 250mm. They found a temperature drop of 20.5 oC in finned model and a temperature drop of 17.7oC in finless model.

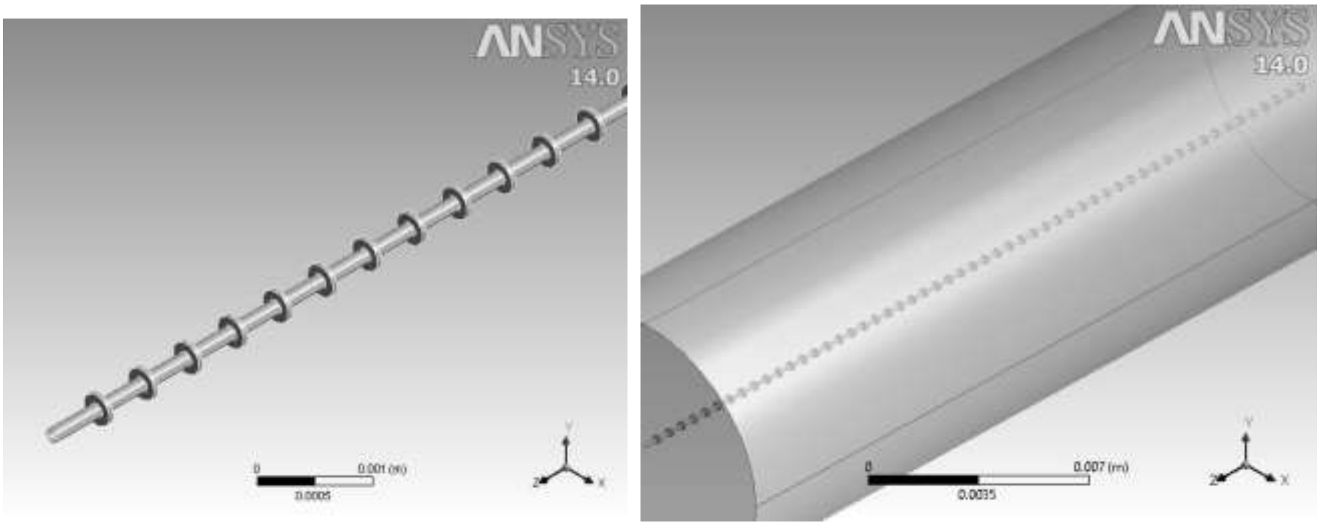

Figure 5: Finned EAHX pipe buried in soil domain [13]

W.H.Leong et al [14] investigate the effect of soil type and moisture content on the performance of ground heat exchanger and found that ground heat exchanger performance depended on the moisture content and the soil type. By varying soil moisture content from 12.5% of saturation to complete dry decreased the ground heat exchanger performance. With the application of a genetic algorithm **Rakesh Kumar et al [15]** designed and optimized earth heat exchanger and found the impact of humidity, ambient air temperature, earth surface temperature and earth temperature at depth on the outlet temperature of earth exchanger was investigated through detailed analysis. They concluded that outlet temperature was affected by ambient air temperature and earth temperature at depth.

Trilok Singh Bisoniya et. al. [16] has developed a quasi-steady state, three-dimensional model for simulation of earth-air heat exchanger (EAHE) system. CFD platform CFX 12.0 is used for development of the simulation model of EAHE system. They validate the simulation results against experimental results obtained from experimental set-up installed at Bhopal (Central India). They found the good agreement between simulation and experimental results. They carried out a detailed analysis to examine the effect of length of pipe, radius of pipe, mass flow rate of air and burial depth on the performance of earth air heat exchanger system for summer cooling. They buried longer pipe of smaller diameter at higher depth and having lower mass flow rate of air which results in decrease in outlet air temperature of EAHE system. In order to limit the initial/installation cost of EAHE system the depth of pipe burial about 2m could be taken. They found that the outlet air temperature decreased at faster rate for first 10m length of pipe and became constant afterwards. So, they concluded that increasing the pipe length more than 20-30m did not cause any significant increase in performance and found the optimal design values for hot and dry climatic conditions of Bhopal. They also concluded that burial depth of pipe and mass flow rate of air came out to have more influence on thermal performance of EAHE system than pipe diameter and length.

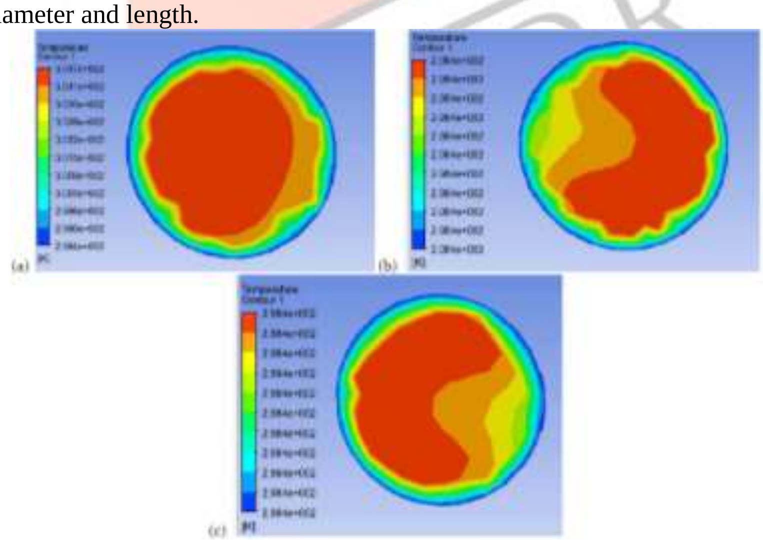

Figure 6: Temperature Contour [16] at (A) 0.557m, (B) 4.557m And (C) 18.661m along The EAHE from Inlet for Air Flow Velocity 2 m/s

Table 4: Thermo-Physical Properties of Materials Used In Simulation [16]

Material	Density (kg/m3)	Specific heat capacity (J/kg K)	Thermal conductivity (W/m-K)	Dynamic viscosity (kg/m-s)
Air at 40.40C	1.1261	1006.9	0.0271 1.	9166E-05
PVC	1380	900	0.16	-
Soil	2058	1843	0.54	-

Arshdeep Singh and Ranjit Singh [17] in performance analysis of rectangular earth-air tunnel system used for air-conditioning of the college classroom designed the metallic earth-air tunnel system considering all the variables like cooling load, heating load of the classroom, underground temperature, and soil weight and condition acting on the underground duct. They design a zigzag Duct of square cross-section. The zigzag duct resulted in less area occupied and shorter length of the duct required for proper air-conditioning effect. They also insulated the part of the duct leading to the classroom in order to stop the temperature variation of the conditioned air. The results showed there is a drop of 13 ^{0}C temperature during summers and during winter the heating effect was found to be relatively less, with just 5 ^{0}C increase in temperature.

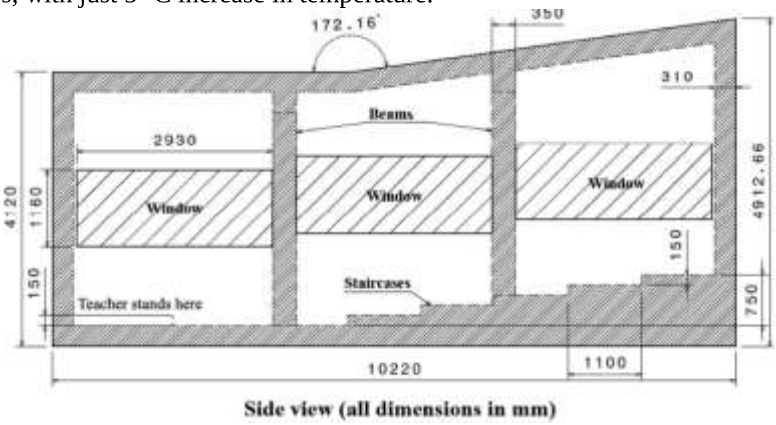

Figure 7: Side view of the room to be conditioned [17]

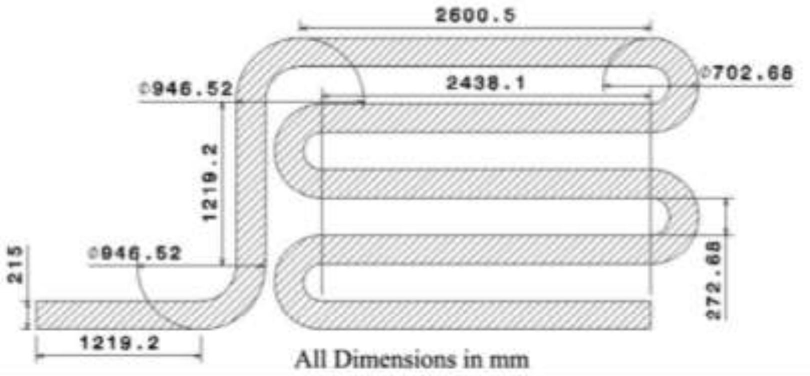

Figure 8: Finalized pattern of the metallic part [17]

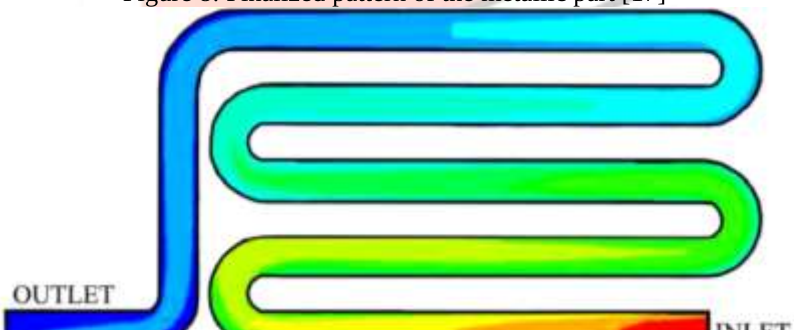

Figure 9: Variation of air temperature along its way in the metallic part of the duct [17]

CONCLUSION

Various types of earth heat exchangers are studied and describe in this paper. Earth tunnel heat exchangers are used to utilize the heat capacity of the soil effectively and for increasing their efficiency they are coupled to heat pump. Different models such as one, two and three-dimensional models can be found in the paper that simulate the heat transfer process. Mathematical models or Simulation may be used for sizing of system and predicts the performance of earth tunnel heat exchangers. It can be concluded that pipe material doesn't affect the performance of EAHE much whereas the air flow rate and ambient air temperature affects the performance of EAHE greatly.

ACKNOWLEDGMENT

I am thankful to **Dr. Manoj Gupta**, Provost and Dean (SET), Poornima University, Jaipur for giving me an opportunity to carry this work. I extend my sincere thanks to **Mr. Ashwani Kapoor**, HOD, Mechanical Department, Poornima University, Jaipur for his continuous support and encouragement. I take this opportunity to express my profound gratitude and deep regards to **Dr. K. Sudhakar,** Assistant Professor, Department of Energy, MANIT, Bhopal, for his exemplary guidance, monitoring and constant encouragement. I also express our deep thanks to all the faculty and staff members of Department of Mechanical Engineering, **Poornima University, Jaipur**, from whom I got direct or indirect cooperation.

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